Situated Navigation Support for Heterogeneous Large Crowds via Augmented Signage

Thesis by

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Declaration

I declare that the work in this thesis was carried out in accordance with the requirements of the University's regulations and code of practice for research degree programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Any views expressed in the thesis are those of the author.

Signature: *Fathi Abuagila A. Hamhoum* **Date:** 6th September, 2011

Glossary

Black Stone – Small black stone set into one side of the Ka'bah, which defines start location for the circumambulations pilgrims perform during Tawaf.

Fatwa – Fatwa is an Islamic religious ruling, a scholarly opinion on a matter of Islamic law.

Hajj – Pilgrimage to Mecca prescribed by the Quran, which involves several rites to be performed a specified times and locations.

Umrah – The lesser pilgrimage, including the initial Tawaf and the say's. It may be completed at any time of year and is also a part of Hajj

Ihram – Simple white garment pilgrims wear during some of the rituals of Hajj.

Jamarat – One of the rites to perform during Hajj, where pilgrims have to symbolically stone the Devil.

Ka'bah – Sacred building in the centre of the great mosque at Mecca.

Al-Quibla – Direction Muslims face when praying, which is defined by the location of the Ka'bah in Mecca.

Quran – Holy book of the Muslim faith

Saai – One of the rites performed during Hajj, where pilgrims walk back and forth seven times between the two hills Safa and Marwa.

Tawaf – One of the pillars to perform during Hajj, where pilgrims have to circumambulate the Ka'bah seven times in counter-clockwise direction.

Rakaat – This is essential part of the prayer (i.e. any prayer consist of a number of Rakaat, e.g. Isha prayer consist of 4 Rakaat.

Zamzem – An object of veneration, built into the eastern wall of the Ka'bah and probably predating Islamic, pilgrims should drink from it and take some for their relatives.

Maqam Abraham – Maqam Ibrahim is located in front of the door of the Ka'bah. The boulder is about 2 x 3 feet. Where it stands today is the place where Ibrahim offered up his prayers.

Dul-al- Hijjah – One of the Islamic calendar or Arabic calendar months, it is the month of the Hajj.

Eid-al-Adha- Festival of Sacrifice or Greater Eid is an important religious holiday celebrated by Muslims worldwide.

Mahdhoorat – Actions are not allowed to do during the Hajj period**.**

Waajibaat – Actions should be done in the Hajj, e.g. pray two rakaat beside Maqam Abraham.

Shuroott – Actions pilgrims must do them, e.g. wearing Ihram.

Aadaab – Actions pilgrims do them to increase rewards, e.g. Shaving the head or trimming the hair.

Abstract

Navigating unfamiliar places is a common problem people face, and there is a wealth of commercial and research-based applications particularly for mobile devices that provide support in these settings. While many of these solutions work well on an individual level, they are less well suited for very crowded situations, e.g. sports matches, festivals and fairs, or religious events such as pilgrimages. In a large crowd, attending to a mobile device can be hazardous, the underlying technology might not scale well, and some people might be excluded due to not having access to a mobile device. Public signage does not suffer from these issues, and consequently, people frequently rely on signage in crowded settings. However, a key disadvantage of public signage is that it does not provide personalised navigation support. We have therefore investigated augmented signage as a navigation support system for use in large crowds.

This thesis investigates the issues of guidance by augmented displays and how this can be made more suitable for people who navigate in groups in unfamiliar areas. In this context we have undertaken three studies as examples to explore how augmented displays can provide aid to people in crowded places. In the first study, we investigated the question of whether the use of dynamic public signage can help pilgrims count or remember the Tawaf rounds while walking around the Ka'bah. We analysed the current situation in Mecca based on a literature review and a series of interviews with pilgrims, who had completed at least one pilgrimage (already visited Mecca). We then presented a prototypical dynamic signage and reported on a user study we conducted in a realistic setting in order to evaluate the system. The results suggest that dynamic signage may be a feasible option to improve the safety of pilgrims in Mecca. In the second study, we introduced a scalable signage-based approach and present results from a comparison study contrasting two designs for augmented signage with a base approach. The results provide evidence that such a system could be easily useable, may reduce task load, and could improve navigation performance. In the final study, we developed public displays (static and dynamic signage) and investigated the ability of using such displays to assist pilgrims of Mecca to find each other after becoming separated while performing rituals inside the Haram (e.g. Tawaf pillar). Once again here we have addressed the issue through a series of interviews with people who had experienced pilgrimage before. Then we constructed

a full idea that allowed us to design the initial system and presented it in a focus group session to gain feedback and redesign the system. Afterwards, we conducted a lab-based user study. The results we obtained suggest that a person can extract information (by reading the dynamic signage), also results showed that users were able to remember their information (whilst completing some distraction tasks), and then they completed the static signs tasks successfully. Generally results showed that the system can indicate people to the right place where they can meet again after becoming separated.

In general, these results provided good evidence that augmented signage supported by colour and visual codes might provide considerable help in situations with large and heterogeneous crowds. It might be developed and used in different settings for provisional navigation information and allow multi-users to extract their personalised information individually.

Publications

1) Fathi Hamhoum and Christian Kray: Supporting pilgrims in navigating densely crowded religious sites. *Personal and Ubiquitous Computing* (8 October 2011), pp. 1-11, doi: 10.1007/s00779-011-0461-6, 2011. Full paper, work of chapter 5.

2) Fathi Hamhoum and Christian Kray: Scalable Navigation Support for Crowds: Personalized Guidance via Augmented Signage. COSIT 2011: Springer (2011), Vol. 6899 p. 40-56. Full paper, work of chapter 4.

3) Christian Kray, Keith Cheverst, Michael D. Harrison, Fathi Hamhoum, Jürgen Wagner: Towards a location model for indoor navigation support through public displays and mobile devices. *MIRW 2008*: 83-92.

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Chapter one Introduction

1. Introduction

1.1 Motivation

Crowdedness today is one of the largest issues in some vitally important locations around the world. These places are frequently very important in our lives and people often visit these places to perform rituals, for example a large number of people would love nothing better than to watch a football game from the comfort of a good place in a stadium. Several facilities or services are not available for people who watch football games in stadiums. Going to a stadium to watch a game causes many people a lot of distress because they have to deal with finding a parking space, waiting in a long line to get into the game, standing in crowds when they try to get food, and then waiting in lines again to get out of the stadium and the car park. Moreover, people (friends, relatives) wishing to sit together to watch and enjoy the game may be unable to easily do so. Friends being together and sharing good times watching an exciting game is what makes football so fun. These issues are facing people who decide to attend games at stadiums. There is no system currently used to assist, organise, and mange people in stadium situations. To overcome those problems, colour and visual codes via augmented displays could be used. A further example of a crowded place is, every year at particular time more than 2 million Muslim people meet at Mecca city in Saudi Arabia to attend the Hajj event. Several issues face them while doing their rituals inside and outside of the Haram. A crowded shopping area is an additional example that could be cited here which causes concern to people who enjoy shopping in huge cities. There are currently some systems available such as coloured signs (supported by arrow and short text) which could assist people in reaching their destination by following a particular colour. Information points are also available to supply people with some information about their current location and points of interest around. However, people still face issues while walking through crowds especially in unfamiliar environments.

The final example concerns tourism, as the majority of people want to travel to a traditional place for their holiday. Whilst researching holidays, people have traditionally used tools (e.g. paper maps, compasses and guide books) to find information on the area they intend to visit. Technological developments have improved this tourism situation, as people can use this technology to find information about their location and destination. Traditional tools, paper maps or guidebooks might be replaced by guide technology such as mobile guides (e.g. online maps) or public displays. Nevertheless, the current navigation systems still have shortcomings and may not be adequate in many settings.

More recently, various types of computer-based guide systems have been proposed and commercialised [1,21]. Most frequently, such systems take the form of mobile guides that dynamically display maps enriched with information such as the user's current location and the proposed route to a target location [8]. Dynamic (public) signage is an alternative approach that has recently been proposed to be used either on its own or in conjunction with mobile devices [74, 44].

While these systems have been shown to work well on an individual level (e.g. a single user navigating urban environments), some settings pose significant challenges for such approaches. In particular, if users wish to navigate in areas that are very crowded, several problems arise:

Difficulty of using a mobile phone in a crowd – Depending on the density of the crowd, it can be difficult (or even hazardous) to take out a mobile phone and interact with it often, as people need to pay close attention to what is going on around them, and the movement of the crowd may interfere with the interaction as well.

Lack of scalability of the underlying technology – If a large number of people try to access a wireless network (e.g. Bluetooth, Wi-Fi, GSM) in a very confined area, it frequently results in errors, low bandwidth or loss of connection.

Lack of mobile device – It is not unreasonable to assume that a percentage of the crowd will not have a mobile phone, e.g. either not owning one at all or not having brought it for fear of it being stolen/lost. Certain events, such as pilgrimages, might also deter people from using a mobile phone.

In order to address these problems and to provide systems that large numbers of people can use simultaneously to access personalised navigation support, we are investigating the use of (dynamic) public signage as a means to deliver this type of information.

Our design solutions proposed for public displays for crowds were tailored to the Mecca scenario, to solve some problems that face pilgrims while performing their rituals around the Ka'bah. The designs were based on particular properties of the scenario. For instance, at Mecca mobile phones are not usable (see section 1.2 in chapter one), and there is no common language (see section 1.1 chapter one). On the other hand, the design solutions proposed are applicable to other scenarios, which share some of the properties of the Mecca scenario – for example Stadia (International Olympics) or huge shopping centres. As a result, the design solutions proposed could be developed and used in different settings.

In this thesis we focused on how to develop augmented displays which are supported by colour and visual codes to improve crowded situations and assist people in finding their personalised navigation information and reaching their destination without any delays, workload, errors or disorientations.

Mecca city is one of the most crowded places and has an especial environment which includes unique properties and constraints (e.g. large and heterogeneous crowds). Based on those aspects we decided to address this area and find optimum solutions to overcome the issues which face pilgrims while performing their rituals in holy places (e.g. around Ka'bah).

Every year, a large number of pilgrims visit Mecca in Saudi Arabia. During their stay, they perform a number of rites in and around the city. Due to large crowds forming on particular days, incidents frequently occur, where people are injured, sometimes fatally. In this thesis, we investigate the question of whether the use of public displays can help people to overcome issues facing people while perform their pillars of Hajj. There are many issues facing pilgrims while doing their rituals inside and outside of Mecca's Haram. Through the interviews that we undertook with people who had visited Mecca before, we concluded that the two main issues experienced by pilgrims are: pilgrims find it difficult to count and remember the number of Tawaf rounds: and the second issue is that people cannot find each other again after becoming separated. These two problems are making the Hajj pillars very difficult and most pilgrims are unable to perform their Hajj pillars successfully. Existing systems were infeasible to use at Mecca for several reasons (e.g. crowds) which is mentioned in the next chapters of this thesis. As Mecca city has especial proprieties and constraints, all current solutions that have been developed in the navigation systems field are not feasible to apply in Mecca city. Therefore, it was necessary to design optimum systems which take the proprieties and constraints of the environment at Mecca into account. Two key aspects were considered to be essential while we designed the systems: “a common factor which can be understood by all people who meet at Mecca”, this factor was ‘*colour and visual codes’*. The other key aspect was “people should not need to carry any personal tools (e.g. mobile devices), see Ihram conditions”. Therefore, we developed augmented displays of specific designs to be appropriate to these requirements. Each situation has a particular interface: Dynamic signage which is designed to support pilgrims and help them count/remember the Tawaf rounds while walking around the Ka’bah. Other interfaces are designed to help pilgrims to find each other after becoming separated somehow whilst performing Tawaf or Saai inside Mecca’s Haram. We concluded that colour and visual codes were the common codes that people can understand regardless of their background, culture, and language.

In the Tawaf system we used dynamic signage supported by a colour code aimed at supporting pilgrims in navigating around one particular area. To evaluate the system, we conducted a user study in a realistic setting, and the results suggest that dynamic signage may be a feasible option in this setting. Regarding the second system (augmented signage) of Mecca which is concerned with how people can find each after becoming separated, we used static and dynamic signage, both complementary mechanisms that combine into a complete system to provide navigation information for pilgrims to help them find each other inside Mecca’s Haram. The designs and evaluation of our prototypes also led to a number of insights regarding the design of such systems. We discuss difficulties encountered during the design process and the evaluation and reflect on implications for the design and evaluation of systems supporting navigation for large crowds.

Augmented displays could be developed and utilised in different settings, for example in public spaces to supply navigation information to pedestrians in unfamiliar spaces. Pedestrians have to face many issues while using static signs or mobile guides and those issues have been described in Chapter 3. It is well known that dynamic displays have many advantages compared with static signs (e.g. being up-to date) and mobile devices (e.g. large screen size). The system that we designed includes three conditions: Base/Arrow (conventional sign, no extra supporting clues), Coloured circle (supported by different coloured circles), and coloured symbol (supported by different coloured symbols).

Our systems have two main advantages: people do not need to be familiar with any particular language to use them; the second advantage is that a user is not required to carry any personal devices in order to interact with the system displays. Another key contribution is that our approaches are available to be used by a large number of users simultaneously. One of our systems contributions is represented in developing augmented displays via colour and codes to provide considerable help to large and heterogeneous crowds simultaneously in different settings, as colours and visual codes can be understood by anyone regardless of their language or culture.

1.2 Limitation on the use of mobile phones at Mecca

Considering the use of mobile guides in the context of the Hajj at Mecca, there are some issues that limit their suitability. First, the garment that pilgrims wear has no pockets, which means carrying a mobile device can be cumbersome and might interfere with the religious experience (not to mention the danger of losing the phone or having it stolen). Second, more importantly, the dense crowd makes using a mobile device difficult and potentially dangerous as people have to pay close attention to their surroundings in order to not bump into other pilgrims. Thirdly, one key aspect of rites such as Tawaf is for people to keep moving at the same pace, but users of mobile devices often tend to slow down while interacting with their device, which might disrupt the ‘flow’ and potentially cause hazardous situations. A fourth reason is that pilgrims should pay full attention to their rituals and saying particular sentences while performing them (i.e. any other actions, such as using mobile phones, during this time could confuse them). A further reason is that the Mecca area is very crowded and many pilgrims are speaking aloud, so these circumstances (too noisy) prevent them from hearing their mobiles’ output (e.g. vibration or any other audio). Finally, as a large number of people using the mobile networks at the same time will cause failed connections due to network instability or a temporary overload (e.g., millions of concurrent users).

1.3 Research Questions

We were interested in finding answers to the following questions:

i) Do augmented displays (dynamic signage and static signs) help and support people to direct their actions in the crowd situation around the Ka'bah. For example: Does the dynamic signage system support pilgrims to keep track of the round count and to navigate successfully? Do dynamic and static signage help pilgrims find each other after becoming separated while performing their rituals in densely crowded settings around the Ka'bah?

ii) In the three case studies, does the current user interface meet user needs, can they use it, or are there any issues that need to be addressed?

iii) Is the idea of installing such systems (augmented displays) at Mecca acceptable and does it improve the pilgrimage experience, e.g. reduce the crowds and help pilgrims to navigate successfully around the Ka'bah?

iv) Can people understand the content of the augmented displays and extract personalised information to direct their actions successfully, e.g. to infer the right direction reliably and quickly?

v) How do the three conditions of case study 2 (arrows only, coloured circles, coloured symbols) compare in terms of task completion time, errors, disorientation events, usability, satisfaction, and workload?

vi) How do the two conditions of case study 3 (Dot and Symbol) compare two groups (pilgrimage and non-pilgrimage participants) in terms of task completion time, errors, disorientation event, usability, satisfaction, and workload?

1.4 Thesis outline

This section gives the outline of each chapter of the thesis and illustrates some important aspects of the thesis chapters.

Chapter 2_______Approach

This chapter consists of three sections: introduction, pilgrimage scenario, and methodology. Section (2.1) will introduce the chapter and give a brief explanation of its important aspects. In addition, it will include a road map of what is going to be presented in the chapter. The second section is the pilgrimage scenario (2.2). In this section we will give an explanation of the Hajj scenario (pilgrimage to Mecca) which contains definitions and descriptions of the Hajj pillars and Mecca, places that pilgrims should visit and perform rituals in, and how they perform those pillars. Issues that face pilgrims will also be mentioned in this section.

The third section (2.3) describes the methods that were applied to collect data about Hajj. These methods were: Interviews, Focus groups, Questionnaires, and User studies. Furthermore, this section gives a description of the simulation methods that we used through the user studies; it also gives an explanation for each method and a rationale for its design.

Chapter3_______ Related Work

Chapter 3 gives an outline of the research that has been done on pedestrians' navigation systems and a brief overview of the different prototypes that have been developed over recent years. The first section (3.1) introduces the way-finding definitions and other concepts such as cognitive map and how wayfinding is important for people to find their way in the natural or built environment.

In section (3.2) 'Pedestrian Navigation System (PNS)', we have categorised the areas of research into three types: static signs, mobile guides, and dynamic signage. This section also gives an explanation to each category and presents some examples to illustrate related issues and explain whether or not they are feasible in providing help at Mecca and why. This section also provides the basic aspects of natural and social navigation such as definitions, and how people use these kinds of navigations as guidance while travelling from one place to another, and why these kinds of navigation are not feasible at Mecca. Furthermore, the section introduces the fundamental of distributed cognition and investigate whether or not the distributed cognition methods feasible to working on Mecca scenario.

Chapter 4_______Case Study 1: The Tawaf System

Supporting Pilgrims in Navigating Densely Crowded Religious Sites

This chapter begins with an introduction section (4.1) which gives an explanation of the chapter and a road map which illustrates the structure of the chapter sections. In this section we will explain what aspects of the research questions are being addressed and why the case study is being done, what we hope to find in connection to our hypothesis, and what the experimental results mean, whether the hypothesis has been supported or disconfirmed and what the significance of the implications of the results for design/re-design are. In addition, we provide an explanation about Mecca's properties, constraints and key issues which face pilgrims during the Hajj event. Then the section introduces the scenario at Mecca which explains the circumstances of Hajj pillars and the environment at Mecca. Next section (4.2) presents interviews, comments, and then focus groups suggestions about the initial system design. Also, how the system was designed, what design decisions were taken, and why it was designed in this way. After that comes a description of the design approach section (4.3) which gives details about initial design, comments and suggestions of the focus group participants, and redesign the system. Subsequently the evaluation section (4.4) is presented, which includes details of the user study, participants, procedures, run study, results, and the summary of the key findings of the study. Discussion and reflection section (4.5) discusses and reflects upon what the experimental results mean, whether the hypothesis has been supported or not and what the significance of the implications of the results for design/re-design are. At the end of this chapter there is a brief summary (Section 4.6) about the chapter conclusions and an introduction to the next chapter.

Chapter 5_______Case Study 2: Augmented Signage System

Scalable Navigation Support for Crowds: Personalised Guidance via Augmented Signage

This chapter presents several sections; firstly section (5.1), there is a brief an introduction, then the motivation and the outline of the chapter which describes the system conditions (Arrow, Colour, and Symbol approaches), is presented. Then comes an illustration of how the system is designed and how it works, this will be in section (5.2). The next section (5.3) describes the system evaluation which includes user study, participants, procedure and results gathered. In section (5.4), discussion and reflection is presented. Finally, in section (5.5) a summary and conclusion of this chapter is presented and there is a brief mention of the next chapter.

Chapter 6_______Case Study 3: Regroup people in crowded situation

Using augmented signage to reunify groups in densely crowded environments

The first section (6.1) gives an introduction to the system; in this section we introduce an introduction about the chapter and its map road. The next section (6.2) concerns the interviews and includes why, who, and how the interviews were organised, and their results. In section (6.3) we describe the design approach. Firstly we provide a description about the initial system design (6.3.1). Then there is a focus group section which relates to the initial system description and focus group comments and suggestions (6.3.2). Afterwards, the final system design is explained (6.3.3). Here, in this subsection we give full details about the dot condition design, then we provide detailed of the symbol condition design. Subsequently the evaluation and results section (6.4) is detailed, which includes the user study, participants, procedure, and distraction tasks (which are utilised to clear the participant’s memory and demonstrate that they can still remember the dynamic information), and results gathered. Discussion and reflection section (6.5) gives some important aspects of the results which obtained from the user study. The final section (6.6) gives a summary of the chapter and refers to the next chapter through a brief introduction.

Chapter 7_______Discussion

Chapter 7 gives a discussion of the important points of the approaches in the different chapters. In the beginning we introduced how we collected the data about Mecca, the methods that we applied and why. Next we discussed why it was infeasible to run Mecca case studies in the actual area (Mecca environment), and discussed the simulation methods that were used in both Mecca studies: (simulated Ka'bah of the case study1 'Tawaf system' and distraction tasks of the case study3). Three sections included in this chapter: Section (7.1) provides a summary of design issues and hypotheses and how they developed across the three case studies. We also include some discussion on how our proposed technology intervention might impact upon the spiritual experience of both those using the system (might they be less engaged in the ritual experience for example?) and those not using the system (for this latter group perhaps the display could represent an unwelcome distraction). Section (7.2) gives a discussion of the strengths and limits of the experimental methods in relation to the question of real world research and ecological validity of lab-simulation in this very real world setting (e.g. the Hajj in Mecca). What might be the obstacles? Section (7.3) regarding the discussion of *Measurements* and how these link to the hypotheses. More critical analysis in terms of usefulness, usability and what the findings and general design principles and guidelines might be. This also includes a consideration of the potential practical obstacles to deploying the systems for use in Mecca.

Chapter 8_______Conclusion

This chapter gives a summary and the important aspects of the whole thesis. It illustrates how the three studies using the developed augmented displays supported by colours and visual codes were undertaken, and then presents the significant results of all the studies. This section (8.1), contributions, which describes some aspects to show that augmented displays supported by visual and colour codes could be of assistance to people in different settings. It is includes two subsections major contributions and minor contributions. The next section (8.2) describes the future work; the future work section introduces some further work which could be done through augmented displays to help people in different situations such as other places at Mecca, crowded shopping centres, or stadia.

Chapter Two Approach

2. Approach

2.1 Introduction

This chapter includes three main sections, the first one concerns the Hajj scenario (Pilgrimage to Mecca), this section will present and discuss several terms that are related to the Hajj event in the Islamic religion; such as definition, rules, places, Hajj pillars, properties and constraints of the situation at Mecca, it will also look at key issues of pilgrimage: what problems pilgrims face while performing Hajj pillars, what methods they use to overcome those problems, and who should perform Hajj. Furthermore, other aspects that occur during the pilgrimage season will be described. Then some examples which illustrate what has happened to some of the pilgrims while performing the Hajj ritual will be given. For example, such as forgetting how many circuits they have completed when they are circling around the Ka'bah, (Tawaf pillar), or losing each other while performing Tawaf, Saai, or on Arafat day. It is quite possible that a man loses his wife, friend or group inside the Mecca's Haram or in other places around that area.

The third section (2.3) focuses on the methods that we have used in our research to collect the data; the methodology section. This section provides full details about the methods that we applied to obtain sufficient information about the pilgrimage situation and places of congestion during Hajj. In addition, we will introduce the methods that we used when collecting, designing, and evaluating the three studies that we undertook.

Finally, section (2.4) will summarise the significant points of the whole chapter and briefly introduce the sections in the next chapter.

2.2 Pilgrimage Scenario

Travelling to Mecca to perform Hajj is not only a highly significant event in the life of a Muslim but the pilgrimage also results in situations, which have unique properties and which pose several challenges that result from the large number of people participating in the event. In order to get a good understanding of this scenario, we reviewed a number of sources and conducted a series of interviews with 45 people who had firsthand experience.

Pilgrimage is the fifth pillar of Islam, which is a pilgrimage to Mecca, Saudi Arabia, during the month of Dhu-al-Hijjah, a religious duty that must be carried out at least once in their lifetime by every able-bodied Muslim who can afford to do so. The Hajj is a demonstration of the solidarity of the Muslim people, and their submission to God (Allah in the Arabic language). The pilgrimage occurs from the 8th to 12th day of Dhu-al-Hijjah, the 12th and last month of the Islamic calendar. Because the Islamic calendar is a lunar calendar, eleven days shorter than the Gregorian calendar used in the Western world, the Gregorian date of the Hajj changes from year to year. For example, in 2007, the Hajj was from December 17 - 21; in 2008 from December 6–10; in 2009 it was from November 25–29, and in 2010 it was from November 14 – 18.

2.2.1 Pilgrimage Pillars and Places

Pillars of pilgrimage are called (in the Arabic language) 'Arkaan', the obligatory actions are called 'Waajibaat', and the conditions are called 'Shuroott', and the etiquette is called 'Aadaab'. If one of the pillars is not performed then everything should be redone whether for Hajj or Umrah. If the obligatory actions are not done, the pilgrim has to offer an animal, or fast for ten days if he, or she, cannot afford to provide an offering. There are also actions, which are forbidden called 'al-Mahdhoorat', if done they can spoil the duties of Hajj or render the Hajj void. In this context we decided to describe only the obligatory actions (pillars or Arkaan) [2].

2.2.1.1 Ihram

During the Hajj, male pilgrims are required to dress only in the ihram, two sheets of white cloth, with the top draped over the torso and the bottom secured by a white sash; plus a pair of sandals. Pilgrims normally travel to pilgrimage in groups. Women are simply required to continue wearing their normal dress, which does not cover the face or hands. The purpose of this is to show the equality of all pilgrims in the eyes of God: that there is no difference between rich and poor. While wearing the Ihram, pilgrims may not clip their nails, shave, using perfume, have sexual relations, cover the head (for men) or the face and hands (for women), and perform any dishonest acts or carry weapons [3].

2.2.1.2 Tawaf

When a person arrives at Mecca, the first thing they should do is to start walking in a counter-clockwise direction seven times about the Ka'bah, the cube-shaped building which exists in the Haram centre and acts as the Muslim direction of prayer. When entering the great Mosque (Masjid Al Haram) pilgrims should all walk seven times around the Ka'bah. Throughout each complete round pilgrims state particular sentences: "*In the name of God, God is Great, God is Great, God is Great and praise be to God*" with seven rounds indicating a complete Tawaf. They should start Tawaf from particular point (black stone position). Pilgrims can enter through several different entrances, but the actual Tawaf will only count from the black stone location, i.e. A pilgrim starts walking from the black stone in a counter-clockwise direction to reach the same point (black stone again). If a pilgrim forgets the number of rounds, they should remember the minimum number of rounds that they are sure they have done and complete to seven, if they cannot remember any number then they must start from the beginning (repeat all rounds). For example, if a person while walking around the Ka'bah is suddenly stuck and cannot remember which round they are currently performing, but is sure that they have done at least 3 rounds, in this case they should complete the fourth, fifth, sixth, and seventh rounds. On the other hand, if they have completely forgotten the number of rounds that they have done, in this case they must start doing seven rounds from the beginning[10, 60] . Eating is not allowed during this process, but the drinking of water is permitted because of the risk of dehydration. After pilgrims have completed the Tawaf rounds, they have to pray two Rakaat at the place of Abraham (Maqam – Ibrahim) which exists inside the Mosque near the Ka'bah. Again because of the crowds, they may instead pray anywhere in the Haram.

2.2.1.3 Saai

After the Tawaf pillar is complete, on the same day, the pilgrims have to perform the Saai rite, walking seven times between the hills of Safa and Marwa. The image shown in Figure 2-1 illustrates how people perform the Saai pillar. Pilgrims should start walking from the Safa hill. When a pilgrim starts from Safa and reaches Marwa this is one round. The return back to Safa again is the second round and so on until the distance is completed seven times [5].

Figure 2-1 Saai between Safa and Marwah (photos from Wikimedia commons-http:// commons.wilki.org)

2.2.1.4 Zamzem

Drinking water from the Zamzem Well is part of the hajj ritual. During Hajj, pilgrims are recommended to drink Zamzem water. They also continue the tradition of bringing it back for family and friends. The pilgrims then return to their accommodation to have some *rest* after a long day's work and to get ready for other rituals [42].

2.2.1.5 Arafat Day

On the eighth of Dhu-al-Hijjah morning, the pilgrims arrived to Mina where they spend the night in prayer. On the ninth day, they leave Mina for Arafat where they stand for prayer and to recite the Qur'an. Pilgrims must spend the whole day within a defined area on the plain of Arafat until after sunset. No specific rituals or prayers are required during the stay at Arafat. A pilgrim's Hajj is considered unacceptable if they do not spend the whole day on Arafat Mountain [60].

2.2.1.6 Throwing Devil

Once the sun sets, the pilgrims leave Arafat for Muzdalifah. This is the place between Arafat and Mina, where they collect stones for the next day's ritual of the stoning of the Devil. Many pilgrims spend the night sleeping on the ground or back in their tents at Muzdalifah before returning to Mina. At Mina the pilgrims perform Ramy al-

Jamarat; throwing stones at the Devil [10,28]. Because of the huge crowds, in 2004 the pillars were replaced by long walls, with catch basins below to collect the stones. After throwing stones in a ritual stoning of the Devil, the pilgrims then shave their heads, perform a ritual of animal sacrifice, and celebrate the four day global festival of Eid-al-Adha.

2.2.2 Key Issues

There are several issues that pilgrims face during Hajj in general and Tawaf in particular. Dehydration and exhaustion can be a grave problem due to the heat and the potentially long duration of the rite. A further danger is tripping or being pushed due to the large number of people present at any time during Hajj. This is particularly bad near the Ka'bah as pilgrims are encouraged (but not required) to kiss/touch the Black Stone set into the Ka'bah.

People often perform Hajj as part of a group (e.g. family members, friends or nationals from the same country). Due to the crowdedness and the resulting density of people, it is easy to get separated from one's group. Therefore, losing other people is another key problem facing pilgrims, which was often mentioned by the people we interviewed when investigating this scenario. One interviewee had personally experienced this problem, and reported having lost his group during Tawaf and then been unable to find them (or his hotel) again for three days.

While this may be a particularly extreme experience, it points towards another key problem: finding various places in and around Mecca. The pilgrims we interviewed reported that there are human guides for hire, who offer to lead people to different locations, and that there are also a number of static signs installed throughout the city. However, they said that they found the signs of limited use only (even though all of our interviewees were capable of reading and speaking Arabic). A related problem particular at Tawaf is a result of the removal of the blinking light and the green line: it is now more difficult for pilgrims to identify the starting location of Tawaf as they have to identify the correct corner of the Ka'bah by themselves.

Another key issue during Tawaf (and also during Saai) is keeping track of the rounds count. As mentioned above, circumambulating the Ka'bah can take a long time and is a highly spiritual experience; it is therefore easy to forget how many of the prescribed seven rounds one has completed. Several of the people we interviewed confirmed that this was indeed a problem (as did the participants of the focus groups and the user study we organised). If pilgrims do forget, there are different opinions about what they should do. While for some, it is sufficient to do a few more rounds until they are sure that they have done seven or more in total, others believe that they have to start over and do another seven rounds.

While forgetting the rounds count is an unfortunate event for each individual pilgrim, it significantly increases the risk for all pilgrims performing Tawaf in two ways. First, people who walk additional rounds are more likely to suffer from exhaustion and dehydration and thus increase the associated risks. Second, they remain longer than necessary at the great mosque and the Ka'bah. This in turn unnecessarily increases the number of people present at these locations at any time and thus the density of the crowd. While there is a constant stream of pilgrims eager to get in, those already on site do not leave as quickly as they could. The problem of forgetting the rounds count hence has a knock-on effect on some of the other issues and negatively impacts the safety of those participating in Tawaf. Consequently, finding a feasible solution to address these issues has a high potential to noticeably improve the situation, which is why we decided to investigate how to help pilgrims to remember the rounds count and help them find each other after becoming separated. Some examples illustrating how people are suffering from those issues will be presented in Chapters 4 and 6. In this thesis we focused on the two main issues which face pilgrims while performing their rituals inside Mecca's Haram, the first study was regarding "how to help pilgrims count / remember the rounds of Tawaf or keeping track of the Tawaf rounds". The second issue we have addressed was concerned with "how to assist people in finding each other after becoming separated in the Haram". The two studies have been done to address and investigate those issues. The 'Tawaf study' was described in Chapter 4 and 'people finding each other' was mentioned in Chapter 6. Several methods have been used to investigate these Mecca city situations and collect the relevant data. Through our investigations via a series of interviews with experienced people and other sources, we understood that this situation needs especial methods to address all issues. The next section gives more details about the methods which are applied in our studies.

2.3 Methodology

2.3.1 Introduction

In order to determine appropriate methods which we could use to gather data regarding our studies, such as design and evaluation of our studies, we used four kinds of methods: Interviews, Focus groups, some types of Questionnaires, and simulation methods. As it was not possible to run our studies concerning Mecca in the actual area, therefore, we conducted lab-based user studies in a simulated environment. Details of those simulation methods will be described later in this chapter. We employed these methods due to the unusual properties and constraints of the actual environment at Mecca. In the first and third studies (regarding Mecca) we needed to collect initial data from people who have experience of a pilgrimage to Mecca. Interviews with those people were conducted and we asked them about the environment at Mecca and details about Hajj terms. To do this we needed to choose an appropriate kind of interview which would allow us to gather sufficient information. Once we had constructed the initial ideas, then we could design initial systems and present them to other people who also had experienced pilgrimage before conducting “Focus Group Sessions”. This allowed us to have feedback and useful comments and suggestions which might enhance and develop the initial systems which resulted from the interviews, and then we could redesign them based on the focus groups participants’ feedback. Before that we investigated some previous research which applied focus group methods to increase our understanding of how focus group sessions can be organised and be of benefit to us, in this context. All focus group methods and considerations have been taken into account such as: How to plan and organise a focus group, which people are appropriate to invite to participate in focus groups (relevant to our study), what are the attributes / properties that should be present in those people, what we might benefit by people providing us with information about our topic or studies.

Thirdly, to gather feedback from user studies participants about the systems such as performance, usability, satisfaction, ease of use, how easy they were to learn, and system simplicity. All these terms could be scaled /measured by using a Questionnaire method. We applied a USE questionnaire in the first and second studies and an IBM Computer Usability Satisfaction Questionnaire has been applied in the third study [53,58]. Moreover, to measure the participants' workload while completing the tasks in the studies, we used a NASA Task Load Index (TLX) (in the second and third studies) [37].

In order to measure the systems in terms of Task Completion Time, Orientation events, errors rate, and subject's behaviour while doing studies tasks, all three studies have been recorded (video and audio). Through these materials we have analysed and evaluated those terms.

In creating a feasible solution for improving the situation during Tawaf we followed a user-centred design approach. Given the spiritual relevance of the scenario, we considered the continuous involvement of users essential not only to expose designs to potential users early on but also to ensure that the designs are acceptable from a 'religious' perspective. Here we intend to give some details about the user-centred-design approach.

User-centered-design approach: The term 'user-centered design' originated in Donald Norman's research laboratory at the University of California San Diego (UCSD) in the 1980s and became widely used after the publication of a co-authored book entitled: *User-Centered System Design: New Perspectives on Human-Computer Interaction* (Norman & Draper, 1986). Furthermore, the term 'user-centered design' (UCD) is a wide term to describe design processes in which end-users influence how a design takes shape. It is both a wide philosophy and set of methods. There is a spectrum of ways in which users are involved in UCD but the important concept is that users *are* involved one way or another. For example, some types of UCD consult users about their needs and involve them at specific times during the design process; typically during requirements gathering and usability testing. At the opposite end of the spectrum, there are UCD methods in which users have a deep impact on the design by being involved as partners with designers throughout the design process. Moreover, Norman (1988) built further on the UCD concept in his seminal book '*The Psychology of Everyday Things*'. In this context, he recognizes the needs and the interests of the user and focuses on the usability of the design. He offers four basic suggestions on how a design should be: (1) Make it easy to determine what actions are possible at any moment, (2) Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions, (3) Make it easy to evaluate the current state of the system, and (4) Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state (Norman, 1988, p.188).

Preece, et. al,(2002) claimed that, the design cycle progresses, prototypes (limited versions of the system) can be produced and user tested. At this point, designers should pay close attention to the evaluations by the users as they will help identify measurable usability criteria. These criteria address issues related to the effectiveness, efficiency, safety, utility, learnability, and memorability (how long it takes to remember to perform the most common tasks) of the system and users' subjective satisfaction with it. One could see how difficult it would be for designers to know or imagine all the usability criteria that are important to the users. It is only through feedback collected in an interactive iterative process involving users that systems can be refined. Dix, et. al, 1997 and Preece, et. al, (1994 and 2002), they have introduced some advantages and disadvantages of the user-centered design approach. The major advantage of the user-centered design approach is that a deeper understanding of the psychological, organizational, social, and ergonomic factors that affect the use of computer technology emerges from the involvement of the users at every stage of the design and evaluation of the system. The involvement of users assures that the system will be suitable for its intended purpose in the environment in which it will be used. This approach leads to the development of systems that are more effective, efficient, and safe. The second advantage is, it helps designers manage user's expectations about a new system. When users have been involved in the design of a system, they know from an early stage what to expect from a system and they feel that their ideas and suggestions have been taken into account during the process. This leads to a sense of designers of the final system that often results in higher user satisfaction. The major disadvantage to user-centered design is that it can be quite costly. It takes time to gather data from users who will provide the initial ideas about the issues being addressed and about the environment where the system will apply, such as properties and constraints. In general, we can say that User-centered design (UCD) is a general term for a philosophy and methods which focus on designing for and involving users in the design of computerized systems. The ways in which users participate can vary. At one end of the spectrum involvement may be relatively light; they may be consulted about their needs, observed and participate in usability testing. On the other end of the spectrum involvement can be intensive with users participating throughout the design process as partners in the design. A variety of methods have been developed to support UCD including usability testing, usability engineering, heuristic evaluation, and participatory design.

In creating our systems to support people in a crowd situation during the pilgrimage at Mecca, we adopted a user-centered design approach. All those considerations mentioned above were taken into account and followed when we designed our approaches. Given the spiritual relevance of the scenario, we considered the continuous involvement of users essential not only to expose designs to potential users early on but also to ensure that the designs are acceptable from a ‘‘religious’’ perspective. We first identified the properties, constraints, and most pressing issues pertaining to the application scenario by surveying existing literature and other sources such as material published by the Saudi Arabian ministry in charge of the Hajj or guide books for people planning to go on a pilgrimage. We then conducted a series of semi-structured interviews (based on the findings of the initial phase) in order to gather further feedback on specific issues during the Hajj while also allowing for additional input that might be relevant for the design of a system to support pilgrims. In our case studies we have adopted some aspects of the methods; the following table illustrates the methods and stages of the designs cycle.

Table 2-1 Summary of methods used in both case studies of Mecca

Technique	Purpose	Stage of the Design Cycle
Literature review and on interviews with pilgrims, and then introduce a prototypical augmented display systems aimed at supporting pilgrims in navigating one particular area.	Collecting data related to the needs and expectations of participants; issues face pilgrims while performing pilgrimage pillar. Both case studies.	At the beginning of the system design
Sequence of work interviews	Collecting data related to the Mecca	Early and mid-point in the

with people who had pilgrimage before.	environment: properties and constraints.	initial design
Interviews	Categorization and sorting the data which about Mecca environment and pilgrimage situation	Final stage of the initial design
Focus groups	Include a wide range of people who have experience about the pilgrimage to discuss initial systems issues, shortcomings, and requirements.	Early in the design of the final systems
Focus groups results	Suggestions and comments	Redesign of the systems
Design and simulations methods, existing methods are not work because Mecca has especial properties and constraints	Design new simulation methods to make the situation of lab user study similar to the actual environment, e.g. simulated Ka'bah in first case study and simulated dynamic signage and distraction tasks in the third case study.	Final stage of the system design
User studies	To investigate whether the results of our small scale studies will actually scale to very large crowds	Early stage in user studies and evaluation
Evaluation	To evaluate the systems, we conducted a user studies in a realistic setting, and the results suggest that dynamic signage may be a feasible option in this setting.	Mid-point of evaluation stage.
Results from questionnaire and qualitative feedback	The questionnaire presented a series of (negative and positive) statements about the augmented displays system and asked them to indicate their level of agreement on a five points Lickert scale, where five corresponded to ''strongly agree'' and one to ''strongly disagree''.	Final stage of the evaluation

Our approaches were to scale down the location so that we could achieve a relatively high density of people with a relatively low number of participants. Our designs were based on the user requirements, as we used several methods to investigate all users need/requirements and design our systems based on that. As one of our study questions was 'Do potential end users find the idea of installing such systems at

Mecca acceptable? And 'Does the current user interface of augmented displays meet their needs, can they use it, or are there any issues that need to be addressed?' The questionnaire results assured us that the user's needs were all met while using the systems throughout the user studies.

Alternative solutions could be just to simulate large crowds convincingly (e.g., using projections and/or audio recordings) or to use tighter spaces (with a potential negative impact on participants' safety). We highlight some issues pertaining to the evaluation of interfaces for large crowds, e.g., the difficulty of creating a realistic simulation in the lab and how best to progress from small-scale tests such as focus groups to larger studies scale prior to real-world deployment.

Finally, as we mentioned that the Mecca environment is an especial case which includes unique proprieties and constraints. Many aspects prevented us from running our studies there at Mecca, such as the initial stages of our studies and the authorities of Mecca (e.g. work needs to be permitted by Mecca's Haram authority). Therefore we decided to use simulation methods to create an environment to be similar to the actual area. More details about simulation will be presented in section 2.3.5.

2.3.2 Interviews

The interview is an accepted way to collect data about studies or research because it is more personal than traditional selection evaluation (e.g., exams) and because it can be used to evaluate aspects of tasks not easily measured with other procedures. Structured, semi-structured, and unstructured are classified into three types of face to face interviews that can be used when running a research project. Each one of those methods has individual characteristics. Each type will be introduced in this section, the differences between them described and an explanation of which kind is feasible for our studies, and why, will be given [55, 31].

2.3.2.1 Structured Interviews

The structured interview is an uncomplicated method. The interviewer has a standard set of questions that are asked of all participants. This makes it easier for the interviewer to measure and reasonably compare participants. Structured interviews are the type used most frequently by quantitative researchers. The method is mainly useful when looking for very specific information. Each question in this type of interview should be read word for word by the researcher without any variation from the procedure [39]. This type of interview is not feasible to use in our studies, because the answers of participants might bring new questions into account. As we mentioned above, the questions in this method should be standard and be determined from the beginning, with no possibility to add any questions once the interview has started. However, in our situation we needed to enquire about every single aspect concerning Mecca (environment and pilgrimage) and as this facility is not available in this type of interview, it was deemed as inappropriate to use. [55]

2.3.2.2 Semi-structured Interviews

This method of interviewing is more flexible than structured interviews. While researchers using this type are still expected to cover every question in the approach, they have the ability to explore participant responses by asking for explanations or additional information. Semi-structured interviewing begins with more general questions. Relevant issues are initially identified and the possible relationships between these issues become the starting point for more specific questions, which do not need to be prepared in advance. Many questions might be created throughout the interview, permitting both the interviewer and participant being interviewed the flexibility to go into detail when needed. Moreover, semi-structured interviews are most frequently used in qualitative research. The method is most useful when one is exploring a study that is very personal to the participants. It might be useful to gain participants' trust, and this relationship will enable a deeper understanding of responses. Data sets obtained using this method will be larger than those using the previous type of "structured interviews". Furthermore, the key advantage of a semi-structured interview is that it is flexible; allowing new questions to be brought up during the interview as a result of what the interviewee says [54, 76]. Lofland et al. (1984) argued that in semi-structured interviews the interviewer is free to investigate and explore within these determined inquiry areas. Interview guides could be used to ensure that interviewers with limited time make interviews more systematic and all-inclusive; and they help to keep relations focused. Interview guides can be modified over time to concentrate fully on areas of particular importance, and ignore questions the investigator has found useless for the goals of the research [55]. Whereas a formalised structured interview method has a limited set of questions. Therefore, the semi-structured interview was feasible to use in our studies as it included all attributes and properties which allowed us to gather all the data we needed for the design and evaluation of our studies.

2.3.2.3 Unstructured Interviews

Unstructured interviews are more relaxed than other interviews types. Unstructured interview are recommended when the researcher has developed enough of an understanding of a situation and their topic of interest to have a clear outline for the discussion with the informant, but still remains open to having their understanding of the area of investigation open to revision by respondents. It is generally best to tape-record interviews and later transcribe these tapes for analysis. This allows the interviewer to focus on interacting with the participant and follow the discussion [54]. The communication between the participant and the researcher is more like a conversation than an interview. Unstructured interviews are most frequently used in types of qualitative research. It might be the best method to use when interviewers want to collect as much information as possible about their studies. The advantage of unstructured interviews is that they frequently uncover information that would not have been uncovered using previous interview styles. Interviewers and participants are not limited by the procedure.

After investigating all three types of interview methods we concluded that the semi-structured interview method was most appropriate for our studies. In our first and third studies we used the second kind of interview method - “semi-structured”. We chose this kind because it was suitable for our context and includes the properties and advantages that we need to collect our data. For example, in our “Mecca scenario” we have to cover every single aspect of Mecca on two levels: the ‘pilgrims level’ which focuses on pilgrims, e.g. which people are visiting Mecca city and how many people meet there, how they deal with the especial properties and constraints of the city’s “Mecca environment”, what they have to do inside and outside Mecca’s Haram, what are the pillars and what restrictions and rules they should follow to perform their rituals. The second is the ‘environment level’, e.g. crowds, similar places, lack of helpful information, and rituals that pilgrims perform during the Hajj season. In addition, this method has several advantages which can provide benefits in gathering useful information. For example, this method allows new questions to be brought up during the interview as a result of what the interviewee says. Furthermore, this method allowed us to extract new questions based on interviewees' answers. Therefore we applied this interview method in our both studies; 'Tawaf system case study 1 ' (details in Chapter 4) and 'People finding each other via dynamic and static displays case study 3' (details in Chapter 6).

2.3.3 Focus groups

To gather feedback about our systems, we planned and organised focus group sessions. It was important to use a focus group method in our context to increase our understanding about the environment at Mecca and to gather feedback about the initial design of the systems. Focus group feedback was very important for us to improve our initial systems, as the focus groups members that we selected had completed pilgrimage before, they had sufficient experience of the issues of Hajj. Through the previous research we have concluded that the focus group method is important to use in such situations, because it allows for in-depth discussion and research on an issue of interest [48, 67]. We can collect opinions of more than one person in one session and the interaction between group participants can result in increased elaboration on a topic and therefore a broader insight into the understanding of an issue. Alexandria, VA (1997) defined a focus group as group of interrelating participants having the same goal; it's a method used to gain information about specific issues [7]. Moreover, they described two important aspects to plan and organise a focus group session: 'Focus group size and the length of group discussion', and 'Questions that should be posed throughout the session'. Theses aspects are very important and should be taken into account when organising any focus group session. Stewart et al. (1990) claimed that the study on focus groups commonly recommended six to twelve participants as optimal for impact. Some state that a focus group might contain up to 20 participants; however, the large size of the focus group could be difficult to manage. Mainly focus groups take 90 minutes to three hours of discussion. Otherwise participants should have breaks to relax and refresh throughout a session. Many researchers believe that focus groups could provide significant answers to the questions which regarding new ideas of systems [81] give information about how groups of people think or feel about a particular study, provide greater insight into why certain opinions are held, and help improve the planning and design.

A lot of suggestions have been discussed such as whether questions should be open-ended (unlimited) so that there are as many replies as possible. Short- answer questions should be avoided, such as those that can be answered with “yes” or “no”. It is also important to avoid leading questions which might influence the participants’ opinion. Based on that, questions should also have an obvious origin and be simple to understand, with easier, general questions prior to more difficult ones, [93]. Questions can be improved to obtain responses related to participants such as personal experiences, behaviours, knowledge, values or morals, or varied based upon their gender, culture, characteristics, life experiences, and feeling or beliefs. All aspects and considerations that are mentioned above have been taken into account when we planned and organised our focus group sessions.

2.3.4 Questionnaire

A questionnaire is a set of questions asked to individuals to gain statistically helpful information on a given study. When properly constructed and responsibly administered, questionnaires become a very important tool by which statements can be made about specific groups or people, or entire populations. They are a valuable method of collecting a wide range of information from a large number of individuals, often referred to as respondents. A useful method for checking a questionnaire and making sure it is accurately capturing the intended information is to pre-test among a smaller subset of goal respondents **[54].**

There are three basic types of questions researchers use: multiple choice, numeric open end, and text open end. ‘Rating Scales’ and ‘Agreement Scales’ are two common types of questions that some researchers treat as multiple choice questions and others treat as numeric open end questions. Here, it can be said that we used Agreement Scales, for example, *how much do you agree with each of the following statements?* Five options are available: Strongly Agree, Agree, Unsure, Strongly Disagree, and Disagree.

We have taken into account two broad issues to keep in mind when considering the question and answer choice order. One is how the question and answer choice order can encourage people to complete our studies. The other issue is how the order of questions or the order of answer choices could affect the results of our studies.

All these considerations have been taken into account while designing our questionnaires. In our three studies we have used the agreement scale type; we used a USE Questionnaire in the first study (Tawaf system) and the second study (augmented signage): USE stands for Usefulness, Satisfaction, and Ease of Use [58], we also used an IBM Computer Usability Satisfaction Questionnaire in the third study (people finding each other in the Haram): [53] Usefulness, Satisfaction, and Ease of Use, these are the three dimensions that emerged most strongly in the early development of those questionnaires. Moreover, NASA Task Load Index (TLX) Questionnaires have been applied in the second and third studies [37]. NASA-TLX is a multi-dimensional scale designed to obtain workload estimates from one or more participants while they are performing a task or immediately afterwards. *How much do you agree with each of the following statements?* Five options are offered as measures; very high, high, unsure, low, and very low.

2.3.5 Simulation methods

In order to run our studies which concern Mecca, we needed to use simulation methods to make the area of study was similar to the actual area. Existing methods are not feasible to use in our context, as the environment at Mecca has especial properties and constraints. For instance, the systems depend on people being in a certain position / situation in order for the system to function. Therefore we developed some simulations which are appropriate to our studies and all especial proprieties and constraints of the actual environment have been taken into account when we designed the experiments (details mentioned in the chapters where the case study is reported).

Finally, our investigation of the Mecca scenarios and the user studies we conducted to evaluate our designs also yielded some insights with respect to the design of systems to support navigation for large crowds. We identified the approach of context-driven personalisation of augmented displays content as a promising way to provide adaptable support for very large numbers of diverse and concurrent users. In addition, we highlighted some issues pertaining to the evaluation of interfaces for large crowds such the difficulty of creating a realistic simulation in the lab and how to progress from small-scale tests such as focus groups to larger scale evaluation prior to real-world deployment.

2.4 Chapter summary

In this chapter we have introduced three sections, in the first section (2.1) we introduced the methods that we used in case studies and why we have used these methods in particular. In addition, we provided a brief description about each method. The second section (2.2) was about the scenario at Mecca which was concerned with two important aspects: the environment at Mecca which concerns the city properties and constraints and how we investigated and addressed every aspect of those issues. The second part was about pilgrims (people who meet at Mecca to perform Hajj); in this part we discussed pilgrimage pillars (several rituals people must perform while they are at Mecca), places they should visit, and issues faced by pilgrims while performing their pillars of Pilgrimage. The second section has relevance to the methodology (2.3), as it is concerned with the methods that we applied in our research studies. We discussed interviews types and why the semi-structured method was suitable for collecting our data. Then we highlighted focus group sessions and why we used this method, afterwards we introduced which type of questionnaires we used and why. Finally we mentioned simulation methods: simulated Ka'bah in the first study and screen display simulation (to show dynamic signage and distractions tasks) in the third study.

The next chapter pertains to the related work and it includes background information on the previous systems which have been done in pedestrians' navigation field and a brief overview of the different prototypes that have been developed over the last few years. We categorised the area of research into three types: static signs, mobile guides, and augmented displays. Then we provide some examples about each category and mention some issues related to them. Afterwards, we illustrate why existing systems are not feasible to work at Mecca.

In addition, this chapter provided basic aspects of other kinds of navigation such as: natural navigation, for example, how people use natural things (sun, moon, stars, landmarks, etc.) to assist when travelling from one place to another. An introduction to social navigation which describes how people can navigate socially instead of using navigation tools is provided. Personal tools which include paper maps, guidebooks, compasses, etc., and a brief description about how people can use them in their navigation (e.g. tourism) is also included. The last section of this chapter presents the summary which includes the important points of the whole chapter.

Chapter Three Related work

3. Related work

Chapter 3 gives an outline of the research that has been done on way-finding and a brief overview of the different prototypes that have been developed over the last few years. This chapter also gives an introduction to the research done on public displays and their capability to help people in crowded environments. There is also a discussion concerning context. Social navigation will be presented in section 3.2.1. Through this section we attempt to give some definitions and several examples of how people can navigate from one place to another using the concept of social navigation. In section 3.2.2, we will explain how people can use natural things in their navigation. A lot of people when deciding to visit an unfamiliar area will use personal tools to help them gather information regarding that area. These means will be mentioned in section 3.2.3. In addition, we also intend to mention some advantages and disadvantages of those tools. Section 3.2.4, which looks at static signs as important means in pedestrian navigation systems, will provide details on important features of the static signs such as in navigation, and the advantages, and disadvantages. Then, we will present some examples about how people find personalised navigation information by using their mobile devices (mobile guides in section 3.2.5). Augmented displays and how they have been developed to provide navigation information to people in different settings will be mentioned in section 3.2.6. At the end of this chapter, we will present the important points which include the conclusion of the chapter (chapter summary in section 3.2.7).

A pedestrian navigation system (PNS) is important and an interesting topic today which could make use of applications that have the ability to track and locate people, for example safety of life applications and commercial applications. From a safety applications viewpoint, it might assist tourists in personal navigation through forest areas and areas of deep shade, and it could help find and keep fire fighting teams safe. Furthermore, it helps the user to navigate through an unfamiliar environment to find the shortest route to a particular destination. All these features and services eventually lead to safer transportation and enable effective management of time, energy and resources. Generally, finding the way in unknown or unfamiliar environments is a common task that people experience regularly throughout their lives. Several supporting tools are available, from conventional paper maps to modern location based services such as sensors and GPS systems. Mobile guide systems have long been the focus of research and are probably the most widely used example of location based services and applications. Their use is now widespread and user acceptance is high. Pedestrian navigation systems on the other hand, as related systems, are still in their infancy and struggle to gain market acceptance. Moreover, in this chapter we introduced some research which discussed many applications and systems which have been developed in the way-finding field.

3.1. Way-finding

Way-finding is an aspect of spatial orientation. It might include all the perceptual, cognitive, and decision-making processes necessary for people to find their way in the natural or built environment [9]. When way-finding becomes difficult, this causes people to feel frustrated and stressed and decreases a building's functional efficiency, accessibility, and safety in the event of an emergency. Human way-finding abilities must be considered by architects and interior designers when designing large, complex buildings (Arthur & Passini, 1992; Best, 1969; Corlett, 1972). In order to understand what people do and how they find their way, one has to understand the underlying process which is not just a concept of ‘spatial orientation’ but an idea integrating all the perceptual, cognitive and decision-making processes necessary to find one’s way. This concept is called way-finding [9, 17, 23]. Other researchers have also defined way-finding as; including a set of tasks that involve different cognitive processes, drawing on different cognitive components. Without way-finding we are unable to make predictions for movement through an environment. Way-finding support (e.g. cognitive maps) is needed to assist both way-finding in a virtual environment, and the usage of a virtual environment to support way-finding in the real world, (e.g. a person needs to see both a view of the virtual world and a map showing where he/she is and where s/he is looking). In order to successfully navigate through an environment, anyone needs to be able to associate his/her egocentric perspective with the information stored in the cognitive map. Cognitive mapping is a process composed of a series of psychological transformations by which an individual acquires, stores, recalls, codes, and decodes information about the relative locations and attributes of phenomena in their everyday spatial environment. In more general terms, Arthur et al (1992) defined a cognitive map as “an overall mental image or representation of the space and layout of a setting”, which means that the act of cognitive mapping is "the mental structuring process leading to the creation of a cognitive map" [9].

Bowman et al (1997) argued that navigation consists of two essential parts; a motor component (travelling) and a cognitive component (way-finding) [19]. It can obviously be argued that both components are strongly interrelated. Other researchers defined and classified the components of navigation and way-finding, for example, Allen (1999) claimed that way-finding involves three tasks: exploratory navigation, travel to a familiar destination, and travel to new destinations. Relocating to a new area and investigating the surroundings is a typical example of exploratory navigation; the exchange between home and the workplace is a typical example of travel to familiar destinations, and way-finding guided by maps is a typical example of travel to novel destinations [6]. In addition, navigation has also been defined by Montello (2001, 2005) as consisting of two components, way-finding and navigation behaviour in response to current sensors that are connected to the immediate surrounding and include tasks such as steering, obstacle avoidance, and the approach of a visible object in view space [64,65]. Moreover, there are six way-finding means by which the tasks can be solved; "oriented search, following a marked trail, piloting between landmarks, path integration, regular locomotion, and referring to cognitive map" as described by Allen (1999). Basically, these means range from essential navigation mechanisms such as following a marked trail or path integration to knowledge retrieval processes such as referring to a cognitive map [6]. In the 1970s researchers began to study how we navigate complex spaces by staging tests of orientation and memory in large building complexes, building interiors and malls.

Nowadays, way-finding has been improved because advanced technologies are used such as public display, GPS, PDAs, sensors and dynamic displays. However, there are many issues still facing pedestrians. As a result the researchers, architects, and designers are continuing to find more and more optimum systems for providing navigational information [69, 74, 75]. A lot of research is focussed on the area of way-finding particularly on pedestrian navigation systems. Almost all of these systems are working with advanced technologies such as Global Position System, handheld devices, and wireless communication. However, there are still some issues which obstruct these systems and have restricted them from working in certain settings. Here we intend to cover significant literature on distributed cognition and investigate whether or not to use it as an appropriate theoretical frame work for Mecca scenario.

Distributed cognition is a theoretical and methodological framework that was developed by Hutchins and his colleagues at the University of California, San Diego in the mid to late '80s (Flor and Hutchins, 1992; Halverson 1992; Hutchins and Klausen, 1992; Hutchins, in press) to explain cognitive activities as embodied and situated within the work settings in which they occur. By explicitly adopting this broad focus the distributed cognition approach provides a theoretical and methodological framework for analysing complex, socially distributed work activities of which a diversity of technological artefacts and other tools are an indispensable part. The applied aim of distributed cognition is to contribute to system design and implementation. This entails going into the workplace and spending time determining and analysing the problems with the existing technology and work practices and then suggesting recommendations as to what needs to be preserved and what systems and work practices need to be redesigned to support and improve the collaboration and coordination of work activities. The traditional view of cognition is that it is a localised phenomenon that is best explained in terms of information processing at the level of the individual. In contrast Hutchins was making the claim that cognition is better understood as a distributed phenomenon. The theoretical and methodological base of the distributed cognition approach derives from the cognitive sciences, cognitive anthropology and the social sciences. Furthermore, the distributed cognition approach emphasises the distributed nature of cognitive phenomena across individuals, artefacts and internal/external representations in terms of a common language of representational states and media. In addition, other concepts coming from the social sciences are utilised to account for the socially-distributed cognitive phenomenon. A distributed cognitive system is one that dynamically reconfigures itself to bring subsystems into functional coordination. Many of the subsystems lie outside individual minds; in distributed cognition, interactions between people as they work with external resources are as important as the processes of individual cognition. Both internal mental activity and external interactions play important roles, as do physical resources that reveal relationships and act as reminders. A distributed system that involves many people and diverse artifacts in the performance of cognitive work is therefore properly viewed as a cognitive system. The theory of distributed cognition forces a shift in how we think about the relationship between minds, social interactions and physical resources. Interactions between internal and external processes are complex and unfold over different spatial and time scales and neither internal nor external resources assume privileged status.

Zhang and Norman (1994) explained that the basic principle of distributed representations is that the representational system of a distributed cognitive task is a set of internal and external representations, which together represent the abstract structure of the task. Internal representations are in the mind, as proposals, productions, schemas, mental images, connectionist networks, or other forms. External representations are in the world, as physical symbols (e.g., written symbols, beads of abacuses, etc.) or as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layouts of diagrams, physical constraints in abacuses, etc.). Generally, there are one or more internal and external representations involved in any distributed cognitive task [103].

Norman (1988), argued that well-designed artifacts could reduce the need for the user to remember large amounts of information, whereas badly designed artifacts increased the knowledge demands made on the user. The rhetorical aim of the “knowledge in the head, knowledge in the world” distinction was thus to draw the designer’s attention to the implications that design decisions had on cognitive processing. Norman (1986) advocated the cognitive engineering approach premised on this view of cognition as distributed between user and artifacts [105, 106].

Zhang and Norman (1994) took the distributed cognition approach back into the laboratory to study human problem solving. Here, unlike much of Hutchins’s work, the emphasis is not on collaborative team working, but rather on the interaction between an individual and a representational artifacts and a comparison of behaviour with different information representations [103103].

In the same context, Zhang (1992) argued that many distributed cognitive tasks have multi-level hierarchical representations. He provided some examples which illustrate this context. At each level of a task’s hierarchical representation, there is an abstract structure that can be implemented by different isomorphic representations.

Internal and external representations are two essential parts of the representational system of any distributed cognitive task. To study a distributed cognitive task, it is important to separate the representation of the task into its internal and external components so that the different functions of internal and external representations can be identified [103]. Zhang (1992) argued that within the distributed cognition framework, therefore, one can adopt different units of analysis, to describe a range of cognitive systems, whereby some subsume others. One can focus on the processes of an individual, on an individual in coordination with a set of tools or on a group of individuals in interaction with each other and a set of tools. At each level of description of a cognitive system, a set of cognitive properties can be identified; these properties can be explained by reference to processes that transform states inside the system.

Furthermore, he identified several general properties of cognitive systems. A general assumption of the distributed cognition approach is that cognitive systems consisting of more than one individual have cognitive properties that differ from those individuals that participate in those systems. Another property is that the knowledge possessed by members of the cognitive system is both highly variable and redundant. Individuals working together on a collaborative task are likely to possess different kinds of knowledge and so will engage in interactions that will allow them to pool the various resources to accomplish their tasks. In addition much knowledge is shared by the individuals, which enables them to adopt various communicative practices (e.g. not having to spell out every time they meet someone what they know about a practice, procedure or state of affairs) [96].

A further important property is the distribution of access to information in the cognitive system. Sharing access and knowledge enables the coordination of expectations to emerge which in turn form the basis of coordinated action.

In this context several examples were provided by some researchers such as: Rogers (1992, 1993) *study of engineering practice*, which is concerned with “how networking technology has changed the working practices of an engineering company”, Halverson's (1995) *study of air traffic control*, the study was investigating “how air traffic controllers interact with a radar system when controlling air traffic”, Hutchins (1995) *study of navigation on a ship*, he provided an example about a distributed cognition analysis of a cognitive system in the navigation of a ship. In this study he focuses on the cultural- cognitive processes that take place when steering a ship into harbour. He also describes the detailed co-ordination of representational states across media that take place for the relatively simple, but critical co-ordinating activity of plotting a fix. A final example was provided by Hutchins and Klausen (1996) *study of cognition in the cockpit*, which analysed the interactions of the distribution of cognitive activity between members of a cockpit flight team and the internal/external representational structure. Hutchins (1995) and Perry (2003) have argued that the human mind is not really contained in a single brain and body, but that, in fact, each individual person is best conceived as a pattern of activation across a socio-cultural network, and across a subset of the physical world including e.g. the tools that the body associated with the mind habitually uses [96].

Zhang (1997), attempted to provide a more substantial model for the analysis of distributed problem solving. The model defines external representations as "the knowledge and structure in the environment, as physical symbols, objects or dimensions, and as external rules, constraints, or relations embedded in physical configurations". Furthermore, he argued that the information in external representations can be picked up analysis, and processed by perceptual systems alone. Zhang's (1997) work has provided two key conclusions are that (i) appropriate external representations can reduce the difficulty of a task by supporting recognition-based memory or perceptual judgements rather than recall, and (ii) certain kinds of externalization can trigger inappropriate problem solving strategies or interfaces. This latter finding was further developed in Zhang (1998). In this context, he identified a general class of displays including alphanumeric, graphical, and tabular displays that he called relational information displays (RIDs). RIDs are "display that represents the relations between information dimensions" [109, 103]. Zhang categorized information dimensions into four types (normal, interval, ordinal, and ratio), each with characteristic properties forming a hierarchical structure.

In summary we can say that distributed cognition is a hybrid approach to studying all aspects of cognition, from a cognitive, social and organisational perspective. The most well known level of analysis is to account for complex socially distributed cognitive activities, of which a diversity of technological artefacts and other tools and representations are an indispensable part. Based on the above, we can conclude that some aspects of distributed cognition are part of the approaches that we proposed and that it might be an appropriate theoretical framework for the thesis research. As everyone in a crowd does really do the same thing. For example in case study 1, everyone in the beginning should keep in mind a specific colour and number of dots, and in case study 3, a person must memorise a colour and a symbol or colour and dots throughout their staying in the Haram. All these aspects relate to the theory of distributed cognition (internal, external, and representations). One of our recommendations for future work is more investigation about how to use the theory of distributed cognition and external representation as a framework for the thesis research. The findings described in this thesis will hopefully encourage more research on the usage of distributed cognition concepts in this context and might lead to the deployment of such systems in a practical context.

The next sections will provide more details about navigation and way-finding and will discuss what some applications have done to provide navigation information for pedestrians.

3.2. Pedestrian Navigation System (PNS)

In the last decade way-finding has made a large jump forward and technology has improved many kinds of life activities (e.g. computer software and mobile phones). The rapid development of mobile technology has created new markets for mobile applications and mobile phones have more or less become commonplace. In the mid 90s the development of mobile technology turned from simple mobile phones to more and more powerful devices. Computers became smaller and PDA's (Personal Digital Assistants) started to appear on the market. This triggered new needs in the market and additional new needs were also created. The public have become increasingly more dependent on their mobile devices and researchers have subsequently come up with new ideas to combine the powerful mobile technology with other common activities. Travel and tourism are two important aspects in most people's lives. Recently researchers have worked on issues regarding a possible replacement of traditional tourist guidebooks and paper maps with electronic equivalents. Since the middle of the 1990s several prototypes of context-aware mobile guides have been developed. Not all of the prototypes developed were meant for the tourist market, but they still have relevance when developing this kind of software on portable devices. Some of the focus on mobile guides has naturally been based on the use of electronic maps. The car industry has used electronic maps together with GPS for a number of years already and there is also now a vast quantity of detailed and well-designed maps available online. Much research has been done in the way-finding field and through those systems a lot of techniques have been used. We have categorised them as shown in Figure (3-1). Then we have provided a description of each category.

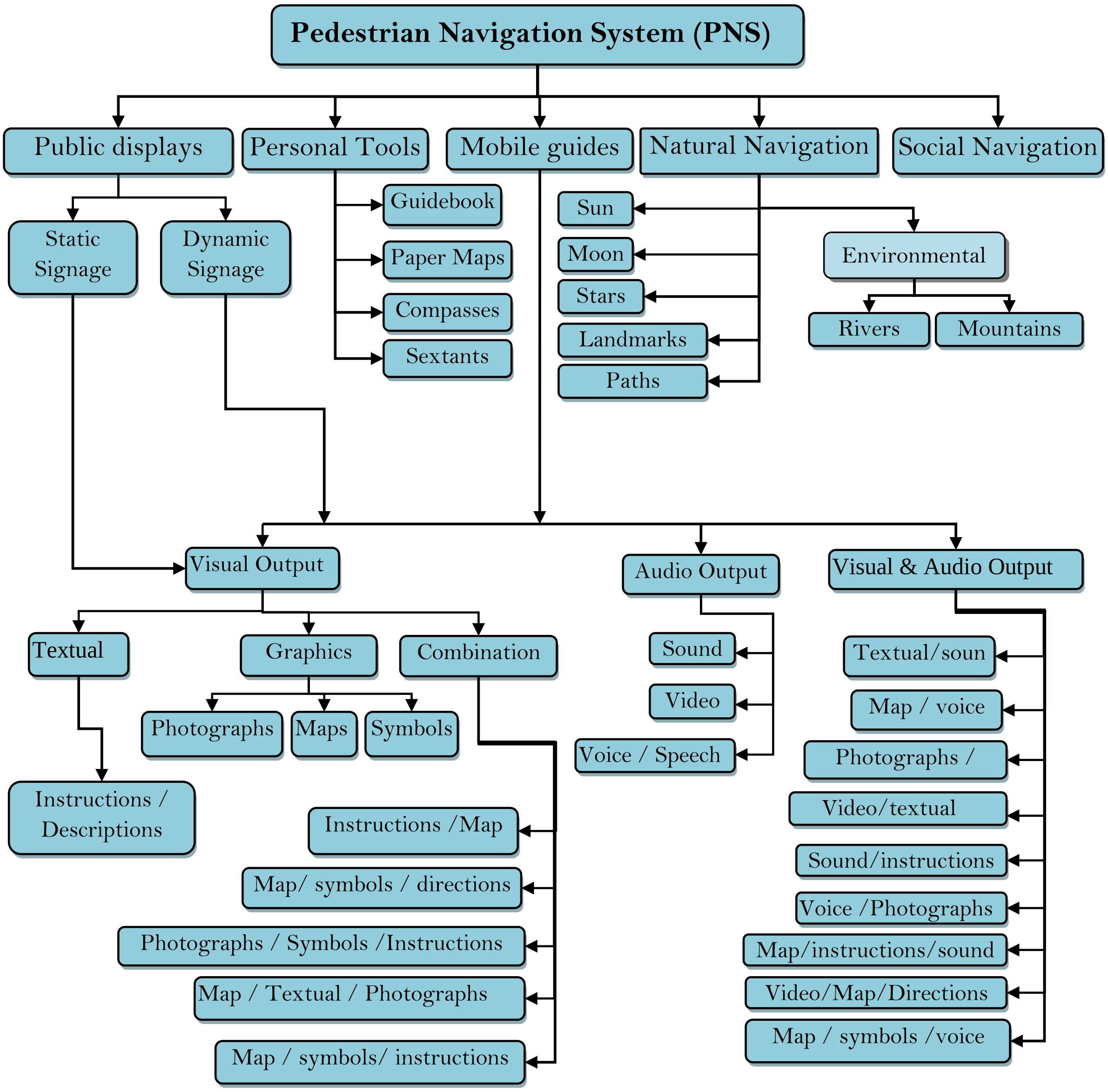

Figure 3-1 Pedestrians Navigation Means

3.2.1. Social Navigation

Social navigation will often be a dynamic, changing, interaction between the users in the space, the items in the space (whether grocery items, books or something else) and the activities in the space [68]. The term "Navigation" immediately conjures into our mind navigation tools: guidebooks, compasses, and images of maps. People use all these tools and others, to get information about their locations and surrounding environment, but are they how we usually find our way? An important question poses itself "How do we usually find our way?" Imagine that you are in huge forest, looking for a way/route to get out, all things around you look the same. A lot of pedestrian routes are available and it is difficult to decide which one is the correct route. One of those routes seems much clearer to you and used more than the others, suggesting that lots of people have used it (walked through it) recently. You may decide it is a better way/route to use than the alternative routes beside it. Or imagine that you are in a library, looking for a book about interface design. A lot of books are available on the shelf with the title you are looking for. Here you are trying to find the best one, but how? One of the books is much more used than the others. This maybe indicates to you that many people have read it so you decide to select it. In both cases, you did not rely on maps or other guides; instead, you used information from other sources to help make your decision. This is a different sort of "finding your way" It is called "social navigation". The concept of social navigation was first introduced by Dourish et al. (1994). They defined social navigation as navigation towards a cluster of people or navigation because other people have looked at something. Social navigation can also work through information traces left by previous users for current users. Just like the well-used route, these traces can show us shortcuts that take us closer to our destinations. With the right kind of software support, we can allow people to leave useful traces with digital information as well [26]. The reader reviews, comments, and message boards popular on websites today can all be used for this purpose.

Actually, social navigation has been identified into two ways: direct social navigation and indirect social navigation. Some people have problems when navigating within information spaces, so it is important to find ways of aiding them. In order to understand social navigation we should have an idea about these two related concepts: information spaces and navigation. Munro et al. (1999) mentioned that an information space is anything that allows information to be stored, received, and possibly transformed. Information space can be physical or virtual; the physical information spaces build up within the world we inhabit. Navigation can be divided into two individual activities: way-finding and exploration. When way-finding, a person has a specific destination they want to go to, and in exploration the navigator simply explores the information space more or less randomly [68]. Way-finding as an activity is composed of four steps which have been defined by Downs et al. (1973) as: "orienting oneself in the environment, choosing the correct route, monitoring the route, and recognising that the destination has been reached". For example, when a person goes to work they are navigating, but after a while they understand the route without thinking and can easily transport themselves to work. Navigation can be said to be a cognitively demanding activity. Being lost and exploring a space are two different things. When a person is lost he has no ability to see a given route, and no sense of location, so by introducing social navigation we try to overcome the problem of being lost in unfamiliar space [40].

Based on the previous discussion on navigation, the only thing that separates navigation and social navigation are the tools. Basically, if we want to have knowledge of social navigation we need to expand our navigational tools to combine social fundamentals. Therefore when we navigate using social navigation there is one more tool available to use, it is namely an agent or a group of agents and this tool can assist us in navigating through an information space. Moreover, a user can use other non-social tools where they are still available, e.g. a user can ask other people about their destination if they are lost in a city (this is a social tool). Then they can use the map to find their target (this is a non-social tool). It might be the same situation in a virtual information space when a user can ask an agent for a specific destination and then use landmarks to navigate to it. Maybe it is more proper to think of social navigation as socially improved navigation [68].

Dieberger et al. (2000) illustrate that the key to social navigation properties is taking advantage of information that has been created by other people and this can happen in many ways [25]. Svensson et al. (2000) describe the important aspects of social navigation, they provide some examples which mention that, for instance, talking to a person at an airport helpdesk who explains how to find the baggage claim is social navigation, but reading a sign with more or less the same message is not. A further example is; walking down a well-trodden path in a forest is social navigation, but walking down a road in a city is not. Both examples seem to involve the same navigational advice; the difference lies in how advice is accessed by the navigator [82].

Harrison et al. (1996) argued that the significant distinction between social navigation and general navigation is how the navigational advice is mediated. Social navigation has a strong temporal and dynamic aspect. A person elects to follow a particular route in the forest because he makes the assumption that people have walked it earlier. Forest routes are transient features in the environment; if they are not used they disappear. Their state (how well worn they are) can indicate how regularly or recently they have been used, which is typically not possible with a road. We see therefore that social navigation relies on the way that people occupy and transform spaces, leaving their marks upon them [36].

3.2.2. Natural Navigation

Natural navigation is the art of finding your way by using nature. It consists mainly of the skills of being able to determine direction without the aid of tools or instruments and only by reference to natural clues including the sun, the moon, the stars, the land, the sea, the plants and other natural things. It is about observation and deduction. It is the potential to navigate naturally on land, sea or even in the air (Tristan Gooley, 2010). There are a lot of methods that people follow to determine their location and reach their destination while using natural things in their navigation. For example, the moon has many features at different times and dates. At the beginning of the month the moon appears to be very small, after seven days it seems to be a half moon, then in the middle of the month the full moon appears. Afterwards it starts shrinking until at the end of month it will appear as very small again. So each shape and position of the moon during the whole month has a particular meaning and people who have experience of natural navigation can understand how to determine their location and navigate from one location to another based on their current position and the shape of the moon.

The sun could be also used to navigate around the desert, so the movement of the sun helps people to know where they are in an unfamiliar environment. For example, in the past Muslim people have used the sun's position to know prayer times and they can also determine the Ka'bah direction by the sun's location. Based on that, it was easy to know the four main directions to travel. However, this facility is available only through the day. At night they used other things such as the moon or stars. People use these natural things by following some natural rules. This is ideal for those who enjoy the outdoors including: walkers, sailors, explorers, travellers, and those who are curious about the world around us. To be able to orient on land, sea, or in the air by day and night, they should understand the principles behind natural navigation [86]. In the past, people have learned natural navigation principles from their families. Nowadays, there are many places are available to teach people this kind of the navigation and provide beginner and advanced courses in this field. The North Star is a prominent star in the night sky which sits very close to the north celestial pole and is known as Polaris or the North Star. It is a highly visible star, but not the brightest, which is a very common misconception. Polaris features so vividly in our cultural history of the night sky that this is often mistaken for true brightness. On a clear night in the northern hemisphere there is a simple method for finding the North Star, using a group of seven stars called the Plough method, Tristan (2010), described the method of how to find the Plough. This large group that consist of seven stars is very easy to recognise in the northern half of the sky, both from its distinctive shape and because each of its stars are bright. Its shape never changes (this is an advantage in helping to recognise it), although it can appear on its side or even upside down. Then the two 'pointer stars' can be identified. These are the stars that a liquid would run off it you tipped up the 'saucepan'. Following the direction of the pointer stars to find a point in the sky five times that distance beyond them. The star on its own in that part of the sky is the North Star. The point on the horizon directly below that star is due north [86]. Polaris is known to almost all northern hemisphere cultures. For example, it was *Grahadhara* in Northern India and *Yilduz* in Turkey. Moreover, it has been known as *al-Qiblah* to Arabs, in testament to its aid in finding the direction of Mecca, as Arab people use it to know which direction Mecca is, to perform prayers or when they are travelling to Mecca to do Hajj. The Chinese had at least four names for it, over the course of hundreds of years. Tristan argued that it is "only the fortyeighth brightest star in the sky”. He also mentioned how to identify the North Star; if you see two stars of similar brightness close to each other you cannot be looking at the North Star, which always appears to be the only star of comparable brightness in its immediate surrounding area. One can say, consequently, that the Plough can be used to find Polaris because it helps organise the sky around a familiar shape.

3.2.3. Personal Tools

Personal tools (e.g. Maps, guidebooks, etc.) have been used to provide personalised navigation information to city visitors. When most people visit an unfamiliar environment they normally use tools which provide them with information about that area. These tools, which they carry, could be a guidebook, a paper map, a list of instructions, a compass, or photographs. These tools are useful in this situation, as pedestrians might be able to reach their destinations successfully via these tools. However, sometimes this may not be true because many issues face pedestrians when they attempt to use carried tools: they might not be clear enough or they may be difficult to follow. Also, some way-finders may have to complete other tasks or may not have time to use the tools. This can happen, for example, when people are carrying luggage and consequently their hands are full. However those tools are still used and many people find them beneficial in several settings, (e.g. tourism). Even though the technology has become available for people to use online maps instead of traditional paper maps, people still use them. Several disadvantages of traditional paper maps are stated when compared with online maps. The advantages of online maps could be concluded in the following: online map navigation can be updated easily, while traditional paper maps go out of date and will take time to be replaced by new ones, (Through that time people could become confused by the information shown on them). Online maps also could be supported by local features that help travellers, details about various hotels, restaurants, and special events in specific neighbourhoods are listed.

In the case of driving, online maps can provide directions and some of these maps provide features which could list which streets you should take (such as the shortest way to your destination) and which roads need to be avoided. However, these facilities are not available on traditional paper maps; all those details are not available on traditional paper maps as well [79]. On the other hand, all those facilities are shown using two options: on the mobile screen or on the PC screen. Regarding the former, the user will find it difficult to recognise and display the personalised information navigation due to the small size of a mobile screen. The latter option, using a PC or laptop screen, enables full information in high resolution to be shown but it is somewhat difficult for a person to take the pc or laptop with them to use on their trip. It could be suitable if this information is shown on a dynamic display (if several dynamic displays are distributed in such an area to show maps that include all the information about that area (e.g. current location of a person and points of interest in that area). However, dynamic displays still have limited use. Guidebooks are also one of the personal navigation tools which a lot of people use to identify their personalised information about the area they are travelling to. A guidebook is a book for tourists or travellers, which provide details about a location, tourist destination, or routes. It is the written equivalent of a tour guide. It will usually include details such as phone numbers, addresses, prices and reviews of hotels and restaurants, and activities. People who travel and stay away from home for more than a day need accommodation for sleep, rest, safety, shelter from cold temperatures or rain, storage of luggage and access to common household functions.

Guide books are generally intended to be used in conjunction with actual travel. Many travel guides now take the form of travel websites rather than printed books. As nowadays most of the information about popular environments is available on websites.

Pedestrians often have the choice of using different maps: either using their own maps (e.g. in city guides), or using maps which are placed in famous area locations. The advantage of using a regular paper map, instead of a billboard map, is that it can be carried around, and thus is available everywhere. Paper maps however, do not have the same possibilities with respect to the use of local information as information board maps [89].

The function provided by an information board map is usually better: frequently, a big red dot indicates the position of the user on the map. On a traditional paper map, the pedestrian has to find his own position by looking at street names. On a traditional paper map, the proximity task depends on the type of map used. If the map is designed specifically for a particular area, the chance that landmarks or interesting locations are emphasised on the map is big. If this is the case, the pedestrian will find the nearby locations without any problems. The advantage of a digital map over a traditional paper map is that it can be generated and updated dynamically. Reichenbacher (2001) argued that a dynamic map can be generated and easily updated. When a person starts his or her route, the map can give an overview of the path to follow, and afterwards, it can always show only the relevant part of the map. A paper map can show the whole map only, and zooming in on one area of interest is not possible. A further advantage of a dynamic map is that it is possible to adapt it for the current needs of certain area: the dynamic map may show only the restaurants. Here as well, the paper map will always show everything [77].

The next sections will introduce some applications which are concerned with to how replace traditional navigation means such paper maps and static signs by using navigation technology such as mobile guides and augmented displays, and develop the compass with other means (e.g. mobile phones, public display,) for the provision of navigation information to pedestrians [21, 44,69,75].

3.2.4. Static signs

Static signage [9] is probably the most common means by which people navigate in unfamiliar areas. When designed and placed properly [95], they can provide large numbers of pedestrians with situated way-finding information in a reliable and accessible way without requiring any specialised infrastructure or devices. The actual content of signage which is designed to help people find their way can vary greatly; unlike road signs, there is no international standard signage for pedestrians. Often, such signs are only consistent within a particular area (e.g. a university campus) but many make use of textual labels, icons or symbols (e.g. for restrooms or information desks) and arrows.

However, signs that are not so well designed or placed in less optimal locations can cause confusion due to issues such as illegibility, ambiguity, inaccuracy, and unreliability. As we mentioned above, static signs are one of the important pieces of equipment for way-finding even nowadays. They can provide considerable assistance to pedestrians to find their locations and directions. However, issues relevant to static signs can be categorised and described as the following [9]:

Illegibility: A pedestrian finds some difficulty in interacting with stationary signs for example, he finds the sign but it is hard to read. (the lettering is too small or the contrast with the background makes it difficult to see) Although a message might be quite clear to a person who originally put the sign up, it may be wholly unclear to the observer. If someone has vision problems (e.g. short / long sighted) or is elderly, some stationary signs may not be suitable.

Ambiguity: Messages that are illegible are those that are too small to be seen (or recognised) from the reading distance of the sign, even though there may be nothing wrong with the actual message. Readability and legibility are not the same. Perhaps, the sign was big enough for its message to be seen, but it made no sense; if people could see it, but not read or understand it, they may ignore it, preferring to ask questions instead.

Conflict: Bits of conflicting information in a sign (or in two signs close together) create difficulties. This happens particularly when new signs are installed and the old ones are not removed. Or it may be the result of two signs that complemented each other at one time, but that conflict in new circumstances.

Deficiency: Too little information is just as bad as too much. A sign must contain all the information that a person needs at that particular place.

Excess: Confusion generally results when more data than a person needs is provided at a given decision point.

Glare: Signs are much more efficient when they are well illuminated. Sometimes a sign can be well illuminated from some standpoints but obscured by reflected light from others. Signs placed opposite windows, for instance, can end up reflecting the outside, cars moving on the street, passers-by, and so on.

Inaccuracy: It is essential to provide all the information that people need, when they need it. But it must be the right information, up-to-date, and accurate.

Unreliability: Most people are prepared to depend on signs in an unfamiliar setting, but only for as long as they are dependable and do not, for any apparent reason, suddenly let them down.

Consequently some people ignore them and prefer to ask questions instead. This is not always true because some pedestrians benefit from static signage such as maps, street numbers, roads signs, and so on. Sets of static signs may contain information such as arrows, text, or maps, these signs are used both indoors and outdoors. Indoors these signs might be mounted on the walls inside buildings or corridors to guide people who are looking for a certain destination, they can follow the information written or drawn on a sign to reach their destinations. Outdoors, the static signs could use the same pattern, and a user can benefit from them for instance, by recognising street names, building numbers, and as means to identify highway directions. As a result, it can be said that static signs are very important and might provide considerable benefits for people to find their ways in unfamiliar environments. Basically, we can categorise the static signs applications into several types as shown in Figure 3-1. Moreover, static maps are very important when the majority of people are using them to find information about paths, routes, and building numbers in an unknown area. In addition, they could be used inside buildings to lead people to reach their target destination.

In the context of the language of wayfinding design, Craig Berger (2005) identified that there are two basic ways to communicate the objects, actions, and feelings in our lives: sounds (words) and images (symbols). Words are an effective way of communicating complicated, interrelated ideas where symbols fail. It is symbols, however, that communicate across the barriers created by different word languages. As obvious as that might sound, designers too often overlook symbols when planning and designing a wayfinding system. Symbols are actually the essential shorthand behind any environmental graphic design project. Arrows are symbols that have gained the status of a universally understood wayfinding vocabulary. Letters and numbers are also symbols that can be used to present places and spaces as images that range from literal photographs to completely abstracted images [104].

Barker, P., et al (2000), argued that one of important things to understand before designing or utilising symbols is the terminology involved in symbol design. Symbols have specific meaning, and are conveyed specially. Every visual message of a wayfinding system has to communicate on its own, without the luxury of being explained by the planner or designer. Sometimes, however, symbol systems can fail to make a wayfinding system work effectively [100]. In this context, several questions have been asked, for instance, 'are there too many symbols?' One of the most common mistakes designers make is to use many symbols. For colour coding, the rule of thumb is to use no more than six colours (e.g. red, blue, yellow, green, and purple); any more causes confusion. If is harder to recommended a maximum number of symbols, even one symbol is too many if it does not communicate well. On the other hand, hundreds of symbols can work effectively if they are well design and used properly. For example, on road signs, the driver must read while in motion, and without slowing down. Here, the use of symbols should be limited to as few as possible; no more than three or four per sign. Sometimes road signs use words in combination with symbols, but symbols usually have a better chance of communicating to the larger audience __ if everyone understands the meaning of the symbols [104].

Regarding the ease of use of the symbols, a question might be posed 'are the symbols easy to remember?' Whether incorporating many symbols or just a few, use familiar images: they are easier to understand and to remember. Use symbols from an established system when possible; for example, symbols signs can be used to present generic service, activities, and regulations. When navigating the urban environment, we often use architectural structures as landmarks. Thus, symbols that use architectural images can be used to effectively identify geographical distances or specific locations. Landscape elements, such as fountains, gardens, bridges, or monuments, also make good symbols image, as do symbols that represent functions, history, and culture. It is a good rule of thumb to use no more than one similar type of symbol image in a given wayfinding system. If it is necessary to use more than on architectural image, for example, make sure that you emphasize the differences between the building types or add details to make the symbols readily identifiable and easily to distinguish [102].

With regard to readability of symbols, i.e. 'can the user read the symbols?' When evaluating the legibility of a symbol, consider both how familiar the symbol is and how well it can be seen. Symbols tend to be highly familiar when they are commonly recognisable generic images, but there are may be a learning curve in connecting the images with the intended message. Consider all possible inferences when select a symbol to avoid confusion between the image and its interned meaning. The visibility of legibility of a symbol depends on a number of factors including form, size, viewing, distance, lighting, colour, and contrast. Craig Berger (2005) has identified that the criteria used in evaluating a symbol's visibility are very similar to those for evaluating the legibility of typography, but we have to keep in mind that symbols are generally more complicated than simple letterforms, which are immediately recognisable and communicate their meaning without needing to be translated. When a symbol is reduced it can lose its clarity; details become ambiguous. Unless the shape is clearly distinguishable, one symbol can be confused with another. Highly legible symbols are simple and direct. Symbols that are too complicated to be recognisable or too simple to have meaning become decoration rather than communication [104]. Symbols can express message with many levels of meaning. They can identify, direct, and inform with clarity. As with names and written messages, it is important to craft symbol messages to get maximum value and effectiveness. Symbols offer designers an opportunity to plan and implement a wayfinding system that visually expresses and supports its unique location, history, and culture. Planners can design or select symbols that make the wayfinding system more consistent, more closely related to its environment, and unique. But we should say that the symbol must work easily for the user. A perfect design is not perfect if it does not communicate to the user. A common design approach in urban wayfinding systems is the use of multi-colour to differentiate urban districts or types of destinations. For example, on hospital signs the emergency room is often represented by a red colour band on a sign separate from the hospital identification. It is important to realise that colour is another sign element, equivalent to an arrow, message, or logo. This means that the same rules regarding efficiency in the number affects legibility is the hierarchy of arrows. A consistent rhythm of arrows is just as important for legibility as arrow placement [102]. All considerations and rules which are mentioned in this literature were applied when we designed our case studies. For instance, we took into account types of colour used, the same is true when creating the symbols we tried to use famous and limited images. Generally, we can say that the rules and conditions of the signage systems design that were illustrated in the above literature was helpful to us when designing all our case studies.

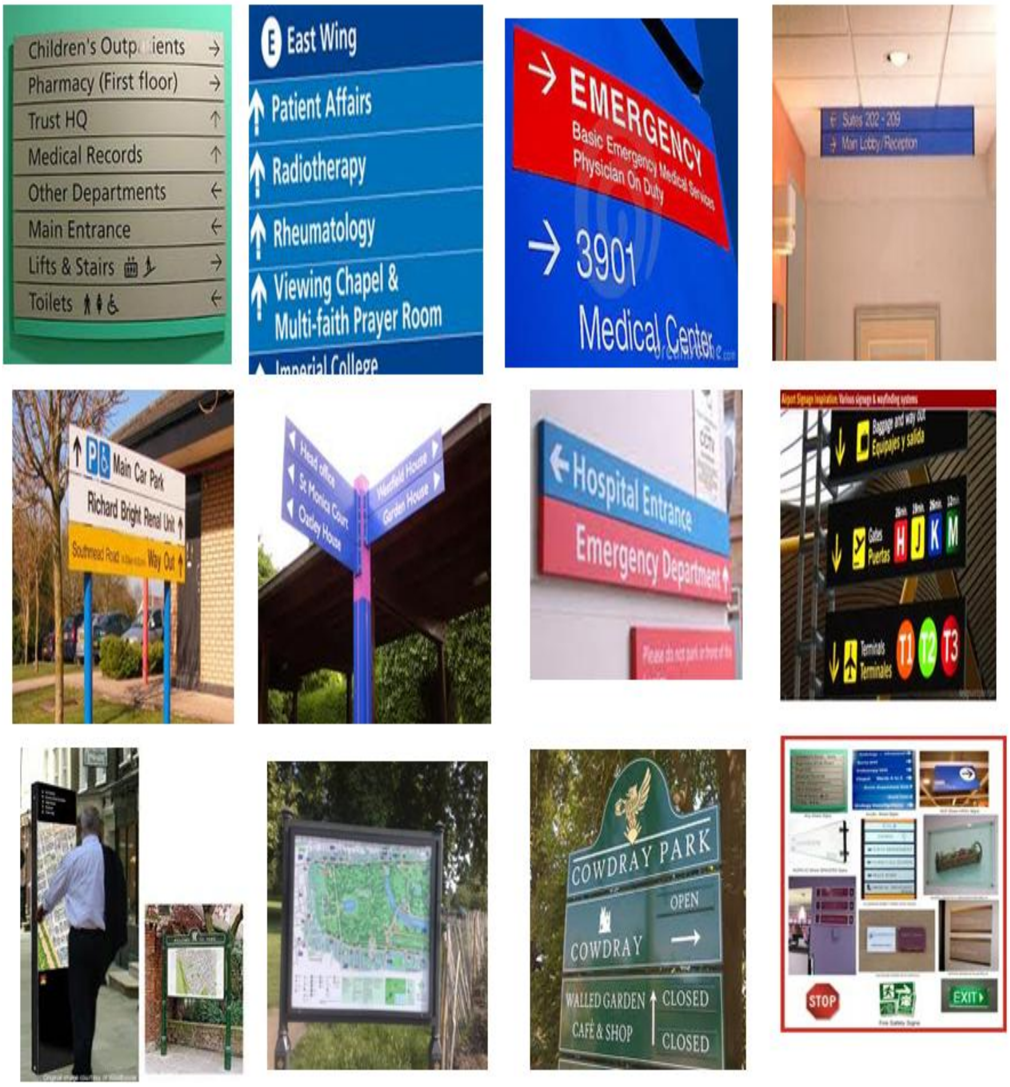

Figure 3-2 several kinds of static signs applications (Maps, directional arrows, and textual information)

Information board: also one of the applications of the static signs, is upright 'monoliths' which list key destinations with associated arrows showing the way to walk.

A larger physical area allows for more destinations and the use of symbols. Information can be displayed at head height, in the 'natural' line of vision. Being outside they are also more vandal resistant and can incorporate 'real time' information.

Great benefits can be provided by board information, especially inside administrative buildings. Usually these boards are located on walls of buildings or corridors to show information relevant to employees, e.g. declarations, timetables, and may include directional arrows to indicate people to particular offices.

In general, one common property of static signs is their lack of personalisation: due to the fixed content, people have to extract the relevant information themselves. For example, if their final destination is not shown on the sign, they need to identify an intermediate target amongst those listed on the sign. This limits the use of static signs for some sites in Mecca (e.g. the Tawaf rite), as people require *individually personalised* information that cannot be easily extracted from static signs.

Regarding the colour blind: Dr. Jeff Rabin (2001) argued that 5% to 8% (depending on the study) of the men and 0.5% of the women of the world are born colour blind. That is as high as one out of twelve men and one out of two hundred women. He limits this discussion to protons (red weak) and deutans (green weak) because they make up 99% of this group.

Hereditary Colour Deficiency: The visible spectrum includes 300 wavelengths (400-700 nm), and in some portions we can discern colour differences of 1 wavelength. The ability to see so many colors depends on the following aspects: A separate cone for each wavelength, colour optic nerve fibers for each colour, visual cortex neurons sensitive to each colour, and difference in stimulation of red, green and blue sensitive cones. Jeff Rabin (2001) concluded that "8 to 10% of males and 1/200 females (0.5%) are born with red or green color deficiency", " sex-linked recessive condition (X chromosome)", "Protanomaly—red cone peak shifted toward green (1%)", "Protan

Dichromate—red cones absent (1%)", "Deuteranomaly—green cone peak shifted toward red (5%)", " Deutan Dichromate—green cones absent (1%)", "Hereditary tritan defects are rare (0.008%)". In our case studies we asked the participants questions about their vision such as *how would you describe your eyesight? (If you are wearing glasses or contact lenses, please describe your vision when wearing glasses or contact lenses.) [Please tick only one] short-sighted, farsighted, and neither short-sighted nor farsighted* [99]. The results obtained showed that all participants in all three case studies have done all tasks successfully. We did not address the potential problems of using colour-based symbology (accessibility and especially colour-blind users), but these could be an essential part of our future work, and we would address them in the context of the importance of achieving a language-independent and culture-free solution.

3.2.5. Mobile guides

Mobile guides support individual users by providing navigation support through their mobile device, e.g. their mobile phone. While originally specialised hardware was needed to sense the location of users and to give directions [56, 21, 14] many mobile phones today include a variety of sensors/actuators, high-resolution displays and powerful processors. These devices are well suited to provide personalised directions to pedestrians, and navigation support services have been successfully commercialised, e.g. Navitime [8]. Moreover, personal navigation device solutions such as mobile phones, PDAs, GPS, and mapping software are easier to update. In addition, the users receive directional information from a web server or central service via their personal device. This information could be visual, such as a map, textual (a set of instructions), photographs, or a mixture of auditory and visual information, for instance, sound / voice, video, music, or hybrid [16]. Another possibility would be to store the necessary data on the mobile devices, but two disadvantages are connected to this solution. On the one hand, there is the limited memory capacity of mobile devices and on the other hand the fact that the stored data may be less up-to-date. Hybrid approaches are also a good possibility; some data are stored on a server and some on the mobile. However, all this information is shown on the personal device's screen. As a result, the user sometimes cannot read or recognise it, because the PDA screen size is small. Also, at times there is no accuracy guidance (i.e. the user must stay seated or stand in the right direction when receiving the information otherwise the guidance will be unsuccessful). In contrast, we cannot always expect that users in complex environments (e.g. railway stations, airports, hospitals) will be able to use a mobile phone or PDA. They might be carrying luggage, which would prevent them from using a mobile phone without a hands-free set; they might not want to attract the attention of other people; or they might need their hands to use a personal aid such as crutches or a walking stick. That means in certain application areas, the user group will be restricted to persons owning a hands-free set or comparable product and to those who are willing to use it in a certain environment.

Abowd et al. (1997) developed one of the first mobile guides “Cyber-guide system”. The system provides maps and information services on particular indoor and outdoor settings [1]. Maps and information have been stored on mobile devices. An infrared beacon was used in indoor places, and outdoor positioning relied on GPS. In addition, the usage of mobile devices for location services such as navigation applications has been the focus of many research applications [15, 16]. These applications typically show a map to the user and present the current location of the user on the map. Including visualisation of nearby points of interest and showing extra information such as route instructions [41, 61].

Five different approaches for presenting route instructions on mobile devices have been discussed by Kray et al. (2003). These techniques: textual spoken instructions (e.g. “Turn left at the next crossing”), 2D routes sketches (e.g. arrows that refer in the right direction, as used in car navigation systems, with no map displayed), 2D maps (e.g. presenting a map with a visualisation of the route and the current location of the user), 3D route maps showing a 3D representation of the environment, and the combinations of those techniques (e.g. a 2D maps, and spoken instructions).

The 2D maps option was more accepted by people, due to the possibility of the maps and users’ familiarity with 2D. However, the 2D maps approach implies two drawbacks: the user exchange between the environment and the small mobile phone screen, the second problem is that it is difficult to associate the map information with the surrounding environment. This second problem was solved by creating a 3D maps technique [45].

The advantage of using spoken instructions is that a user does not need to think about the relationship between the map and the environment while using 2D route sketches. Nevertheless, the user must be actively attentive to the system at all times since the system defines when the information is transmitted to the user.

May et al. (2003), describe the quality of information that pedestrians need while navigating from one place to another. It is necessary to understand the information requirements of pedestrians when navigating, and in particular, what information they need and how it is used. In addition, they argue that there are several important questions which should be taken into account. For instance, what information do pedestrians need when they navigate in an unfamiliar environment? What terminology is used to describe this information? How is information used, at and between, key navigation decision points? How important is particular information in enabling key navigation objectives? To what extent is information redundancy employed in navigation instructions? [62]

Beeharee et al. (2006), discuss how pedestrians can reach certain places (such as buildings and parks) by using photographs already stored in a handheld device. They undertook an initial study of a guiding system that utilises photographs. The photographs are not directly used as the main source for giving route orientation, but provide additional visual cues. A user of this system sees a route description as text and a map that referred to a series of photographs. An experiment has been done to test the system concept. Results of the study suggested that proper photographs definitely help with particular types of routing instructions for users who are not familiar with an area. A further contribution of this system is based on the facility of mobile devices that have the ability to take and store photographs, this facility has been utilised for guiding and routing services [16] To solve the issue of mainly depending on giving instructions while using maps and text, they suggested a series of references to photographs to use for explaining routes, where destination directions or turning instructions can be given with reference to photographs. As a result, the photographs are very important as support references for pedestrian navigation, not as the main reference.

Based on the approaches which are mentioned in this context we can conclude that compared to static signage, mobile guides can provide directions to a user in different ways including, for example, textual or spoken instructions, 2D maps, 3D route maps and fly-thrus [13, 33], photographs of landmarks or route sections [13] and directional audio [15]. There has also been research on minimising the interaction and distraction caused by using a mobile device [71]. A key advantage of mobile guides over static signage is therefore their capability to tailor directions to the needs and location of an individual user.

Considering the use of mobile guides in the context of the Hajj at Mecca, there are some issues that limit their suitability. The garment pilgrims wear has no pockets, which means carrying a mobile device can be cumbersome and might interfere with the religious experience (not to mention the danger of losing the phone or having it stolen). More importantly though, the dense crowd makes using a mobile device difficult and potentially dangerous as people have to pay close attention to their surroundings in order to not bump into other pilgrims. One key aspect at rites such as Tawaf is for people to keep moving at the same pace but users of mobile devices often tend to slow down while interacting with their device, which might disrupt the 'flow' and potentially cause hazardous situations. In addition to these considerations, there are also questions relating to the scalability of the infrastructure in terms of coping with the large crowds usually observed during Hajj. Additionally, the approaches discussed so far were based on mobile devices, but as public displays occur in more and more public spaces, they can also be used to provide personalised navigation information. Moreover, as we mentioned previously, mobile navigation applications have some disadvantages (e.g. the small screen). This leads us to say that in many settings the use of mobile guides is (infeasible). The next section describes how public displays could provide personalised navigation information.

3.2.6. Dynamic signage

Public dynamic displays are increasingly being used to provide information to users, to entertain (e.g. showing news announcements), or to advertise products within public environments such as airports, city centres, and retail stores. Within these displays, advertisers typically utilise a variety of delivery methods to maximise the number of different adverts displayed, and thus increase their overall exposure to target audiences. In addition, there have been several publications investigating the combination of mobile devices and public display. For example a number of interactive public displays have been proposed that support a connection with a user via their personal devices, such as mobile phones or PDAs [47, 43].

In recent years, technological advances in computer software and audio visual hardware have brought this concept to the high street, corporations, and public bodies and into industry replacing traditional methods of providing information. The advantages of dynamic displays are that they are up to date and they have ability to deliver the right message to the right people at the right time.

In recent times researchers have worked on the issue regarding a possible replacement of the traditional static signs with dynamic signage, especially in the context of the pedestrian navigation system. As public displays become more widespread, this leads us to say that they can be also be used for provision of personalised navigation information to a user. It could improve the pedestrian navigation situation and overcome current drawbacks which face pedestrians who use previous systems such as static signs and personal devices. The approaches that are discussed above were based on the usage of mobile guides and some disadvantages with mobile applications (e.g. the small screen), which leads to the fact that users may not be presented with all the information that they need, such as maps.

Dynamic signage can perform several services or have more advantages than static sign guides and mobile devices; they may have bigger screen sizes to present maps or other information or more up-to–date information. For instance, in airports, travellers are able to find information about their trip; in hospitals: people can deal with them to obtain personalised information such as appointments, etc. This might be available via dynamic touch screens. A good example which illustrates the importance of the usage of public displays for the provision of location information is the GAUDI system [44]. The advantages of this system are that the user does not have to understand a map, the navigation information is personalised, and also the user does not need be familiar with the indoor localisation system.

This system demands knowledge of the user's location. Therefore, a beacon is worn by the user and sensed by the displays, which in turn, provides information on the location of the user. However, as the system is designed to present navigation information to only single users on one display, consequently, this system is not particularly scalable.

Currently several systems that use public displays has been investigated, however, they each look at the study from different perspectives and attempt to utilise these displays to serve different purposes. Some of these approaches will be presented in the next sections to illustrate how utilising these displays could help people in different situations. For example, pedestrians are navigating in a public space or people doing activities in crowded places.

Kray et al. (2005) describe a public navigation system, which uses adaptive displays as directional signs. They identify a novel approach called a GAUDI System. The system consists of two main components: a navigation server and an arbitrary number of independent display clients. The navigation server supports those administrative operations that apply to all display clients, such as the definition of the global route network, calculation of the routes, and the description and generation of the display interfaces. The display clients consist of autonomous wireless computers running the GAUDI software. The clients determine their positions or allow the administrator to set them through a GUI. They adapt their presentations according to the interface descriptions they have received by the server. A user can interact with displays in several ways, such as manual procedures via an administrator, by sensors, or by touch screen. In addition, he/she can obtain full information about the paths in that building, as information arrows can appear on the display with a brief description, or on a photograph shown on a large screen. The user can touch a photograph of the person they want to see, and then all the situated displays in the building will display arrows. These arrows all point towards the target office [44]. In addition, information points are distributed in certain areas to provide people with information about locations; these can show maps, texts or photographs to illustrate to the user's directions and destination. However, this system interacts with a single user, and the authors have argued that in the future they will complete this prototype to be able to provide navigation information to multiple users and allow them to interact with it simultaneously.

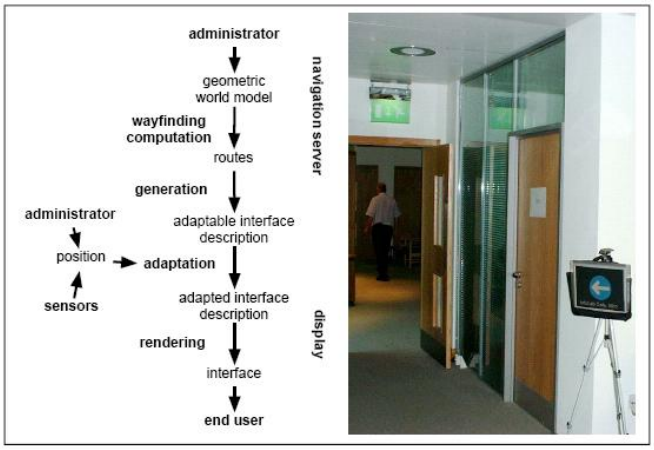

Figure 3-3 Adaptation process and a GAUDI unit [44]

As mentioned above, mobile devices have been improved to include advanced technology such as GPS and sensors. As a result, researchers have benefitted from these technologies which are available on public displays and mobile phones and they attempt to improve pedestrian navigation systems via combining public display-dynamic signage and mobile devices to produce a novel system which might provide navigation information for pedestrians in different settings.

We have previously mentioned that static signs are very important in the pedestrian navigation field even today. They could include important properties in their guidance which might demonstrate on stationary signs that landmarks are considered, e.g. "turn left after blue sign", "go straight until you find a large directional sign" [16]. Some previous systems have used static signs as input data for mobile devices to produce important information which could help a user to get personalised information about their locations and points around. Eissele et al. (2007), for example, focused on indoor navigation environments. Their system was concerned with providing assistance to users looking to find their location and destination within an indoor context. Users could utilise their mobile devices to capture some visible locations such as: text phrases of door plates, posters, or labelled installations which are then used to indirectly identify the user's current location. A database of mappings for text paragraphs to additional Meta data, and most importantly the location inside the building, is used in combination with a server system. This service is used by the developed client software running on a PDA and allows users to capture images of text inside the building to access additional information. Actually, the system consists of two main components: A server connected to a database to perform optical character recognition and text matching and a hardware specific client application to perform navigation tasks and access additional information to real world texts. In order to be able to deploy the proposed system in an environment, unique text phrases have to be identified. Good examples for such text strings inside buildings are: door plates or room numbers, unique placards or posters, labelled access ports or switches, etc. The server calculates the position of the camera relative to the text entity during the perspective correction of a received image. The users should take into account that the system implementation does not perform a perspective correction and therefore assume that the camera is facing the text orthogonally, at a distance of about 30cm, then all this information will be sent to the server. The server combines both pieces of information and transmits the global position and orientation to the client (see Figure 3-6). The user's current view direction can be shown in map drawings, to help them finding their orientation relative to the map. It could be said that this system has two advantages; no further installations in buildings are required in order to use the system, and, authors have utilised static signs and used them as input for their system to gather navigation information about particular area inside building [27]. Figure 3-5 shows how the system is structured.

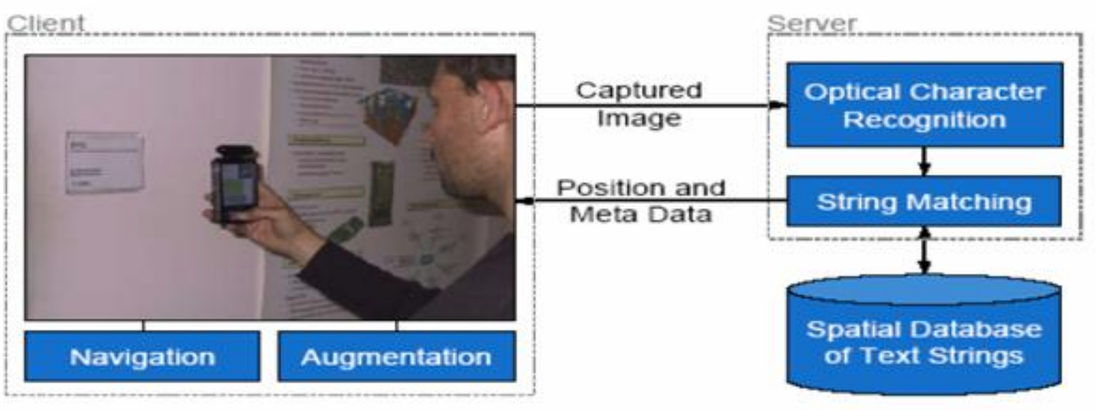

Figure 3-4 Location system overview and the system structure [27]

Other approaches have been developed to provide personalised navigation information by combining personal devices and public displays, for example, REAL system. It was one of the first approaches that were used to provide assistance in pedestrian navigation situations [14]. However, in this system, the same information was shown on both displays (mobile phones and public display) and consequently this is not useful in a multi-user situation.

Rotating Compass [74,75] and CrossFlow [69] systems have addressed this issue and resolved it. Here, a combination of public display and mobile phones is used: the public display (a floor projected abstract moving pattern) and a synchronised mobile phone with a strategic actuator to help multiple users to more easily extract the information that is relevant to them. The phone of users would vibrate whenever the public display was showing a flow pattern in the direction where a person had to walk.

In this system all users have handheld devices, and the displays show four directional arrows. There is also synchronisation between the display and the user's PDA; the distance between the users and the display should be appropriate to allow users to recognise and understand the information which appears on the display, a user should also be in a relatively clear space, otherwise the information will be unclear and noisy. When the public display highlights the direction that a person needs to go, the personal device of this person will vibrate. The display highlights the directions independent of the people around. Figure 3-6 shows how users interact with the system by utilising their mobile phones.

In addition, they described that there are drawbacks of using a map-based navigation application for mobile phones such as the small screen size and that users have to associate the information provided by the mobile phone with real world. Then, they compare four techniques to explore the effectiveness of the system. Where the goal of the experiment is to compare between four different techniques, these techniques are: using a paper map (traditional map), using a map shown on a mobile phone (which means only the user can access the mobile phone), a rotating compass synchronised with the display, and navigation information via public display. The results that were obtained from this study pointed out that the public display provides individual information to each user. According to the study results were reached, such as: Rotating compass performance was better than the map-based techniques (multi-user), Rotating compass performance was equivalent when compared with a public display, and a paper map was better than the map shown on the mobile phone navigation, as the mobile devices has a limited screen size. So, the significant advantage of this approach is that the public display can be used to deal with a large number of users. A further advantage is that the users do not have to listen to spoken instructions and do not have to view or to interact with a map.

Moreover, it is the first system tested in a real outdoor context compared with previous systems. However, this system uses public display and mobile phone navigation as a combination. Consequently, a user should be carrying their mobile phones in *Synchronisation* with the public display to gather personalised navigation information. This means that the mobile phone is an essential part of this system, so if any damage occurs to a mobile phone or there is an unsuccessful connection, then the system will be meaningless.

Systems such as these [69, 74, 75] mainly depend on the personal devices output (e.g. vibration), and as a result users are required to carry their mobiles to receive this. As we mentioned, there are many issues that might occur while using mobile phones in such a context. (e.g. network connection failure due to networks instability or a temporary overload). These systems are infeasible at Mecca for several main reasons: Firstly, as a lot of people use the mobile networks at the same time this causes a failed connection due to network instability or a temporary overload. The second reason is that pilgrims have no pockets to keep their mobile phones in (restricted by Ihram clothes). The third reason is that pilgrims should pay full attention to their rituals and saying particular sentences while performing them (i.e. any other actions during this time could confuse them, such as using mobile phones). The fourth reason is that the Mecca area is very crowded and many pilgrims are speaking aloud, so these circumstances (too noisy) prevent them from hearing their mobiles' output (e.g. vibration or any other audio).

Figure 3-5 Illustrates how the system working [74]

A key benefit of using such dynamic signage systems in the context of Mecca is that public displays can deal with a large number of users. However, these approaches depend on mobile phones to 'personalise' or 'read' the public display. Even if users do not have to look at the mobile phone screen to use either system, they still have to carry a mobile device, which is not practical during Hajj (as explained above), and which would also exclude a large number of users who do not own a mobile phone. In addition, the dense crowd at Mecca might make it difficult to sense vibrations (or hear audio output), and displaying something on the floor would be infeasible.

3.3 Chapter summary

Through this chapter we have introduced some types of pedestrian navigation systems; much research has been done during the last decade in this context. In the first section we gave some details about social navigation and described some examples which mentioned this kind of navigation. The second section illustrates natural navigation and how people utilise nature to navigate and determine their location and information about their direction. Then we talked about the tools which a person can use in their navigation. These tools (e.g. paper maps, guidebooks) have provided extreme assistance in some settings. Static signs are still important and provide considerable help for pedestrians even nowadays. Moreover, some issues facing pedestrians while using static signs have been mentioned. Then we described how static signs are not feasible for providing help at Mecca, (section 3.2.4.). Then we moved to other kind of guides such as 'mobile guides', we mentioned some examples of mobile guide applications and how mobile devices can be used to help people navigate in different situations. On the other hand, we described the shortcomings of the mobile guides which limit their use in some settings such as the environment at Mecca or other crowded places. All those points have been presented in section 3.2.5. Section 3.2.6 was regarding the public displays (e.g. dynamic signage), as this kind of navigation system provided a good solution for almost all of the previous navigation systems issues. The approaches described so far were based on the usage of a mobile or wearable device, but as public displays occur in more and more in public spaces, they can be also used for the provision of personalised navigation information to the user. Mobile navigation applications also have some disadvantages (e.g. the small screen). So in this section we have presented some approaches of public displays and illustrated how users can benefit from them in different settings. However, these approaches include some disadvantages (e.g. they mainly rely on the mobile phones).

The next chapter pertaining to the Tawaf system includes the whole system details (e.g. design and evaluation). The Tawaf system is proposed to solve one of the pilgrims' issues "Help pilgrims to remember / count Tawaf rounds while walking around the Ka'bah". We will give a full description of the Mecca area and how pilgrims deal with it whilst performing their rituals inside Mecca's Haram around Ka'bah. Then we mention the properties, constraints, and key issues relevant to Mecca city. Afterwards, we give some details about the methods that pilgrims use to overcome the issue of forgetting the number of rounds of Tawaf. We also explain how we collected the data about the situation by interviewing some people who have experienced Hajj. Then we talk in detail about how we designed the initial system and presented it to the focus group to get feedback about it. After this we started to redesign the system based on the focus group feedback. The system was then evaluated through a lab-based user study as it was infeasible to run the system in the actual environment, the reasons for this are mentioned within the chapter. Evaluation and results are presented at the end of the chapter.

Chapter Four

Case study 1: Tawaf system

Supporting Pilgrims in Navigating Densely Crowded Religious Sites

4. Case study 1: Tawaf system

4.1 Introduction

Each year, millions of pilgrims from more than 100 countries [10, 85] converge on Mecca to perform Hajj, one of the five pillars of Islam [35]. The Hajj involves performing a set of rituals over a five-day period. During that time, pilgrims move between different locations in and around Mecca, and in doing so, they depend on human guides, static signage and security personnel for their safety and for finding their way around the city. Despite an ever-improving degree of organisation and planning, pilgrims often face considerable problems. For example, people lose sight of their friends or group, and they have to locate the different sites where particular prayers or rituals are performed. These issues occur in the context of the extreme crowdedness of the city, particularly at relevant religious sites. In some places, the crowd can be so dense that pilgrims are injured, sometimes fatally. Overcoming this problem is not straightforward; details of those issues are mentioned in chapter 3.

Restricting access to Mecca by limiting numbers would prevent some people from performing the pilgrimage that constitutes a cornerstone of their faith. In the past, most means put into place to address this issue focus on optimizing the 'flow rate' of pilgrims at certain hot spots. For example, to prevent accidents during the Jamarat event, a four-tiered bridge has been constructed, which significantly increases the number of pilgrims who can perform this rite at the same time.

In this chapter a particular element of the whole experience is explored in more detail, we investigate whether dynamic signage (public displays) can reduce crowdedness by helping pilgrims negotiate their way during the Tawaf ritual [35], which involves *Circumambulating* the Ka'bah seven times and can take a long time to complete. A multi-tiered building has already been constructed that increases the number of people that can perform this rite simultaneously, yet it is still very crowded at peak times (see Figure 4-1). A key issue facing pilgrims in this context is that they forget how many times they have circled the Ka'bah and then start over, which results in many people remaining at the site for much longer than necessary. So here we attempted to answer some research questions “Does the dynamic signage system support pilgrims in keeping track of the round count and navigating successfully?”, Does the current user interface meet their user needs, can they use it, or are there any issues that need to be addressed?, and Is the idea of installing such systems (augmented displays) at Mecca acceptable and does it improve the pilgrimage situation, e.g. reduce the crowds and help pilgrims to navigate successfully around the Ka’bah? Our hypothesis was that if the system was implemented well the dynamic signage will provided useful support for pilgrims to remember and count the rounds successfully. Our results confirmed this and provided us with good evidence that dynamic signage might work well at Mecca and support people while perform their Tawaf around the Ka’bah.

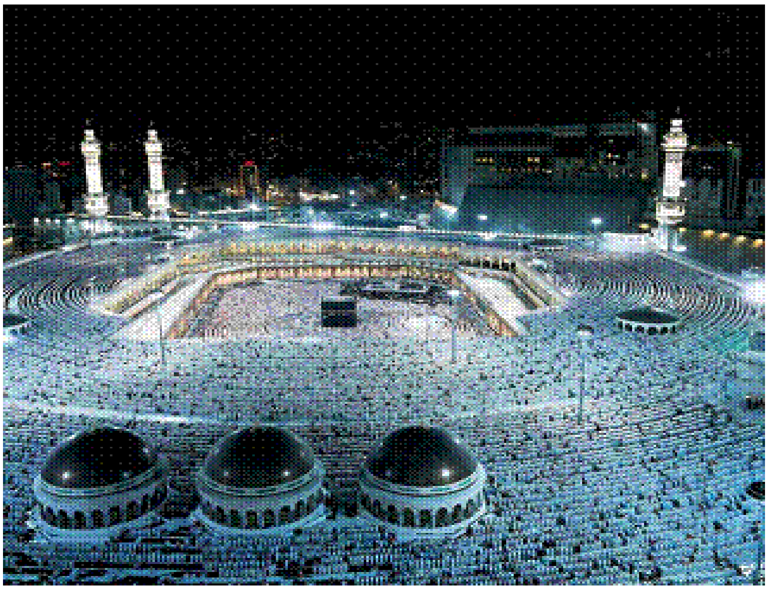

Figure 4-1 around Ka’bah (Tawaf pillar) – (used in compliance with image license)

This chapter presents an analysis of the scenario and identifies key issues and constraints resulting from it. We first review the interview section (4.2) in the context of our scenario. This section also gives full details about the interview aspects, e.g. participants: who, how, where they have participated, and results obtained (comments and suggestions). The design approach section (4.3) describes the stages of design: initial system design (4.3.1) gives the description about how the initial system was designed and why the system was designed this way. The focus group subsection

(4.3.2) gives details about the role of the focus group and how it was organised: who, how, where, and the results gathered. The design of the Tawaf system (4.3.3), in this case we provide full details about the final design of the Tawaf system, how we redesigned it after gathering suggestions, comments, and feedback from the focus group participants. Then we introduce the Evaluation section (4.4), this describes how the system was evaluated and how the user study was organised: participants, stimuli, procedure, and the details of the results. Then we have the discussion and reflection section (4.5), this discusses three aspects: the feasibility of the system, its applicability in other scenarios, and designing interfaces to support navigation for large crowds. The final section is a summary chapter (4.6), this introduces two aspects: a summary of the important results of the case study and gives a brief an introduction to the next chapter.

4.2 Preliminarily Interviews

In order to gain an initial understanding of the situation at Mecca, we attempted to gather full information about this city and pilgrimage event in particular. One of the methods that we used was to contact some of the Islamic research centres which exist in some Islamic countries. Unfortunately, the information that we gathered was not adequate to enable us to understand the whole Mecca environment. Some information that we obtained represented the number of pilgrims who visit Mecca every year, places pilgrims should visit while doing Hajj, and some issues facing pilgrims in Hajj. The second method that we used was to interview people. We conducted informal interviews with 45 people, by organising three sessions, each session included 15 people (male and female, aged 25 to 60), who had previously been to Mecca.

4.2.1 Participants

The three sessions of interviews with these 45 people revealed that they were from different cultures, languages, and nationalities: Africa, Asia, and Europe, they were male and female, aged 25 to 60. All of them had completed hajj before at least once in their lives. They have provided us much information and many ideas regarding the Hajj situation and Mecca environment.

We interviewed them in order to investigate the Hajj situation and issues relevant to this field. A semi-structured method has been used and the method details are mentioned in Chapter 3. Indeed, the majority of people emphasised that navigation during Hajj is terrible, i.e. some pilgrims become confused and lose count during the Tawaf ritual and many lose each other in crowded situations such as Tawaf and Saai.

4.2.2 Results

During these interviews we have collected a huge amount of information from which we concluded that the majority of pilgrims' issues are the following:

i. The majority of people (40 out of 45 (89%)) agreed that no technology navigation is used to help people to navigate from place to another. Also, there are no any particular systems in place to guide people and let them know about the pillars of Hajj.

ii. People use static signs and human guides to move from one place to another. Those interviewed stated that the information shown on the static signs is not adequate and as a result pilgrims find difficulty in reaching their destinations. In addition, some pilgrims ask local people or people who have experience to assist them to reach their target destination. However, other pilgrims are often focused on themselves and do not always answer when someone asks them or help due to the overcrowding and stress, and because everyone is concentrating on how they can complete this duty without any risk to themselves.

iii. Some people (22 out of 45 (48 %)) said that they were not able to recognise some places close to Ka'bah, and they depended on guesswork to find those places.

iv. Some pilgrims lose each other while doing Tawaf or Saai, i.e. anyone might, at any time, lose his group, wife, or friends. The important thing that should be mentioned is that it is not easy to find anybody who lost is in the Haram; it could take three days or more to be reunited with family or friends.

v. One person stated that he got confused from the start point in Jeddah airport. He could not find anything to indicate to him which was the right way, partially due to unclear information shown on static signs, which was hard to recognise and follow, some of human guides are very uncommunicative, and they do not provide full help to people.

The key issues facing pilgrims when they want to make Tawaf or Saai are count confusion and loss of friends or family.

Through the interviews, we have gathered much information about a number of problems that people have experienced. In the following section we present some examples as evidence that people have suffered whilst performing their rituals of Hajj. One participant reported that he went to make Tawaf and pray around Ka'bah. When he completed his work and he attempted to find his group, he was unable to do so; he also forgot his accommodation address. Consequently, he stayed around Ka'bah for three days, away from his accommodation and his group.

Another interviewee said that when he arrived at the Ka'bah area to make Tawaf he did not find any sign guiding him to the start point of Tawaf. He stood still for about one hour thinking about how he could start Tawaf, all the people around him moved as a complete circle but he could not understand where to start Tawaf. He then decided to focus on some of the people around him and tried to do as they were doing.

Another person indicated that many pilgrims have difficulty in performing Tawaf or Saai despite the considerably effort they put into these rites. Yet another person reported having visited Mecca many times and having good experiences. He added, sometimes when he has completed Tawaf or Saai he spends some time helping people who are visiting Mecca for the first time and have no idea about Tawaf, Saai, or other pillars of Hajj. From these circumstances he concluded that the pilgrims need a better system to lead them to perform their pilgrimage in the right way. Such a system could provide substantial advantages such as saving the pilgrims' time. Finally, we interviewed some pilgrims who had issues in Mecca during Hajj. For example, one person who works in the airport says, "*I have noted that the pilgrims were unstable, fear, and confusion, because they have not any knowledge about the places, also there is no system used to guide them to right ways*." *(sic)*

Another person commented: "*this fear and confusion could cause bad effect on the pilgrimage, where the pilgrims should be in full relax that's to know what they are going to do and say during performing Islamic religious such Hajj, prayer, etc". (sic)*

Yet another person told us: *"he says I have faced a lot of problems in Mecca such as how to start pillars, nothing exist to let me start, no electronic displays which providing pilgrims information, I have asked local people but they ignored me, after that I have started pillars rely on my guess*". *(sic)*

Finally, a further person said: "*I could not travel to Mecca alone, because in last time I went to Mecca alone and I have faced a lot of problems during performance duties of pilgrimage. So if I do that again I should go with someone who has good experience about Mecca situation to help me completed my pilgrimage pillars in peaceful and safety". (sic)*

4.3 Design Approach

In creating a feasible solution for improving the situation during Tawaf we followed a user-centred design approach. Given the spiritual relevance of the scenario, we considered the continuous involvement of users essential not only to expose designs to potential users early on but also to ensure that the designs are acceptable from a 'religious' perspective. We first thoroughly investigated the properties, constraints and most pressing issues pertaining to the application scenario by surveying existing literature and other sources such as material published by the Saudi Arabian ministry in charge of the Hajj or guide books for people planning to go on a pilgrimage. We then conducted a series of semi-structured interviews (based on the findings of the initial phase) in order to gather further feedback on specific issues during the Hajj while also allowing for additional input that might be relevant for the design of a system to support pilgrims. Based on the understanding we gained through this process, we developed and refined the dynamic signage system (introduced in the focus group section) through two focus group sessions. Once we were satisfied that the system met the basic requirements we had identified through this process, we evaluated the final design through a lab-based study in a simulated environment.

Existing solutions for keeping track of the rounds count are largely targeted at individual users. One option suggested is to carry seven small stones when entering the great mosque and dropping one of them each time a circumambulation of the Ka'bah is completed. Another possibility is to hire a human guide to keep track of the count or to liaise with other group members who walk at the same speed. None of these solutions scale very well.

If everyone was to carry and drop small stones the ground would quickly be covered in stones and increase the danger of slipping. Large numbers of human guides would contribute to making the place even more crowded. Groups trying to stay together for the purpose of counting rounds could disturb the flow of the crowd, and some people are not part of a group. We therefore concluded that we should focus on a solution that would work for every pilgrim without any of the drawbacks of the approaches that are currently used.

4.3.1 Initial design

From the interviews with people who have visited Mecca to perform pilgrimage we have extracted some issues which people face during their pilgrimage when they navigate from one place to another or when they perform some duties such as Tawaf and Saai. Crowds, stress, limited space, and lack of navigation guidance; all these factors are causing confusion to pilgrims and making it difficult for them to count or remember Tawaf rounds. Based on that, we attempted to present some ideas to improve the pilgrims' situation there. Nowadays augmented displays which may (or may not) be supported with personal devices (e.g. Mobile phones) could present significant advantages over static signs or mobile guides in pedestrian navigation situations, as augmented displays include many advantages such as sufficient screen size, enough memory capacity, are easy to setup, and display updated information.

Therefore, we tried to design a dynamic sign rotating on screen display which could help pilgrims keep track while they walking around the Ka'bah. We proposed that such a system could improve the Tawaf pillar and reduce the crowds inside the Haram.

4.3.1.1 Description

Basically, our design goal is to solve the issue of Tawaf, as pilgrims forget how many circles they completed while walking seven times around the Ka'bah. In some cases (e.g. confusion) people started Tawaf rounds from the beginning or tried to add two or three rounds to sure that they had completed seven circuits. Our suggestion is to install a dynamic display at suitable place to be clear for all pilgrims. It could be installed at the point where people start Tawaf rounds, as pilgrims should start their walking from a particular point. Based on that, there are two functions for this display (see Figure 4-2). Firstly, the dynamic display will indicate to pilgrims where the start point of Tawaf is as the dynamic display should be huge in size and be seen by everyone walking there. So people will consider the display as the start point of Tawaf, as a result pilgrims will clearly be able to find the Tawaf start point.

The second function would allow pilgrims to start their Tawaf by particular colour and dots available in that moment (i.e. pilgrims, groups, individuals might interact with the display and catch a colour and dots available at that time, where there are three signs rotating on the screen display). So that's why we designed the display in this way.

The idea of our system is a dynamic signage design rotating on the screen display, the dynamic signage interface designed as three circles, each circle divided into a number of wedges; each wedge has a particular colour, also a fixed line has been designed on the dynamic display to be start point where the circles rotate. Once rotation is a complete full circle of 360^o one dot will appear on the wedge that has reached the fixed line, one dot will be incremented whenever any wedge completes a full rotation, When the number of dots reaches seven, the counter starts at one dot again.

The speed of the dynamic display corresponds to the average speed of pilgrims walking around the Ka'bah. When reaching the start point of Tawaf pilgrims should look at the display and spot a colour available at that moment, keeping in mind that colour and how many dots are on it (e.g. blue 4, means blue colour and four white dots). Once they have completed one round the dots will number 5 and so on. In this case they will continue walking until the dots became 4 again, that means they finished walking around the Ka'bah seven times.

An Illustration of how the system is designed and how it works is presented in the following steps:

Three or more circles are shown on the dynamic display, each circle is subdivided into a number of wedges, and each wedge has a different colour which rotates on screen.

Rotation speed corresponds to the average movement speed of pilgrims around Ka'bah, i.e. when they have walked a full circle, it will have completed a full 360^{o} rotation. After completing a full rotation, the number of dots inside a wedge will be incremented by one. When the number of dots reaches seven, the counter starts at one dot again.

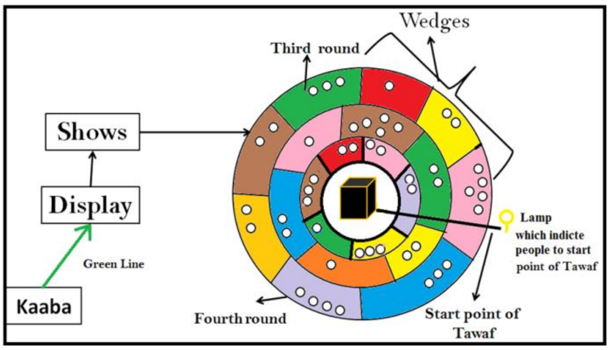

Figure 4-2 Proposed design for Tawaf system

4.3.1.2 Design Rationale

Our system was designed in this way (see Figure 4-2) for several reasons, these reasons resulted from the interviews that we have done with many people who had completed Hajj before. The system interface was design to show colours and dots to solve one of the significant issues: some people could not understand Arabic or the English language. We found that colour is the only common factor that could be understood by all people who meet there, regardless of what their language is. The second reason is that during Tawaf people should be walking around the Ka'bah seven times to perform the Tawaf pillar. They have to start from a particular point (Black stone), i.e. Pilgrims should start from the Black stone and end at the same point, this means a full circle of 360^{o}. Based on that, we have designed our system: dynamic signage divided into wedges rotating on the screen display, once a full rotation of 360^{o} is completed, dots in that wedge will increment by 1. So, the speed of the dynamic signage should correspond to the average speed of pilgrims walking around the Ka'bah. For example, if someone sees the Red colour with 3 dots and starts walking, once he/she has completed a circle and is back to the start point of Tawaf (indicated by display) they will find that the Red wedge now has 4 dots. We can conclude that the design of our system was extracted from the idea of Tawaf itself.

4.3.2 Focus group

4.3.2.1 Participants

We organised two focus group sessions. For these two sessions, we also recruited people of Muslim faith, who had previously been on a pilgrimage. 14 people participated in the first focus group (5 female, 9 male) and they were of different Nationalities: Arabic and Asian, aged 26 and 63. Some of them are students and some were employees in Newcastle city**.** Two of them were in visiting Newcastle city, both were from Saudi Arabia and they work in Islamic religion centre, they have significant knowledge of the Islamic religion conditions. Five were in the second focus group session (all male). All focus groups participants have had a good experience of pilgrimage, understanding all the requirements of Hajj, all of them had experienced pilgrimage before, and some of the participants had performed hajj more than once.

At the beginning of the focus group sessions we introduced ourselves then we provided them with a brief explanation about our study purposes and goals. It was necessary to explain to them about the essentials questions behind our idea such as: ‘What is dynamic signage and what is it used for?’, ‘How can people benefit from it in their lives?’, ‘What are the advantages of dynamic signage?’, ‘How are people able to interact with it to get information about places in unfamiliar environments?’ In addition, we mentioned to them, the techniques available that might be able to provide information for people about their locations and destinations via dynamic signage. Also we mentioned to them about some techniques which might be used to provide navigation information through dynamic display such as: textual, audio, images, video, etc. We also mentioned to them all the details of the Mecca scenario idea that we had gathered from the interviews we had done previously. For example, ‘what is the aim of the Mecca scenario?’, ‘why this idea?’ and ‘why the Mecca situation in particular?’ After that, we asked them to provide us with some ideas about how people can perform their Pilgrimage rituals, what methods they used for that, and is there any help available to guide people and lead them in the right direction? e.g. signage.

4.3.2.2 Suggestions and comments

All participants emphasised that the pilgrims navigate there through static signs and human guides. There is no technology used to guide people and provide them with information about pilgrimage pillars. The majority of pilgrims are dependent on the human guides and people who had experienced pilgrimage before. Actually, they argued that technology is very important to help people find their way, particularly in unknown areas. Pilgrims need to use technology in their navigation to organise movement and to allow them perform their rituals peacefully and safely.

Then, we have demonstrated our initial system and mentioned to them our idea, why we designed our system in this way and what help the system will provide to pilgrims to help them perform Tawaf pillar (remember and count the rounds of Tawaf). In addition, we explained to them how the system works and how pilgrims can interact with it.

The other key aspect which has been discussed with focus groups participants was the issue of the different walking speeds of pilgrims (how the proposed system deals with the problem that people on the outside of the circle will complete a rotation more slowly than those on the inside). In the context of the issue of different walking speeds, we have proposed and discussed three options which can be used to solve this problem.

The first option, the area of the Tawaf should be measured and divided into regions. Each region will include a dynamic display to provide personal navigation information for the pilgrims who walk in that region. For example the area of the Tawaf has a radius of 45meters, in this case, the Tawaf area could be divided into 3 regions, and each region will be 15 meters. So Pilgrims groups who walk in a particular region should look at their left side and read the closer display and extract their navigation information. The measurements of the Tawaf area is one of importance for future work. Once the area of the Tawaf (walking around the Ka'bah) has been correctly measured and displays installed then pilgrims can easily extract their information and perform their rounds successfully. In the discussion section we discussed how the Tawaf area can be measured and how we can know the average speed of pilgrims while walking around the Ka'bah exactly, (e.g., using GPS-based tracking of a few pilgrims). This can be also used to calculate the radius of Tawaf area and then divide it into regions as required.

For the second option, we created a design which consists of a public display showing three concentric rotating circles (see Figure 4-2). Each circle rotates around the centre and is subdivided into a number of wedges. Inside those wedges, a number of dots are shown, which are increased whenever a wedge completes a full rotation. Wedges correspond to groups of pilgrims circumambulating the Ka'bah. People can keep track of their round count by monitoring the dot count of ''their'' wedge. For example, the group of pilgrims who walk close to the Ka'bah will follow the internal circle which rotates faster than the other circles and the group who walk away of the Ka'bah will follow the external one. However, this design has the disadvantage of making the sign much more difficult to understand and making people confused.

For the third option, the speed difference might not actually be very big: the central areas are much more crowded, thus the speed there could be lower and therefore, it could be that people on the outside walk faster and complete a circumambulation in the same time as the people who walk near the centre. All the three options have been discussed with the focus groups participants and they agreed with option 1 and option 3 and disagreed with the option 2, as it has the disadvantage of making the sign much more difficult to understand.

Individual comments

One participant stated that, hopefully one day all pilgrimage pillars will utilise modern technology. As a result, pilgrims can do their Hajj without any issues. In addition, he added, 'Mecca situation is a unique place which includes special properties and this makes it important to use technology.'

Another participant believed that, it is necessary to use technology in the pilgrimage situation; this will enhance and develop the pilgrims' navigation in Mecca.

A further participant said that Mecca is a crowded location throughout the year and includes many different places, many people with different cultures and languages, all those aspects should be organised by a particular navigation system. Participants argued that, it should be encouraged by people who are specialists and scientists in the technology field to design systems such as digital displays and directional signs which might improve the pilgrimage situation in Mecca and other places.

Another participant who has experience of the Islamic religion said, any technologies which contribute in enhancement and aid pilgrims is allowed and can be used even in holy places such as Ka'bah, Saai, and Arafat.

Their suggestions and comments have been concluded and summarised and duplicated in table 4-1.

Table 4-1 shows the Focus group comments

Participants	Comments and suggestions
19 out of 19 participants (100 %) discussed and said that	The current interface may confuse pilgrims because it includes three circles and each circle is divided into a number of wedges. They suggested that one circle divided into a number of wedges instead of many circles will avoid any confusion which could occur.
15 out of 19 participants (79 %) claimed that	The idea of colour and dots was very interesting, the advantage of that is that it overcomes the different language issue, where people meet in Hajj coming from different countries all over the world. Colour is recognised by all human beings, i.e. it is the main key of our idea. It will provide much help in remembering and counting Tawaf rounds.
16 out of 19 participants (84 %) believed that	This idea it could make Tawaf less crowded. i.e. anyone can complete his/her Tawaf quickly via dynamic display and this leaves space for other pilgrims.
11 out of 19 participants (58%) argued that	Proposed that we must install three displays to show the system, two on the ground floor and one on the first floor .i.e. we have to divide the area of Tawaf into regions; each region contains a display and every display should be designed according to the average speed of people walking in that region.
19 out of 19 participants (100 %) emphasised	That the colours used should be very clear and easy to distinguish between them.
18 out of 19 participants (95%) proposed that	Dots should be easy to identify: it is important to take into account the colour and size of dots. (e.g. white is the best colour for the dots)
16 out of 19 participants (84 %) claimed that	The placement of the display is very important: it should be placed in a position to provide full benefit for all pilgrims. (display location and size)

The other key aspect should be mentioned here is how the system proposed deal with the problem that people on the outside of the circle will complete a rotation more slowly than those on the inside. Based on the discussions which we done with the interviews and focus groups who were participated in our case study, we concluded that the area of Tawaf should be measured and divided into regions. Each region will include dynamic display to provide personal navigation information for those pilgrims who walk in that region. For example the area of Tawaf radius is 45meters, in this case, the Tawaf area could be divided into 3 regions, each region will be 15 meter. So Pilgrims groups who walk in a particular region should look at left side and read the closer display and extract their information navigation. The measurement of Tawaf area is one of our important future work. Once the area of Tawaf (walking around Ka'bah) has correctly measured and displays probably installed then pilgrims can easily extract their information and performing their rounds successfully. In discussion section we have discussed how the Tawaf area can be measured and how we can know exactly the average speed of pilgrims while walking around the Ka'bah, (e.g., using GPS-based tracking of a few pilgrims). This can be also using to calculate the radius of Tawaf area then divide it into regions.

In general, it can be said that all participants were satisfied with our system design and they strongly agreed with the use of technology at Mecca. Some of the participants' are specialists in the Islamic religion and work in the Mecca pilgrimage centre. They believe that the technology could be used in Mecca, i.e. it is acceptable to install any kind of technology which might be helpful and enhance the situation experienced during Hajj, for example, digital displays and signs. Their comments and suggestions have been taken into account when we redesign the final design of the system. For example, they proposed the use of one circle rotating on the screen display instead of three circles; other relevant suggestions included the size of the dots and kinds of colour for the wedges.

4.3. 3 Design Tawaf System

The content of the dynamic signage system we developed in response to these considerations is shown in Figure 4-3. It consists of a large circle that is subdivided into a number of coloured wedges and a smaller central circle. The wedges correspond to a group of people in specific areas as they circumambulate the Ka'bah in the middle. Each wedge has a different colour to facilitate recognition and differentiation. The starting line (i.e. the location of the Black Stone) is shown as a white line pointing outwards from the centre.

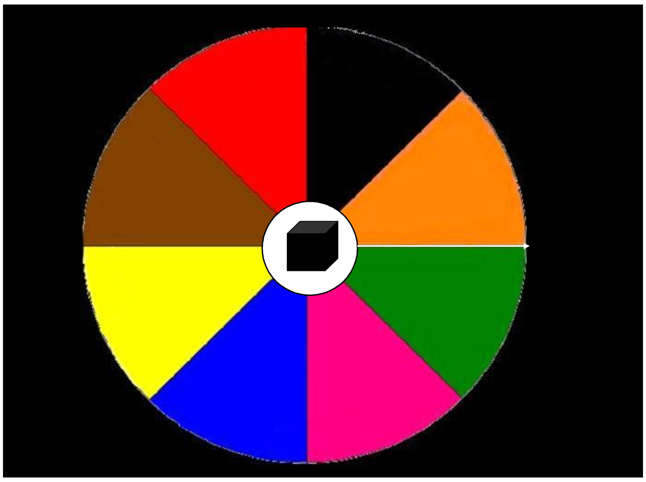

Figure 4-3 Basic design of the dynamic signage system

The large circle slowly rotates counter-clockwise around the centre. When a wedge completes a full rotation a white dot is added to it. As further rotations are completed more dots are added. When seven dots are shown in a wedge and another rotation has been completed, all dots are removed and the dot counter starts counting up from one again. Figure 4-4 illustrates the underlying mechanism.

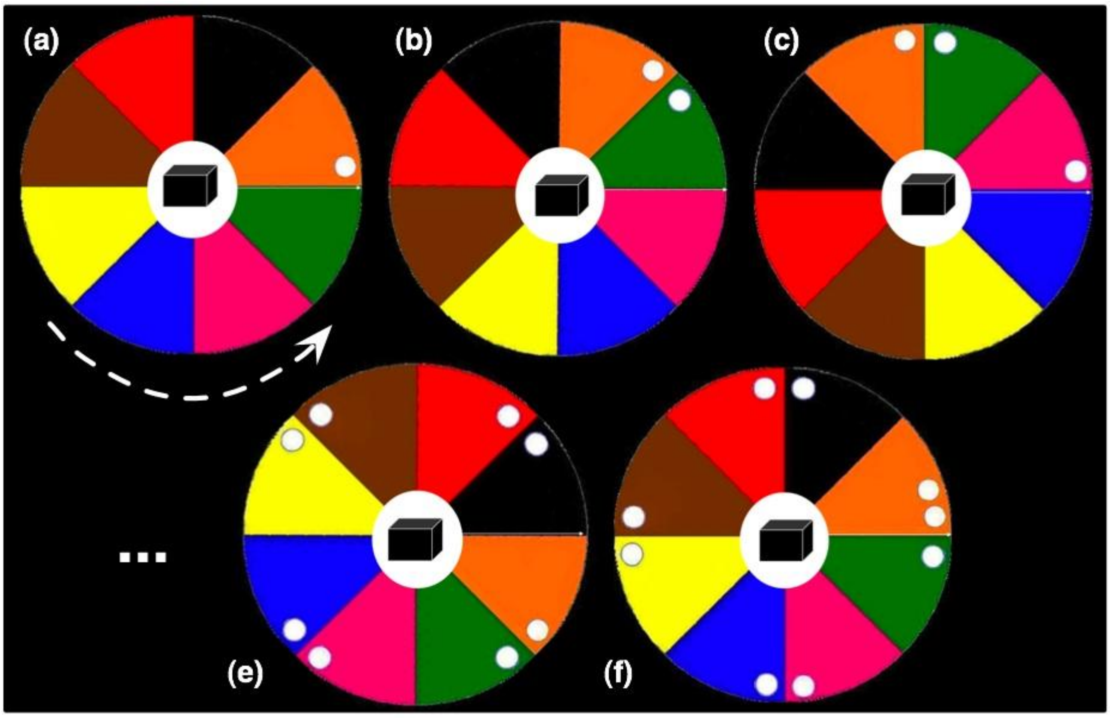

Figure 4-4 Change over time of the dynamic sign: as the circle rotates counter-clockwise the number of dots in each wedge is incremented up to seven dots

Figure 4-4 (a) shows a state, where the orange wedge has just crossed the line extending outwards from the Black Stone and consequently, a single dot has been added (compared to the state shown in Figure 4-3. As the circle continues to rotate, dots are added to each wedge that crosses the line, i.e. the green wedge in Figure 4-4 (b) and the pink wedge in Figure 4-4 (c). Figure 4-4 (e) shows the state just before a full rotation has completed, and Figure 4-4 (f) depicts the state just after completing a full rotation. As wedges cross the white line, dots are added until there are seven, after which the cycle starts all over again.

Pilgrims can use the dynamic sign to keep track of the round count in the following way. When they start Tawaf (at the line defined by the Black Stone), they can look at the dynamic display and memorise the colour of the wedge that is currently shown on the screen at a location that corresponds to where they are with respect to the Black Stone. In addition to the colour of the wedge, they can also memorise the number of dots in the wedge. For example, they might remember “blue 3” or “green 5”.

Once pilgrims have memorised 'their' combination of colour and number, they can start circumambulating the Ka'bah. Assuming that the rotation speed of the dynamic sign corresponds to their walking speed, pilgrims will know for sure that they have completed the required seven rounds once their memorised combination of colours appears again on the display.

4.4 Evaluation

Before we present the user study we conducted to evaluate the design for the dynamic sign, we need to analyse the proposed system with respect to the properties and constraints we identified in the scenario section.

With our system, pilgrims need to remember only a single combination throughout the whole duration of Tawaf. This combination of a colour and a number does not change and is visualised on the sign to facilitate recognition. Previously, people had to keep track by remembering the round count and incrementing it after every full circumambulation without any external cue, which arguably is cognitively more demanding and thus more error-prone.

One key consideration relates to the international nature of the crowd – people come from many different countries and cultures. Our design takes this into account by not using any textual components – it relies on colours and symbolic numbers, which are largely independent of particular cultures and languages, and thus 'readable' by a broad range of people (though not by visually impaired people).

The large crowd, the spiritual nature of the event and type of garment worn during Tawaf largely rule out mobile devices. Instead of using mobile phones to help people 'personalise' the display content, our approach makes use of the relative position of users with respect to the Ka'bah.

In order to evaluate our dynamic signage system in a realistic context and with potential users, we ran a user study in an environment simulating some aspects of the actual setting at Mecca**.** Testing the interface at the Ka'bah was infeasible due to logistic considerations and the early stage of development.

4.4.1 Aims of study

The main goal of the study was to gather feedback from potential end users and to observe their interaction with the system in a realistic setting. More specifically, we were interested in finding answers to the following questions:

(a) Does the dynamic signage system help participants to keep track of the rounds count?
(b) Do end users find the idea of installing such as a system at Mecca acceptable?
(c) Does the current user interface meet their needs, can they use it, or are there any issues that need to be addressed?

4.4.2 Participants

We recruited 27 participants of Muslim Faith through the local Mosque and a number of university societies. All participants were male, aged between 18 and 49 years. Their cultural background was varied with people originating from Northern Africa, India and Asia. The majority of the participants claimed to be knowledgeable in terms of the pilgrimage but no one had been to Mecca before**.** One key piece of information we gathered from the people we interviewed and those people who had done the focus group sessions is that the majority of pilgrims who lose track of Tawaf rounds are those who are on their first visit to Mecca to perform pilgrimage. Based on this consideration we have used none pilgrimage people in our user study to examine our approach, whether when providing personalised information for users they can understand how to deal with the display content and extract their personalised information.

4.4.3 Stimuli

As it was infeasible to run the study at Mecca, we tried to set up an environment in the lab that shares certain key properties with area around the Ka'bah. The Great Mosque at Mecca (where the Ka'bah is located) has a very symmetrical layout, which makes it difficult for people to remember where they entered and how much they have progressed in completing a round.

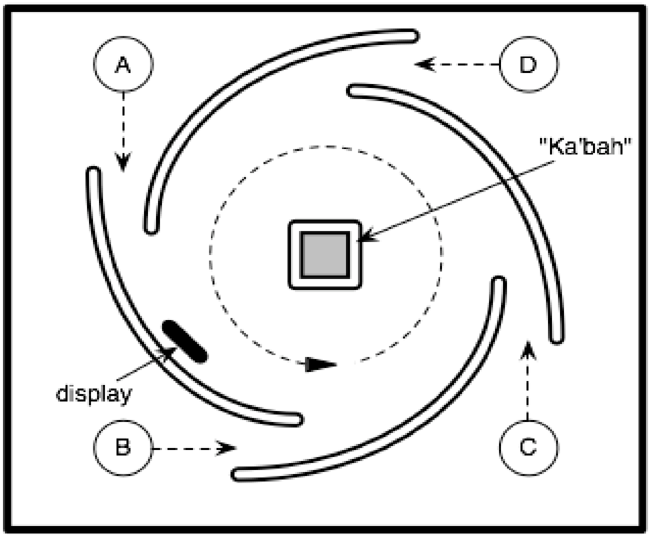

Figure 4-5 Layout of the experimental area: participants entered the inner area from positions A to D and walked around the "Ka'bah" in counter-clockwise fashion.

We used a subsection of a performance space with black ceiling-high curtains enclosing the entire area used for the study (9.40m x 9.60m). For the physical assembly of the structure, we acquired a number of large but light-weight slabs used for insulating buildings. Using those slabs (2.40m x 1.50m x 30cm) we constructed a square box in the centre of the area (to simulate the Ka'bah) and then erected a circular wall around it with four entrances (see Figure 4-5). The entrances were built in such a way that it was not possible to see the outside area from within the circle, where the square box was located. We kept the layout symmetrical and uniform to mimic that of the great mosque.

The dynamic signage system used a 19" colour display mounted on metal stand (total height: ca. 1.60m). The computer running the system was hidden behind the walls.

Figure 4-6 shows the experimental area photographed from a raised position outside the circle.

Figure 4-6 Photograph of the experimental setup (taken from a raised position outside the inner area), showing the "Ka'bah", the display and two of the three entrances.

We attempted to build our experiment to be somewhat similar to the real environment. We limited our simulation to the layout and some basic visual properties (e.g. symmetry) of the area around the Ka'bah. We did consider asking participants to perform the prayers/rites that pilgrims are supposed to recite during Tawaf but eventually decided against it for two reasons. It would be difficult to assess whether they did actually comply with such a request, and we felt that participants might find it inappropriate to engage in such activities during a formal user study inside a simulated environment constructed in a laboratory. Actually, the simulated Ka'bah was a good representation which included several important aspects such as people entering into the area of walking from three entrances, they walked (as mentioned previously) in a counter-clockwise direction and the dynamic display was installed in the proper place to allow them to extract their personalised information. Upon completion of the seven rounds, each participant immediately goes to the closest gate to exit. These aspects and participants behaviours while performing the study tasks helped us to evaluate several terms such as measuring completion time of tasks, disorientation events, and error rates, as the study was recorded (video and audio).

In order to determine an appropriate rotation speed for our set up, we invited five students to participate in a test run prior to the main study. We instructed them to slowly walk around the simulated Ka'bah seven times and measured the time it took them to complete the task. We found that the average time per round was 56 seconds, which we then used to set the rotation speed of the dynamic signage system during the main study.

4.4.4 Procedure

Each participant first had to fill in a brief questionnaire, which contained questions about the (cultural) background of each user and about basic demographic properties such as the participants' age.

We then briefed participants about the task they had to perform (walking slowly around the centre of the circle seven times) and the display they could use to help them remember the rounds count. We split up participants evenly amongst the four entrances. To simulate the constant influx of people at the Ka'bah in Mecca, we had the subjects enter the inner area every 20 seconds in batches of four through each of the four entrances. Participants were also told to leave the study area immediately once they felt they had completed seven rounds. The entire study was recorded on video.

In the last phase, subjects had to fill in a final questionnaire, which contained various questions about the dynamic signage system and its properties. After completing the questionnaires, people were paid and discharged.

4.4.5 Results

In the initial questionnaire, the majority of the participants (85%) reported that they were familiar with the pilgrimage in general, although nobody had visited Mecca prior to taking part in this study. Participants listed a number of sources, from which they had acquired their knowledge about the pilgrimage: TV, books, family, the Internet, and mosques were the most frequent ones.

If people had indicated that they were familiar with the situation, we asked them to list three problems they associated with the Tawaf rite as well as three helpful aspects in this context. The three most frequently mentioned issues included the extreme crowdedness during the Hajj, forgetting/remembering the rounds count, and people praying while others are performing the Tawaf rite. In terms of helpful aspects participants only mentioned three items: paid guides who help pilgrims to perform the rite, volunteers who perform the same job, and the flashing lamp that is used to indicate the starting location (which has now been removed).

4.4.5.1 Time completion and Error Rate

We used the video recordings to extract the completion times of all participants. Figure 4-7 summarizes the results we obtained. In general, the first round took slightly longer to complete on average (57s) than the other six rounds (between 55s and 56s). The standard deviation was low at between 1s and 1.6s per round. The average time per round across all rounds and all participants was 55.9s with a standard deviation of 1.33. All times were very close to the rotation speed that the system was set to (56s). All participants successfully completed exactly seven rounds and walked around the box in the correct direction (counter-clockwise). One participant reported having forgotten the rounds count during round six but being able to recover after completing round seven and seeing their combination (wedge colour plus number of dots) on the display. All participants left by the nearest exit after finishing.

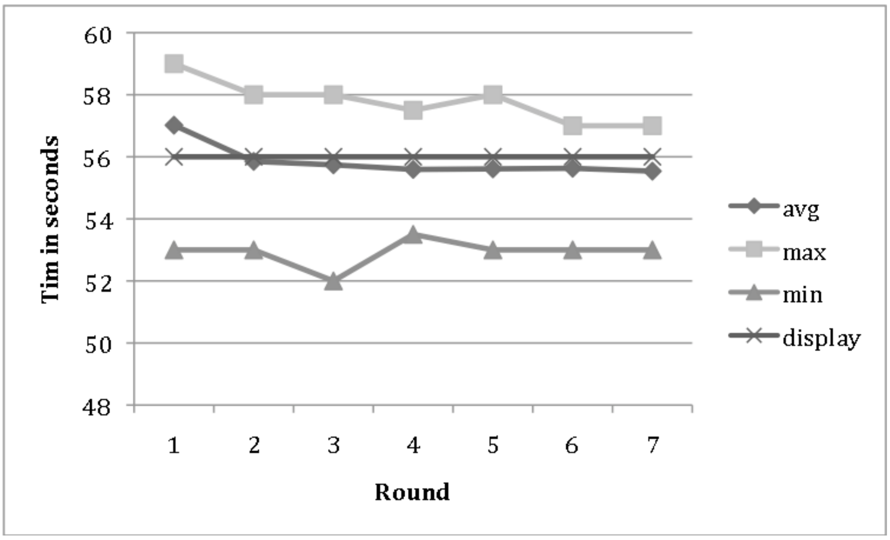

Figure 4-7 Completion time per round: average, maximum and minimum time taken for each circumambulation as well as rotation speed of dynamic signage display.

4.4.5.2 Observation from the video

We counted ten instances of people stopping briefly (for about two to three seconds) to look at the display before resuming their circumambulation. This typically only occurred during the first or second round after a subject had entered the experimental area. Furthermore, we recorded five instances of participants looking back at the display after they had passed it. In addition, seven subjects engaged in conversations with other subjects while walking around the experimental area.

4.4.4.4.1 Results from questionnaires

In the questionnaire that subjects had to fill in after completing the experiment we presented them with a series of (negative and positive) statements about the dynamic signage system and asked them to indicate whether they agreed with these. We used a five-point Likert scale, where a value of five corresponded to "strongly agree" and a value of zero to "strongly disagree". In the following section we report on the participants' responses, which we computed by combining all questions relating to the same category. Figure 4-8 shows the usability and satisfaction of participants.

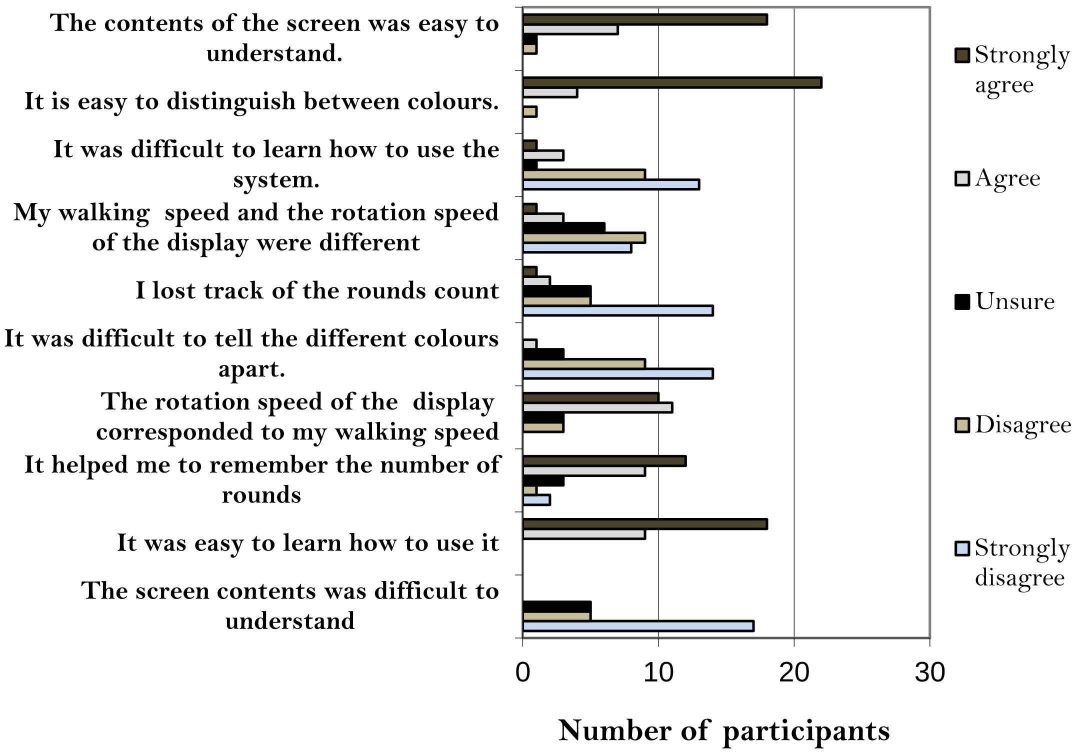

Figure 4-8 illustrates usability and satisfaction of the participants

When asked about the screen content, there was a strong agreement that it was easy to understand (average: 4.53, standard deviation: 1.41). Similarly, participants found the colour scheme we used easy to distinguish (average: 4.54, standard deviation: 1.41). Subjects also agreed that the system in general was easy to use (average: 4.39, standard deviation: 1.24), and that it helped them to remember the rounds count (average: 4.06, standard deviation: 0.97). The statement that received the lowest score related to the rotation speed of the display and whether it corresponded to an individual's walking speed. Participants still agreed that this was the case but less so (average: 3.89, standard deviation: 0.75) than in the other categories.

Besides statements that directly linked to the system, we were interested in the perspective people would take towards installing such a system in Mecca. Participants agreed (average: 4.63, standard deviation: 0.93) that the dynamic signage system would improve the experience of pilgrims performing the Tawaf ritual.

We also asked participants whether they thought installing such a system at the great mosque in Mecca was acceptable. The majority of the participants (81%) agreed that this would be the case.

4.4.4.4.1 Qualitative feedback

The questionnaire provided several occasions for participants to give feedback through free text responses. One aspect we asked participants to comment on was whether they think it would be possible to understand and use the system without being given instructions, and if not, what would be the best way to convey instructions to pilgrims. A large percentage of the users felt positive that the system would be usable with little or no instructions. Typical comments include "All the system contents were very clear and easy to use, and understand without instructions." (sic) and "Before the study run we thought that the illustrative instructions are not enough to understand […] But during the study running we found that the system easy to use and the instructions were not necessary." (sic). In terms of conveying instructions on how to use the system, subjects suggested leaflets or large (static) signage outside of the great mosque.

The questionnaire also included open questions about key benefits and drawbacks of the system. Subjects frequently mentioned the ease of use and the clearness of the design as benefits, and generally, e.g. "The colours are very clear and the system easy to use." and "Use colour it very good idea, where all people can understand it." (sic) Negative comments often referred to the rotation speed as being either too fast or too slow ("we go faster than the display", "The rotation of the … screen is slow") and to the size of the screen and its content ("the size [of the dots] was not suitable", "screen was a bit small").

4.4.5.5 Summary findings

In this chapter, we investigated the question "Does the dynamic signage system help pilgrims to keep track of the Tawaf round count and to navigate successfully around the Ka'bah?" We presented an analysis of the situation in Mecca based on a literature review and on interviews with pilgrims, and then introduce a prototypical dynamic signage system aimed at supporting pilgrims in navigating one particular area. To evaluate the system, we conducted a user study in a realistic setting, and the results suggest that dynamic signage may be a feasible option in this setting. The design and evaluation of our prototype also led to a number of insights regarding the design of such systems. We discuss difficulties encountered during the design process and the evaluation and reflect on implications for the design and evaluation of systems supporting navigation for large crowds.

We used video recordings to extract the completion times for all participants. In general, the first round took slightly longer to complete on average (57 seconds) than the other six rounds (between 55 and 56 seconds). The standard deviation was low at between 1 and 1.6 per round. The average time per round across all rounds and all participants was 55.9 seconds with a standard deviation of 1.33. All times were very close to the rotation speed that the system was set to (56 seconds). All participants successfully completed exactly seven rounds and walked around the box in the correct direction (counter-clockwise).

Through the video we also observed the following:

i) We counted 10 out of 27 participants stopping briefly (for about two to three seconds) to look at the display before resuming their circumambulation. This typically only occurred during the first or second round after a subject had entered the experimental area.
ii) We recorded 5 out of 27 participants looking back at the display after they had passed it.
iii) 7 out of 27 subjects engaged in conversations with other subjects while walking around the experimental area.

We can say that all that occurred because the participants did not follow the instructions that were given to them before the study started.

Results from questionnaire: The questionnaire presented a series of (negative and positive) statements about the dynamic signage system and asked users to indicate their level of agreement on a five point Lickert scale, where five corresponded to ‘‘strongly agree’’ and one to ‘‘strongly disagree’’. The results obtained from the questionnaire showed that the participants were satisfied with the system’s aspects. For example, when we asked participants about the screen content, there was a strong agreement that it was easy to understand (average: 4.53, standard deviation: 1.41).

Similarly, participants found the colour scheme we used easy to distinguish (average: 4.54, standard deviation: 1.41). So we gathered evidence that users found the system easy to use, they were able to extract personalised information relevant to them from the display.

The statement that received the lowest score related to the rotation speed of the display and whether it corresponded to an individual's walking speed. Participants still agreed that this was the case but less so (average: 3.89, standard deviation: 0.75) than in the other categories. Negative comments often referred to the rotation speed as being either too fast or too slow ("we go faster than the display", "The rotation of the … screen is slow").

In general, we can say that the results provided us good evidence that dynamic signage can support pilgrims to keep track of the Tawaf rounds while walking around the Ka'bah.

4.5 Discussion and reflection

The user study provided us with feedback on several key aspects of the dynamic signage system. In general, we gathered evidence that users found the system easy to use, and that they were able to extract information relevant to them from the display. The feedback we obtained also suggests that the deployment of such a system inside the Great Mosque at Mecca could be acceptable (despite the religious significance of the location). In addition, the study yielded some insights related to the design of systems aimed at supporting navigation for large crowds in general, e.g., with respect to evaluating them prior to deployment.

4.5.1 Feasibility of the system

In terms of improving the system, the users' comments suggest that the underlying concept of extracting personalized information from a public display based on their relative position can be understood and used but the actual instantiation (choice of colour, size of wedges, size of the screen) might have to be adapted. Occasionally, the rotation speed was mentioned as not being optimal. This is a critical aspect though as the function of the system hinges on the sign being synchronized with the movement of the pilgrims around the Ka'bah. Ideally, the system would sense the movement speed of the pilgrims (e.g., using video analysis or GPS-based tracking of a few pilgrims) but for the study, the speed was set manually based on measurements from a pre-test. An interesting alternative approach would be to investigate whether the system could actually be used to ‘‘induce’’ a particular walking speed (thereby potentially contributing toward increasing overall safety).

4.5.2 Applicability in other scenarios

The interface we proposed for the Tawaf scenario relies on people extracting personalized information from the dynamic display content by themselves based on their relative location at the time of interaction with the system.

This approach can be generalized to the principle of ‘‘manual’’ context-driven personalization of public display content, where users effectively adapt what they see on the screen based on readily observable contextual factors such as time or location. The screen content in turn is designed to facilitate mapping it to the real-world scenario—in our case, we visually mirrored both the layout of the deployment location and the motion of people around the Ka’bah. While we will further explore the applicability of this idea in the context of other problems we identified for the Hajj, we believe that it can be applied to a broad range of interfaces for large crowds. One key benefit of this approach is that it does not require users to carry/use a mobile device in order to obtain personalized information.

It thus increases the number of potential users and can also help to address the issue of scalability in the case of very large crowds.

4.5.3 Designing interfaces to support navigation for large crowds

The design and evaluation of the interface to support large crowds during the Tawaf ritual posed several challenges. After our initial investigations into the scenario, it was clear that the density of the crowd was a key factor to consider. This raised the question how we could simulate that aspect convincingly without compromising the safety of our participants and without having to recruit large numbers of subjects. Our approach was to scale down the location so that we could achieve a relatively high density of people with a relatively low number of participants.

Alternative solutions could be to just simulate large crowds convincingly (e.g., using projections and/or audio recordings) or to use tighter spaces (with a potential negative impact on participants’ safety). Therefore, while we can state that the dynamic signage scales with its visibility (all users who can see it can use it), further research is required to evaluate whether the results we obtained in our small scale study will actually scale to very large crowds.

4.5.4 Interacting with spirituality

Another key problem specific to the Tawaf scenario was the spiritual significance of the activity we tried to support through our system. While informed participants about the intended deployment site (i.e., the Great Mosque in Mecca), we did not try to recreate the mosque visually (e.g., by painting the walls or the block in the middle). Instead, we limited our simulation to the layout and some basic visual properties (e.g., symmetry) of the area around the Ka'bah. We did consider asking participants to perform the prayers/rites that pilgrims are supposed to recite during Tawaf but eventually decided against it for two reasons. It would be difficult to assess whether they did actually comply with such a request, and we felt that participants might find it inappropriate to engage in such activities during a formal user study inside a simulated environment constructed in a laboratory. Clearly, this question deserves further research, i.e., in terms of how to factor in experiential factors into the design and evaluation of systems supporting large crowds in navigating specific areas [24]. On a more general level, an interesting question is whether there can be (and should be) a middle step in the design process of interfaces for large crowds that sits between well-established techniques such as focus groups or design workshops, and the actual deployment ‘‘to the masses’’. One argument for such a middle step would be that it might provide insights not afforded by smaller scale approaches (e.g., crowd behaviour, interferences introduced by more than a few people interacting with the interface at the same time). For our design aimed at supporting pilgrims during the Tawaf ritual, we decided that we might be able to replicate some key aspects of the real setting in a lab study. While we did gain some insights through this approach (such as the fairly consistent walking speed and the success rate in a nontrivial setting, where people enter and leave at different times), it is not clear whether these could have been obtained with less effort. One technique we are currently investigating is the use of Immersive Video Environments [25] as it might enable us to create realistic environments quickly.

4.6 Chapter summary

In this chapter, we analysed properties, constraints and key issues facing people that take part in the yearly pilgrimage to Mecca. In order to improve the safety of pilgrims during one of the rites (Tawaf), we designed a dynamic signage system to help people navigate around the Great Mosque in the context of extreme crowdedness. It is based on a dynamic public display, from which individuals can extract personalized information using their relative position with respect to the Ka'bah. We evaluated our approach against the constraints we identified through a lab-based user study in a simulated environment.

The results suggest that dynamic signage may be a promising option to improve the safety during Hajj and that the installation of such signs around the Ka'bah may be acceptable to pilgrims. The study also emphasized the importance of the rotational speed of the dynamic sign, and we discussed several options to achieve a high degree of synchronicity between the people circumambulating the Ka'bah and the sign.

Losing track of the rounds' count is only one of the problems facing pilgrims (specifically at Tawaf and Saai), and the solution we proposed may help in addressing it. There are however a number of further issues such as groups getting separated and being unable to find each other again, or finding their way around the city. In the future, we plan to look into these problems and develop solutions that are also usable by very large numbers of pilgrims from different cultural backgrounds and with varying abilities.

Our investigation of the Tawaf scenario and the user study we conducted to evaluate our design also yielded some insights with respect to the design of system to support navigation for large crowds. We identified the approach of context-driven personalisation of public display content as a promising way to provide adaptable support for very large numbers of diverse and concurrent users.

In addition, we highlighted some issues pertaining to the evaluation of interfaces for large crowds such the difficulty of creating a realistic simulation in the lab and how to progress from small-scale tests such as focus groups to larger scale evaluation prior to real-world deployment. We should introduce the next study "Case study 2: design dynamic signage for pedestrian navigation to overcome drawbacks of previous systems", (e.g. static signs) based on the results that we gathered from Tawaf study which demonstrated that dynamic displays supported by colour codes might provide help in hajj situations and help pilgrims to perform their Tawaf rounds around Ka’bah. In the next chapter we will address some issues that face pedestrians in their navigation while using previous systems such static signs or mobile guides. We will also use the next chapter to investigate those issues and design a new system via dynamic display and colour code to provide navigation information for pedestrians in unfamiliar environments.

Chapter Five

Case study 2: Augmented signage

Scalable Navigation Support for Crowds: Personalised Guidance via Augmented Signage

5. Case study 2: Augmented Signage System

Scalable Navigation Support for Crowds: Personalised Guidance via Augmented Signage

5.1 Introduction

In recent years, the popularity of mobile navigation systems has increased. Almost all approaches focus on providing the user with: information on their current location, nearby points of interest, directions, and navigation. Mobile guides are fundamentally intelligent replacement solutions for paper maps that provide extra services to the user. However, a key disadvantage of mobile navigation is that the user still has to associate the navigation information with the surrounding world. As result, people frequently rely on signage in crowded settings. Nevertheless, a key disadvantage of public signage is that it does not provide personalised navigation support. Those systems have been shown to work well on an individual level (e. g. a single user navigating urban environments). Many issues face users when navigate in areas that a very crowded: the difficulty of using mobile phones in crowds, a lack of scalability of the underlying technology, and exclusion of some users. In order to address these problems and to provide a system that large numbers of people can use simultaneously to access personalised navigation support, we are investigating the use of (dynamic) public signage as a means of delivering this type of information.

In this context, we present an approach that augments standard signage (either static or dynamic) with additional information that enables users to extract personalised directions. As an added benefit, the approach provides a means to influence the flow of people through a space. We also report on a user study we conducted to investigate different designs of augmented signage for navigation support.

Case study 2: augmented signage was an extension of case study 1 where we were developing augmented display (dynamic signage, case study 1: Tawaf system) to support pilgrims count/remember their Tawaf rounds while walking around the Ka'bah. The results that we obtained from case study1 provided us with good evidence that an augmented display can support people navigating in crowded situations. In this case study we developed augmented signage as a means of providing navigation support for large crowds. For example, pilgrims at Mecca can benefit from such systems to obtain navigation information about their destination.

Pilgrims, after they have completed their rituals inside the Haram, go back outside for reasons such as shopping and refreshments.

Through the study we attempted to answer the following questions:

i. Can people ‘read’ the system and use it to infer the right direction reliably and quickly?

ii. How do the three conditions (arrows only, coloured circles, coloured symbols) compare in terms of task completion time, errors, disorientation events, usability, satisfaction, and workload?

We conducted a user study in a realistic setting, and the results suggest that dynamic signage may be a feasible option in a heterogeneous crowd situation. The design and evaluation of our prototype also led to a number of insights regarding the design of such systems. We discuss the difficulties encountered during the design process and the evaluation and reflect on implications for the design and evaluation of systems supporting navigation for large crowds. We introduced a scalable signage-based approach and presented results from a comparison study contrasting two designs for augmented signage (Coloured circle and coloured Symbol conditions) with a base case. The results provided initial evidence that such a system could be easily useable, may help to reduce task load, and has the potential to improve navigation performance. In general, we gathered evidence that users found the system (both augmented signage) easy to use, and that they were able to extract information relevant to them from the display. In addition, the study yielded some insights related to the design of systems aimed at supporting navigation for large crowds in general. Furthermore, the results were supported our hypothesis, as we assumed that users will prefer the colour condition and they will satisfied with it more than the other conditions (Symbol and Arrow).

Based on these initial results, our next step will be to apply this approach to a specific scenario and to evaluate it under more realistic conditions. In order to achieve this, we intend to investigate its use in the context of the pilgrimage that brings many Muslims to Mecca every year. This scenario poses a number of challenges such as the scale and diversity of the crowd that will enable us to test and refine the approach further. As it is unlikely that a research prototype could be deployed at Mecca, we also plan to look into different ways to increase the realism of lab-based studies.

Section 5.2 (Personalised Navigation Support for Crowds) gives details about how people navigate in a crowd situation considering design appropriate systems for people who do not own a mobile phone, or who do not speak the local language or cannot read well. This section includes three subsections: spatial portioning (5.2.1) which describes the situation of crowds and how people move through, e.g. every single person in crowds might want to go to a different destination but in practice the number of actual destinations is often much smaller. Subsection (5.2.2) augmented signage, in this subsection we give an introduction to how to design a system to provide personalized guidance to large numbers of users. We also describe the system proposed, where people can use visual cues that are embedded into standard signage to extract personalized information. In subsection (5.2.3) Flow Management we provide some details about the system' construction, as it consists of three conditions: base case, coloured, and coloured symbols. Section 5.3 describes all the details about the user study section, which includes: the user study introduction, the aim of study, participants, procedure, and discussion of the results obtained. In the discussion and reflection section (5.4) we discuss the significant aspects of the chapter such as some shortcomings that limit the generality of the results obtained. We also discuss an issue related to the lack of crowdedness, which is hard to emulate in the lab without compromising the safety of participants. In addition, we discussed the USE questionnaire which we used to measure time completion, workload, and usability and satisfaction. In the last section (5.5) we provide a summary chapter which presents the important points from the whole chapter and concludes by highlighting key contributions.

5.2 Personalised Navigation Support for Crowds

A number of key requirements immediately emerge when considering how to provide personalised navigation support to large crowds. Obviously, a feasible solution needs to be easy to use and learn, ideally with little or no training. In addition, it is clearly appropriate to design a system that enables the largest possible percentage of people to benefit from it rather than excluding particular groups (e. g. people who do not own a mobile phone, do not speak the local language, or cannot read well). Related to this, it is desirable to minimise technical requirements (e. g. the use of specific sensors) to enable use on a large scale and also at sites without much technical infrastructure. Furthermore, such a system should not function at the expense of other people, who are not using the system (for example, by interfering with the standard use of the locations, where it is being deployed). Finally, it would be beneficial if the system would allow for some degree of flow management, e. g. to avoid people overcrowding particular areas.

Our solution is inspired by a signage system described in Ender's Game, a novel by Orson Scott Card [22], which uses colour-coded lines to provide directions to different groups in a large training facility. The basic principle of using colour codes that map to areas and routes also underlies our approach but instead of this coding scheme replacing the traditional signs, we embed the code into standard signage in order to preserve the original artefact and its function. The two key components of the proposed system are spatial partitioning with corresponding mapping to colour codes, and augmented signage that embeds colour codes into standard signs used for navigation.

Figure 5-1 Example partition of an inner city area around a football stadium (marked by an `X' on the map) - map generated from open street map [70]

5.2.1 Spatial Partitioning

In order to provide large numbers of people with personalised directions, it is worthwhile considering where they might want to go to. In principle, every single person in a crowd might want to go to a different destination but in practice the number of actual destinations is often much smaller. For example, after a football match the spectators might want to go to a relatively small number of parking areas or public transport hubs. Similarly, if a concert hall has to be evacuated, there will be a limited number of assembly spots and escape routes that people have to follow depending on where they are at the time of the emergency. Finally, at large events such as the Olympic Games or pilgrimages, large groups of people might have the same target destination (e. g. a particular stadium or site).

Consequently, in many cases it will be sufficient to provide guidance to a relatively small number of destinations. These destinations in turn can be used to partition space. Figure 5-1 showed an example, where an inner city area around a football stadium has been partitioned into six areas that were then mapped to specific colours. Such a mapping enables not only the augmentation of existing signage (see 3.2) but also facilitates navigation as users only need to remember a particular colour code rather than a sequence of names of intermediate and final destinations. In order to increase the number of possible partitions beyond the number of clearly identifiable colours, it is possible to assign symbols to sub-partitions.

Figure 5-2 Example sub-partition using four symbols to divide area corresponding to one colour - map generated from open-street-map [70].

Figure 5-2 shows an example, where the large red area has been further divided into four sub- regions. Each sub-region has been mapped to a symbol (e. g. triangle, heart) and thus people will need to remember (and follow) a combination of colour and symbol (e. g. red circle). While the number of clearly identifiable symbols is also limited, by combining them with colours it is possible to create mappings that are more fine-grained; for example, using eight colours and ten symbols it is possible to directly address 80 areas. Mapping (colour only or coloured symbols) can then be embedded into signage as described in the following.

5.2.2 Augmented Signage Design

One key concern in designing the system to provide personalised guidance to large numbers of users was to preserve the main function that public signage provides to all nearby people. We thus chose to augment existing signage rather than replacing it with something that would only be readable (and therefore usable) by people who have been taught how to use it.

Consequently, we propose a system where people can use visual cues that are embedded into standard signage to extract personalised information, i. e. how to get to a specific target location. By remembering a simple code, individuals can look at a sign and use the embedded visual cues to infer which way they need to go in order to get to their desired target destination. The visual cue is constructed based on the colour mapping and spatial partitioning described above.

The `individual' code could initially be acquired in several different ways: it could be printed on entrance tickets, it could be agreed on by a group of people who want to meet up after an event, or it could be transmitted by a dynamic display at strategic locations (e. g. on the main paths leading to the event). In this chapter we are mainly concerned with the augmentation of standard signage and scalability, and therefore, we assume that people will be in possession of the correct code when they are looking at the signs.

We created two designs for the augmented signage. The first one adds coloured circles to items shown on a sign (see Figure 5-3, top left). Each colour corresponds to a specific destination; e. g. `red' might correspond to a specific Metro Station or city area. In order to infer the direction to follow at a sign, a user would first have to remember the colour, and then find the red circle and follow the arrow shown next to the entry near the circle (regardless of whether that entry reads ‘Metro Station’ or not). For example, given the colour red and the sign shown at the top left of Figure 5-3, a user would have to walk straight ahead to reach their destination.

The second design combines symbols and colours (see Figure 5-3, top right), so that a user needs to remember, for example, `green heart or `purple square. The process of extracting individual information is the same as with the first design. Using the example sign shown at the top right of Figure 5-3, a user following `purple cross' would thus have to walk straight ahead to reach their destination. In either design, the cues could be changed dynamically, e. g. to provide updated directions, to control the flow of people, to include new destinations, or to guide to multiple destinations (see section 5.5 for more detail). The user study reported in section 5.4 evaluates and contrasts these two designs against a base case (Figure 5-3, bottom left).

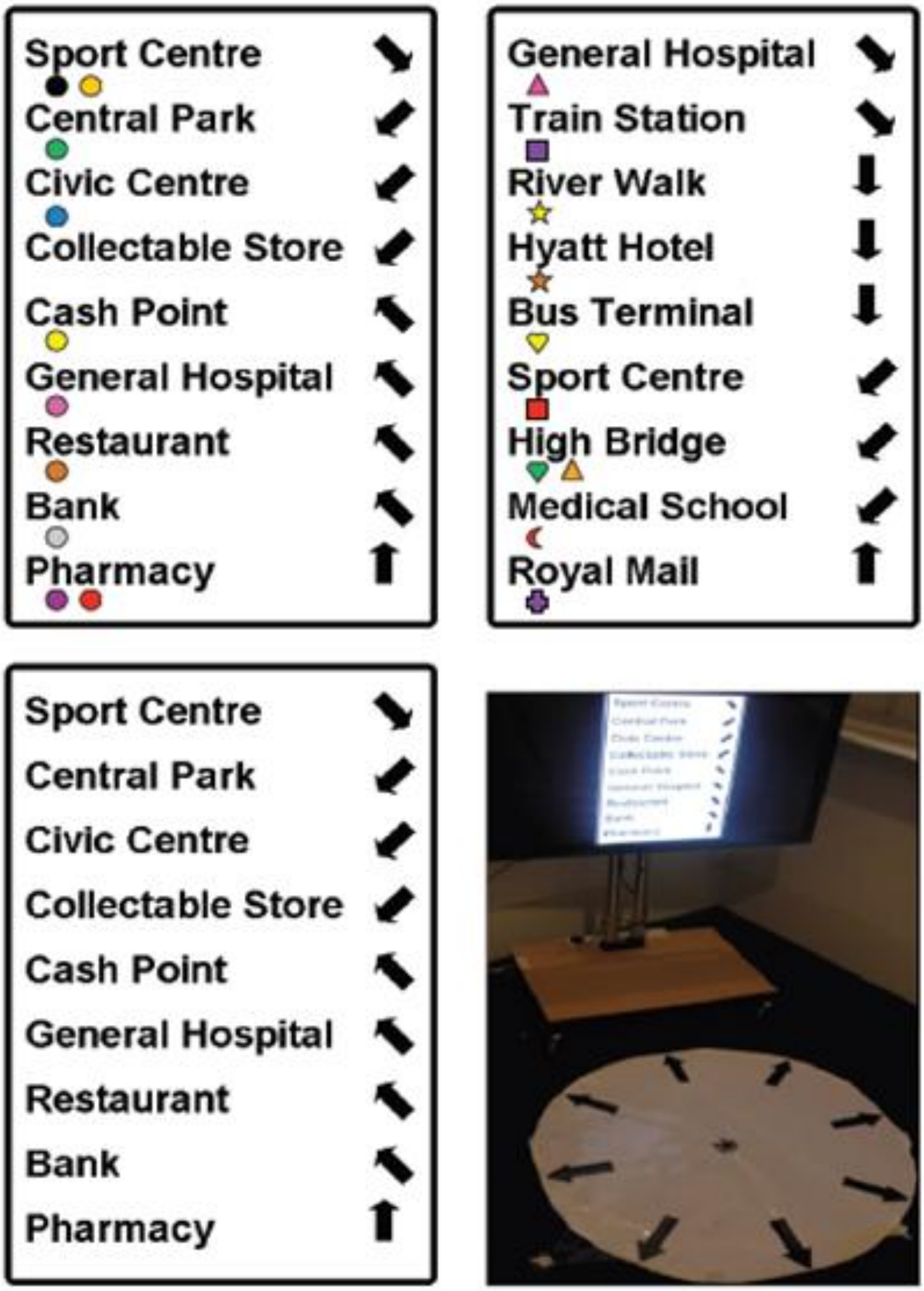

Figure 5-3 Augmented signage designs (top row), base case (bottom left) and study setup (bottom right)

5.2.3 Flow Management

Since flow control and crowd management play an important role in ensuring the safe running of large events, it makes sense to consider augmented signage in combination with spatial partitioning in this context. Even when disregarding dynamic signage (see section 5.5), the approach described above provides some beneficial features to shape the flow of people. Figure 5-4 provides an example illustrating this. The gray areas correspond to streets (which are numbered from one to four) and coloured arrows to routes suggested via augmented signage.

Assuming the destinations corresponding to red, blue and yellow are all located to the North of streets shown, then in principle every person walking along street four from the West could turn into street one. If street one is narrow, this could potentially create congestion.

Using the colour coding it would be possible to control where people would turn. In the example shown, the augmented signage placed at the intersection of street one and four would annotate the North-pointing arrow with red and the East-pointing arrow with blue, yellow and purple. The sign placed at the intersection of street two and four would add a blue annotation for the North-pointing arrow as well as include yellow and purple annotations for the East- pointing arrow. Finally, the augmented signage placed at the intersection of streets three and four would add yellow to the North-pointing arrow while the East-pointing one would solely be annotated with purple.

Therefore, only people following the red colour code would turn at street one, whereas those following blue would turn at street two and those following yellow at street three – thereby distributing the crowd more evenly among streets one to three despite three out of four destinations being located in the same direction.

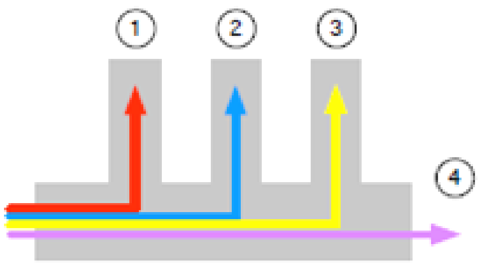

Figure 5-4 Example illustrating flow management using colour coding

It is worth noting that this would be difficult to achieve with standard signage without compromising its regular use as it would require the removal or redirection of some destinations on a number of signs. In the example given in Figure 5-4 a sign placed at the intersection between street one and four would have to align destination names in such a way that only a certain number of people would take street one while the majority of people would keep following street four. Depending on the topology and arrangement of destinations this is likely to result in longer than necessary routes in every day usage (i. e. non-crowded situations) and could also cause confusion as signs no longer direct people along the shortest routes.

5.3 Evaluation

In order to determine whether these designs would be acceptable and to gather feedback from potential end users, we conduct a lab-based study contrasting a base condition with the two designs. More specifically, we were interested in finding answers to the following two questions:

- Can people 'read' the system and use it to infer the right direction reliably and quickly?

- How do the three conditions (arrows only, coloured circles, coloured symbols) compare in terms of task completion time, errors, disorientation events, usability, satisfaction, and workload?

5.3.1 Participants

We recruited 18 participants (9 female and 9 male) from around the Newcastle University. Some of them are employees at Newcastle city and the others were students. They were aged between 22 and 52 years (mean = 35 years). Their background was different (Asia and Africa). We invited them via several ways such as University libraries declarations, student union, and Newcastle societies.

5.3.2 Stimuli

For each of the three conditions, we created 12 signs that each showed between four and nine destinations; for each destination an arrow pointing in one of eight directions was included (cardinal and ordinal directions). In the first condition (Arrow), no augmentation was added to those signs (see Figure 5-3, bottom left).

In the second condition (Colour), the signs were augmented by a number of coloured circles (see Figure 5-3, top left), and in the third condition (Symbol), the signs were augmented with a number of colour symbols (see Figure 5-3, top right). We used nine different colours - Blue, Red, Yellow, Brown, Green, Black, Orange, Gray, and Pink - in condition two and three, and eight different symbols - Circle, Star, Triangle, Moon, Heart, Square, Cross, and Rectangle - in the third condition. We chose those colours and symbols based on how easily they could be distinguished from one another and also based on whether they could be easily verbalised, which we hoped would facilitate remembering of them.

The signs were played back via an automated slideshow that presented each sign for 20 seconds before turning the screen black. The signs were shown on a 50” plasma screen, and participants were instructed to stand at the centre of a circular mat placed in front of the screen. The circular mat had a diameter of one meter and eight marks around the edge to indicate the cardinal and ordinal directions (see Figure 5-3, bottom right).

5.3.3 Procedure

After a brief introduction, each participant first received a short questionnaire that we asked them to fill in to gather some background information. We provided a maximum of ten minutes to do this, and everyone completed it within that timeframe. Next, each participant was exposed to the three conditions we were testing. Each condition consisted of a brief explanation of the task participants had to perform followed by twelve trials. After completing the final condition, participants were asked to fill in another short questionnaire, were debriefed and received a small payment.

Each trial was structured as follows: the experimenter first verbally provided the participant with a target destination or visual code depending on the condition. In the Arrow condition, the experimenter would instruct participants by saying “Your destination is X”, where ‘X’ would be a destination such as “the general hospital” or “the civic centre”. In the Colour and Symbol conditions, the instructions given would be “To get to your destination, you have to follow Y”, where ‘Y’ would be either a colour (e. g. “blue”) or a coloured symbol (e. g. “pink moon”, “yellow square”).

Once participants indicated (verbally, by nodding or via a gesture) that they had understood the instructions, the experimenter triggered the display of the next sign on the plasma screen. Participants then had to scrutinise the sign to determine, in which direction they would have to move to reach the destination they were given beforehand. When they had figured out the direction they should move to, they had to put one of their feet onto the mark around the edge of the circular mat that corresponds to the direction. Once this was done, the experimenter moved on to the next trial by blanking the screen and providing the next instruction. Each sign was shown for a maximum of 20 seconds, after which the screen would go blank automatically. If people did not select a direction within that time, we classified this as a disorientation event.

We recorded all trials on video, and used the footage to take the following measurements: disorientation events (no direction selected within the 20 seconds a sign is displayed), errors (selection of an incorrect direction) and completion time (time from the appearance of a sign until on foot made contact with one of the marks corresponding to the directions.

5.3.4 Results

As part of the initial questionnaire, participants filled in the Santa Barbara Sense of Direction questionnaire. The results revealed an average score of 3.55, which is very similar to the score of 3.6 that Hegarty et al. (2002) reported for their 211 participants.

5.3.4.1 Task completion Time

Figure 5-5 shows a significant difference when analysing the task completion time of the three different conditions. A one-way ANOVA analysis indicates that the average values for the three conditions are significantly different with a p value of 0.001 (<0.01). To find out where the differences are located a post-hoc Tukey test was performed. This indicates that the average time value of 10.80 seconds for the colour condition is significantly different from the average time value of 12.64 seconds for the symbol condition with a P value of 0.001 (<0.01). Similarly the average value of 10.80 for the colour condition is significantly different from the average value of 16.33 seconds for the arrow condition with a P value of 0.001 (<0.01). Also the average time value of 12.64 seconds for the symbol condition is significantly different from the average value of 16.33 seconds for the arrow condition with a P value of 0.001 (<0.01). There is sufficient evidence beyond chance to suggest that the participants used less time to complete tasks when using the colour condition compared to either the Arrow/base or symbol conditions; there is also sufficient evidence beyond chance to suggest that the participant's entire task was completed quicker when using the symbol condition compared to the arrow condition.

Figure 5-5 Average task completion time with confidence intervals

The overall number of error situations in which the participants left the predefined direction and moved in another direction was very low. In total 2 errors occurred when using the symbol condition. No errors at all occurred when using the colour and arrow conditions. Disorientation events were counted when the participants completed in the time determined for each sign which appeared on the screen display. This occurred once when using the symbol condition and never when using the arrow and colour conditions.

5.3.4.2 Usability, Satisfaction, Ease to use, and Ease to learn

The results of the selected questions from the USE questionnaire [58] are depicted in Figure 5-6 which shows the mean results of all participants. A 1-way ANOVA analysis indicates that the average values for the three conditions are significantly different with a P value of 0.001 (<0.01). However, this does not tell us exactly where the differences are between the three conditions. To find out where the differences are located a post-hoc Tukey test was performed. This indicates that the average value of 4.42 for the colour condition is significantly different from the average value of 3.15 for the symbol condition with a P value of 0.001 (<0.01). Similarly the average value of 4.42 for the Colour condition is significantly different from the average value of 2.36 for the arrow condition with a P value of 0.001 (<0.01). Also the average value of 3.15 for the symbol condition is significantly different from the average value of 2.36 for the arrow condition with a P value of 0.001 (<0.01). There is sufficient evidence beyond chance to suggest that participants agreed that the colour condition is significantly better than the symbol or arrow conditions; there is also sufficient evidence beyond chance to suggest that participants agreed that the symbol condition is significantly better than the arrow condition.

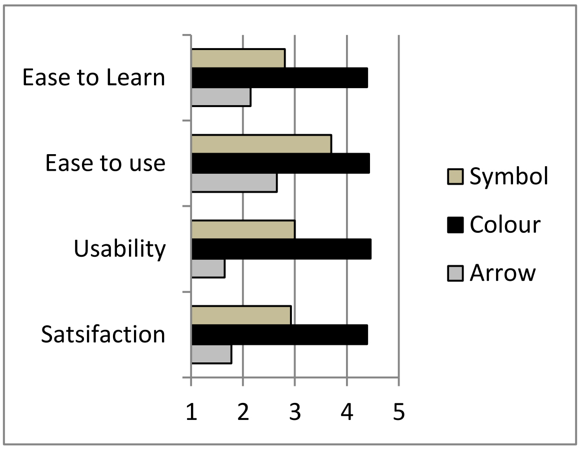

Figure 5-6 Average results regarding USE questionnaire (Scale: 1- strongly disagree, 2 - disagree, 3 neither agree nor disagree, 4 – agree, and 5 – strongly agree)

All questions show significant results favouring the colour condition followed by symbol over the arrow condition.

5.3.4.3 Workload

The results of the selected questions of the NASA Task Index [37] are depicted in Figure 5-7 and show the average results of all participants for each condition for all NASA questionnaires.

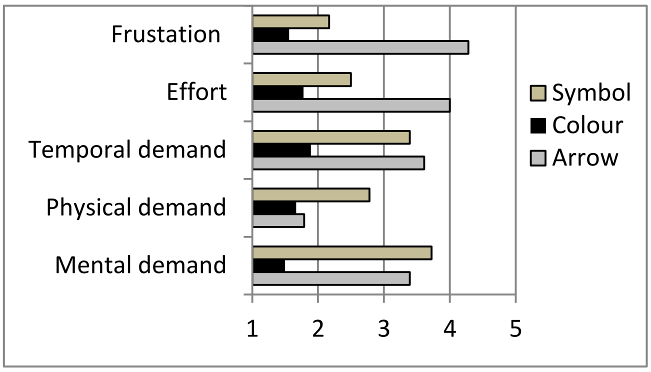

Figure 5-7 average results regarding workload (scale: 1 – very low, 2 – low, 3 – undecided, 4 – high, 5 – very high)

Figure 5-8 shows the median of each condition for the NASA questionnaire. The average value for each condition is just like the median, the arrow condition has the highest average of 3.46 with a standard deviation (SD) of 0.28; the symbol condition has the second highest average value of 2.90 with a SD of 0.37. The colour condition has the lowest average value of 2.13 with a SD of 0.16. The SD shows that for all the three conditions the way the participants rated the colour condition is less varied because this condition has the smallest SD compared to the SDs of both the arrow and the symbol conditions. Also the colour condition has the smallest minimum value and the smallest maximum value. The average and the median values seem to indicate that for the NASA questions the participants agreed more with the colour condition when compared to the arrow and the symbol conditions.

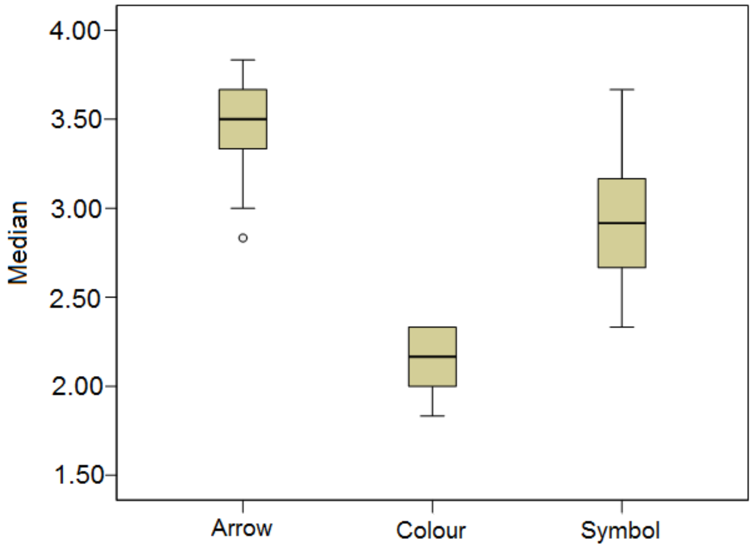

Figure 5-8 Box-plot showing the median for each condition for NASA questionnaire

A one-way ANOVA analysis indicates that the average values for the three condition are significantly different with a P value of 0.001 (<0.01) in the NASA Load Index results. To find out where the differences are located a post-hoc Tukey test was performed. This indicates that the average value of 3.46 for the arrow condition is significantly different from the average value of 2.90 for the symbol condition with a P value of 0.001 (<0.01). Similarly the average value of 3.46 for the arrow condition is significantly different from the average value of 2.13 for the colour condition with a P value of 0.001 (<0.01). Also the average value of 2.13 for the colour condition is significantly different from the average value of 2.90 for the symbol condition with a P value of 0.001 (<0.01). There is sufficient evidence beyond chance to suggest that participants agreed that the colour condition for the NASA questionnaire is significantly better than the arrow or symbol conditions; there is also sufficient evidence beyond chance to suggest that the participant agreed that the symbol condition is significantly better than the arrow condition. Figure 5-9 summarises the average values for each condition.

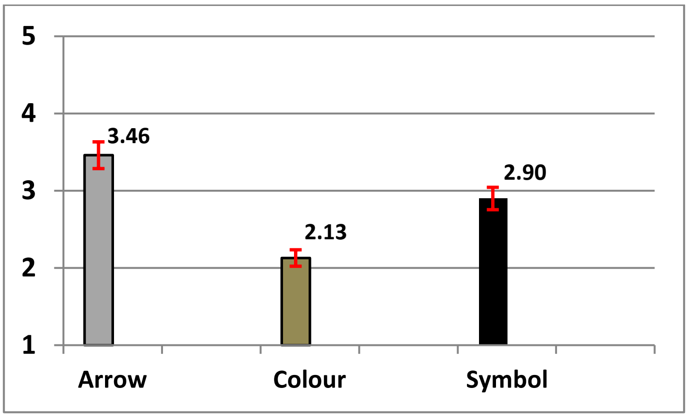

Figure 5-9 presents the overall average values for each condition, scale: 1- very low, 2- low, 3- unsure, 4- agree, and 5- strongly agree.

5.3.4.4 Qualitative feedback

The questionnaire provided several occasions for participants to give feedback through free text responses. One aspect we asked participants to comment on was whether they think it *would be possible to understand and use the system without being given instructions*. Regarding the colour condition, the majority of the users felt positive that the system would be usable with little or no instructions. Whereas their answer relating to the symbol condition was different, they commented that the symbol condition was a little bit complicated because it contains both symbols and colours and as a result users should be provided with instructions to deal with it. The majority of participants argued that users of this condition should use instructions. The second aspect we asked subjects to comment about was *whether they think that installing dynamic displays (such as the one used in the study) in public spaces would improve the experience of pedestrian's navigation systems and allow them to quickly get accurate directions*. The typical comment which was given in response to the colour condition was "the system uses colour as cues to indicate people to their destinations, the idea was very attractive, fun, and easy to use, consequently, this condition will improve pedestrian navigation in public spaces." Concerning the symbols condition the comments revealed "it was fun and includes two kinds of cues (colour and symbols) which helps pedestrians find their personalised information, however the system could be difficult to understand and make people confused, where users need to remember two things; symbols and colours”.

The questionnaire also included open questions about key benefits and drawbacks of the system with both conditions. With regard to the colour condition, subjects frequently mentioned that the ease of use and the clearness of the design as benefits, e.g. “The colours are very obvious and the system easy to use.” and “Use colour as cues to providing personalised information for a large number of people simultaneously it very good idea, where all people can understand it.” (sic). Their comments about the symbol condition were “generally the condition was fun and simple to understand but it requires more concentration from the user than colour condition because there are a lot of coloured symbols which might be difficult to remember while navigating from one place to another”.

Further comments often referred to both conditions: (“both conditions have brought optimum ideas in pedestrians’ navigation situations, key advantages of this novel system were: dynamic signage, colours, and symbols”).

A typical comment was “this system with both conditions will be helpful in navigation system but colour condition is the best” (sic).

5.3.4.5 Video observation

The following results were gathered while analysing both the video (showing the usage of the three conditions by the participants) and by analysing the comments of the participants made whilst filling out the questionnaires.

Pervasive display: More than 85% of participants mentioned how easy it was to use the colour condition. One participant mentioned that it was very easy to follow colours to find the right direction and that it was interesting and fun when using colour. A large percentage of participants’ mentioned that the significant point of this system is that multiple users can interact with it simultaneously and without requiring use of any additional devices (PDA, mobile phones) to interact with the system display. Participants were satisfied even when they used the complex signs (a lot of entries, directional arrows, and concurrent routes).

Participant's behaviour: Most participants were in full attention once they interacted with the screen display, they moved a foot in a particular direction depending on the predefined destination; this was noted in all three conditions. A few of the participants pointed to the screen display with their hands to indicate their destinations, and two participants were observed saying the destination name or the name of the colour.

Arrow condition: Many participants mentioned that they found it necessary to read all entries shown on the sign; seven participants mentioned that they spent a lot of time attempting to find their destinations; particularly with the complex signs (those containing a lot of information). Four participants said that they had issues when the destination was at the end of the sign.

Symbol condition: The majority of participants mentioned that this condition was fun. However, four participants mentioned that they found it a bit difficult to remember two things; a colour and a symbol, particularly when regarding complex signs. Two participants said that some of the different coloured symbols made them confused. As mentioned previously one participant was 'disorientated' and two participants made errors while using this condition.

5.3.4.6 Preference

At the end of the study, the participants were asked to state their best, second best, and the worst condition preference. The results are depicted in Figure 5-10. The resulting score for colour condition was 1.4, 2.2 for Arrow, and 2.7 for Symbol condition. 12 out of the 18 participants (67%) ranked the Colour condition as their favoured condition, 8 out of the 18 participants (44%) ranked the Arrow condition as their third choice, and 9 out of 18 participants (50%) ranked the symbol condition their third condition.

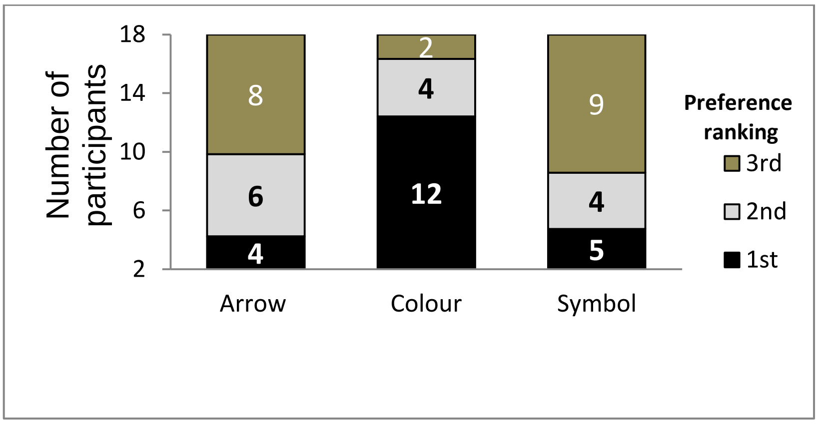

Figure 5-10 preference of Participants

While both systems can support any number of users, their scalability is limited by the number of simultaneous destinations they support. The coloured circle design allows for as many destinations as there are colours, which realistically limit it to about 10 destinations (primary plus secondary colours, less foreground and background colour). It would be difficult for people to remember specific shades of colours or colours that they cannot reliably name.

5.3.4.7 Summary of findings

In order to determine whether the designs for augmented signage conditions would be acceptable and also to gather feedback from potential end users, we conducted a lab-based study contrasting a base condition with the two designs. More specifically, we were interested in finding answers to the following two questions: Can people 'read' the system and use it to infer the right direction reliably and quickly?, How do the three conditions (arrows only, coloured circles, coloured symbols) compare in terms of task completion time, errors, disorientation events, usability, satisfaction, and workload?. The results provided us with some initial insights into whether people can use augmented signage. The results are generally quite encouraging in a number of ways: we recorded very few errors or disorientation events, which indicates that participants were able to use augmented signage conditions (coloured circle and coloured symbol) well.

We recorded all trials on video, and used the footage to take the following measurements:

Disorientation events: were counted when no direction selected with 20 seconds a sign is displayed, overall, we only observed this once during the symbol condition, no disorientation occurred with the Arrow and Colour condition.

Errors: we counted when a participant selected an incorrect direction, only two errors occurred throughout the entire study, both errors observed in the symbol condition.

Timing: both augmented signage conditions (Colour and Symbol) were lower than the non-augmented condition (Arrow). Overall, participants were fastest in the Colour condition (10.80 seconds), followed by Symbol condition (12.64 seconds), with the Arrow condition being the slowest one (16.33 seconds).

Workload: The combined NASA (TLX) scores for the different conditions were as follows: the Arrow condition has the highest average of 3.46, the Symbol condition has the second highest average value of 2.90, and the Colour condition has the lowest average. Perceived task load was thus highest for the Arrow condition, lowest for the Colour condition and second lowest for the Symbol condition.

Usability, Satisfaction, Ease to use, and Learnability: the results of the selected questions from USE questionnaire showed that of all categories the colour condition is rated best followed by the Symbol condition, whereas the Arrow condition is consistently rated lowest. This indicates that participants found the Colour condition to be the easiest to learn and use, and also rated it best in terms of usability and satisfaction. The Symbol condition was rated second best in all four conditions, and the Arrow condition worst (attracting particularly low scores in the usability and satisfaction categories).

Preference: The colour condition was clearly the most favoured one, while the Arrow and symbol condition tied in the second place. It is worth noting that the few errors and disorientation events we recorded during the study occurred only in the symbol condition (state them), despite the workload being rated lower than the Arrow condition.

The outcomes of this study provided initial evidence that augmented signage can be used successfully with little training and without incurring large penalties in terms of delays, workload, errors or disorientation. In general, the colour-only condition was preferred followed by the coloured-symbol condition, which supports a considerably larger number of concurrent destinations. The base case (text and arrow only) was consistently rated lowest in almost all tests. We also reviewed the potential of our approach in terms of managing people flow, and discussed different ways to improve and expand the system. In addition, compared to existing systems, the proposed approach offers a number of benefits. It does not require users to carry a mobile device, it works well with static signage, and it maintains the original purpose/function of the signs. The use of colours and/or symbols also makes the system accessible to people, who do not speak the local language or who cannot read at all.

5.4 Discussion and reflection

While the study provides some initial insights into whether people can use augmented signage, there are some shortcomings that limit the generality of the results we obtained. One of these issues relates to the lack of realism: while participants had to physically move to select a direction, this movement was very small compared to the amount of walking that would be required if the system was deployed in the real world. Related to this is the lack of crowdedness, which is hard to emulate in the lab. Finally, we varied the overall complexity of the sign within very narrow boundaries (i. e. between five and nine items per sign), whereas in the real world, sign complexity could vary more widely, e. g. in terms of the layout, number of items and directional indicators being used.

While a real-world test with an actual deployment would overcome these issues, there are some considerable safety implications that this would incur. A more realistic simulation environment [80] could thus be a sensible intermediate step.

Nevertheless, the results are generally quite encouraging in a number of ways: we recorded very few errors or disorientation events, which indicates that participants were able to use the augmented signage well. Completion times for both augmented signage conditions were lower than for the non-augmented case, and the ratings in the different USE categories were also higher. The same is true for the workload, which was lower for augmented signage than it was for non-augmented signage. In general, the Colour condition scored higher than the Symbol condition in all these tests. In terms of overall preference, the Colour condition was clearly the most favoured one; in this case, the Arrow and the Symbol condition tied in second place. It is worth noting that the few errors and disorientation events we recorded during the study occurred only in the symbol condition, despite the workload being rated lower than the Arrow condition.

Considering the limitations of existing systems (mentioned in Chapter 2) and the requirements identified in section 5.3, the proposed approach offers some benefits. It does not require users to carry a mobile device, it works well with static signage, and it keeps the original purpose/function of the signs. The use of colours and/or symbols also makes the system accessible to people, who do not speak the local language or who cannot read at all. The study outcomes provide initial evidence that augmented signage is usable, easy to learn and enjoyable without incurring large penalties in terms of usage time, error rates or disorientation events.

While both augmented signage designs can provide personalised directions to any number of users, their scalability is limited by the number of simultaneous destinations they support. The coloured circle design allows for as many destinations as there are colours, which realistically limits it to about ten destinations (primary plus secondary colours, leaving out the background colour), as it would be difficult for people to remember specific shades of colours or colours that they cannot reliably name. The coloured symbol design significantly extends the number of simultaneous destinations, effectively multiplying it by the number of symbols used - we used eight symbols and nine colours in the study reported above, resulting in up to 72 concurrent destinations. However, to display that many destinations on a single sign, it would be necessary to rotate through them. If they were all displayed simultaneously, individual symbols might be too small to be recognised well. In order to further increase the number of destinations, hierarchical approaches or multi-colour codes could be used, which would most likely have an impact on usability.

Using dynamic augmented signage cannot only help with scalability; it can also provide a means of assigning visual codes to groups of people, e. g. by cycling through them over time so that passers-by pick up codes depending on when they walk past the sign. In addition, dynamic signage would enable real-time adaptations, which would be beneficial in terms of responding to changes in the environment or crowd behaviour. For example, the size of target areas could be adjusted dynamically in response to how many people are assigned to it. Combining dynamic displays with various sensors (e. g. flow rate sensors, people counters, presence sensors) could potentially fully automate this process. Another interesting option would be to combine the two augmented signage designs presented in section 5.3. By collocating all destinations corresponding to a particular colour, signage could be augmented hierarchically: signs outside the area corresponding to a specific colour only include colour codes, not symbols for that colour. Signs inside an area corresponding to a colour do include symbols for that colour. This would simplify the signs without reducing the number of addressable destinations, and would also account for people's overall preference of the Colour condition by minimizing their exposure to the coloured symbols.

5.5 Chapter Summary

In this chapter, we presented the design and evaluation of a novel approach via dynamic signage for pedestrian navigation. Our system includes three conditions, in the Arrow condition, signage shows the a number of entries and a number of directions, while in the Colour condition it shows a number of entries and a number of directional arrows supported by a number of coloured circles (concurrent routes). In the third condition signs show entries and directional arrows, and a number of coloured symbols. The circle which is drawn on the floor was used to indicate and help us to measure the terms of task completion time, disorientation event, and errors. This system was compared in a user study with approaches finding destinations via dynamic display in the three different conditions. The study conducted was a lab-based user study. The results provide clear evidence of the advantages of colour for provision of information and improving the pedestrian's navigation system. This has increased our understanding that colours could be helpful to people especially those who meet in crowded places with different cultures and languages, e.g. Mecca area, the place where Muslim people meet every year. The next chapter will present how dynamic displays can help pilgrims to find each other in crowded areas in Mecca's Haram. As we understood the importance of using a colour coding technique in pedestrian navigation, we therefore decided to use colour and symbols with dynamic and static signs to solve pilgrims issue and reduce the crowds in Mecca.

Chapter Six

Case study 3

Using augmented signage to reunify groups in densely crowded environments

6. Case study 3: Using augmented signage to reunify groups in densely crowded environments

6.1 Introduction

As mentioned in Chapter 4, Mecca city is the place where Muslim people meet every year to perform a big event called Hajj. A large number of people from different countries travel to this city in Saudi Arabia to attend this event. During their stay, they perform a number of rites in and around the city. In Chapter Four we attempted to solve one of pilgrims' issues of losing count of Tawaf rounds, "Case study1". We analysed the current situation in Mecca based on a literature review and a series of interviews with pilgrims who had at Mecca before. We then present a prototypical dynamic signage /static signs and report on a user study we conducted in a realistic setting in order to evaluate the system.

In this chapter, we investigate the questions of whether the use of augmented displays (static and dynamic) can support pilgrims find each other inside Mecca's Haram and regroup them after becoming separated, and the question of do pilgrims can understand the displays content and able to extract their personalised information in crowded situation inside the Haram. As we explained in chapter four, all previous systems were not feasible in the Mecca situation where the area of Mecca has special properties and constraints such as: all places in the Haram look the same, a large number of heterogonous people meet in a limited space. To address these aspects and to provide a system that large numbers of people can use simultaneously to get personalised information to support them find each other after becoming separated, we are investigating the use of augmented displays (dynamic and static signs) as a means of delivering this type of information. The system proposed consists of two conditions: dots and symbols, which we augment with additional information to enable users to extract personalised information. As an added benefit, the approach provides a means of influencing the flow of people through Mecca's Haram area. We also report on a user study we conducted to investigate our different designs for augmented displays for pilgrim support. We compared the two conditions in terms of task completion time, errors, disorientation events, usability, satisfaction, and workload. Two groups of people took part in the study (pilgrimage group: who had made the pilgrimage before and non-pilgrimage: who had not visited Mecca before).

In addition, we discuss what the experimental results mean, whether the hypothesis has been supported or disconfirmed. Our hypothesis is that all participants (pilgrimage and non-pilgrimage groups) can understand the displays and are able to extract their personalised information while interacting with the dot condition. While in the symbol condition we assume that the pilgrimage group will be more confident than *i*n the dot condition. In general, the results suggested that public display signage may be a feasible option to help people find each other after becoming separated in Mecca. The structure of this chapter is a brief introduction to the issues associated with the Hajj, particularly people losing each other whilst performing their pilgrimage duties (e.g. the Tawaf rite). We then present in detail the interview sessions we have done, e.g. how, who, when, and where we performed these interviews, and the interview results these will be presented in section 6.2. This is followed by the design approach section (6.3). In this section we describe the initial system design, i.e. introduce the system conditions (Dot and Symbol) and give some details about each condition, and then we mention that the initial system design has been built based on the suggestions and comments of the interviews, all that will presented in initial design system (6.3.1). The second subsection (6.3.2) gives details of the focus group: who, where, how, and suggestions/comments regarding the two conditions (Dot and Symbol). The system design subsection (6.3.3) is concerned with the final system design; this subsection gives detailed descriptions of how the initial design was redesigned based on focus group comments and suggestions and how the final system works to support pilgrims find each other in a crowded setting. Section (6.4) provides details of the study evaluation: user study, participants, aim of the study, study procedure, and the study results. In the discussion and reflection section (6.5) we discuss the significant aspects of the results and other aspects such as the issues related to the lack of realism and this is followed by the issue related to this, the lack of crowdedness. The final section is the summary chapter (6.6), in this section we introduced the important points that we discovered about properties, issues, and significant results that we obtained.

6.2 Preliminary Interviews

To gain information about the environment in Mecca, we organised a series of interview sessions with people who had experience regarding that situation. Basically, previously when we collected information about Mecca relevant to our first study which was mentioned in Chapter 4 we had more two session interviews. People who were participants in those sessions provided us with a lot of information regarding the issues faced by pilgrims while performing their duties. They argued that one of the main issues is: people forget how many rounds they have completed whilst performing the Tawaf pillar. They should walk seven times around the Ka'bah. The second issue is that people lose each other during Tawaf and Saai pillars. The information we gathered from previous sessions was important and useful, however we organised another series of interview sessions with different people to increase our understanding about second issue "*pilgrims are losing each other at Mecca while performing Tawaf and Saai".*

6.2.1 Participants

15 people (6 Female and 9 Male) have been interviewed to gather more information about the issue that the majority of pilgrims suffer from. People who were interviewed were both male and female, they were from different countries and different cultures, their nationalities are: Arab, Pakistan, Mulish, Indian, and Indonesian. Some of them were students at Newcastle University and some were employees in Newcastle city. Many means were used to invite those participants to interview: sending emails via Islamic societies, posters at Mosques and the Saudi Arab Islamic club centre. The interviews took place in two places; Newcastle University Mosque and the Saudi Arab Islamic club centre. All of them had been pilgrims before. We asked them some questions about the situation in Mecca in general and specifically about issues of pilgrimage. They explained to us how they perform pillars of the Hajj, how they navigate between places, what techniques they currently use to find each other in crowded places, and they mentioned so much about the confusion, stress, and feeling nervous while they perform the Tawaf rite. In order to understand the issue from another point of view, we interviewed 5 people (all of them male) who had not visited Mecca before. Their experience was limited to conversation with some relatives who had performed a pilgrimage before. Basically, they provided us some information about the issue and how people overcome it by using several traditional approaches.

In general, we have adequate information relevant to issues of pilgrimage. Through the interviews we have done (i.e. previous interviews in the first study and the two interviews (pilgrims and non-pilgrims) which were done in this study) we concluded that all the results that we gathered were the same and the common result is that people have two issues which affect them in Hajj: the issue of counting rounds during Tawaf which was addressed by the section on the Tawaf system (Chapter 4) and the second issue is that people have difficulty in finding each other after becoming separated at Mecca while doing Tawaf. Detailed results will be presented later. In total we have interviewed 20 people, male and female, aged between 25 and 56 years, fifteen of them had completed pilgrimage before, the other 5 people had not been there but they did know someone who had undertaken a pilgrimage before.

In our interviews we used a semi-structured interview method, this method is appropriate in this context. The most important advantage of this method is that it allows the interviewer to pose any question that comes into mind during the interview. This option is not available in other interviews methods. As we mentioned in many different places of this thesis in order for us to investigate an especial environment we needed to know as much as possible about it. All our interviews in this study have taken place at Islamic societies and Mosques of Newcastle city. Participants mentioned a lot of negative aspects regarding the situation of pilgrims while performing Hajj pillars such as poor means of navigation, people were not able to move between places easily, and that human guides were not enough to provide help to pilgrims. They believed that people becoming separated in crowds and not being able to meet again is one of the main issues that they suffer from while performing the Tawaf rite for example. In fact we focused on this issue, and we asked them some specific questions relevant to this particular problem. Then we started to ask them how they are able to find each other in the Haram, and what methods they use to do that. Actually, they mentioned to us some ways that they use, e.g. groups of people agreed to meet in particular place (say door X), this agreement would be made before they enter into the Haram. Unfortunately, they found that when they lost each other it was difficult to meet in that place (door X) because all the doors are similar and it was hard to distinguish between them.

A further way that pilgrims can try to stay together is by holding onto each other and walking as a group. e.g. a man and his wife should hold onto each other and walk together. However, pilgrims find it difficult to complete all rounds in this way, some participants argued that this way could be useful for one or two rounds but then they would tend to split, also this way is not suitable for a group (5 or 6 people). Another strategy they agreed on was that if they lost each other, one continues to walk and they would finally meet back at their accommodation. However, some pilgrims are unable to go back to their accommodation alone.

6.2.2 Evidenced examples

Based on our interviews, we extracted some examples as evidence that the majority of pilgrims face this issue. Also examples are used to illustrate how pilgrims feel while doing Hajj pillars. One participant said "I was alone walking around the Ka'bah doing Tawaf and I saw an old man sitting beside Maqam Ibrahim, who was trying to talk to people but everyone ignored him. When I completed my Tawaf I went back to him and asked 'Are you lost?' He said 'Yes I lost my group three hours ago.' I said 'Do you know your accommodation address?' He said 'No'. I took him to centre (where people try to help people find each other). After three days I went back to that centre to ask about him, they informed me that they had reunited him with his group that morning. This means, the old man stayed away from his group for more than three days".

A further participant stated that, "someone informed me that while praying inside the Haram with his wife, suddenly he felt something like a strong wind and after that he could not find his wife. He looked right and left but with no success, so he asked the police, 'How can I find my wife?' The police suggested to him to try to find her randomly here and there, if he did not find her she might be back at home. He knew that his wife would be unable to travel back home alone, so he stayed searching for her in the Haram all day with no luck. He felt so bad, and thought that he would never find her. He went back home at midnight and found her there, his friend's wife had found her somewhere inside the Haram and brought her to their accommodation".

Another example provided by a participant, is that it is very important to perform hajj rituals with other people as a group, with friends or any other relatives, the advantages of that is that groups can help to remember each other's rounds of Tawaf, Saai times, they can also share enjoyment, and look after each other. It is a big risk if someone loses a friend or wife in this situation where they intended to stay together all day;

some people are unable to continue to perform hajj rituals if they have lost one of their relatives or a member of the group. Some pilgrims decided to perform Tawaf rounds with some people who have completed a pilgrimage before, to guide them. However, this leader could disappear at any time. Based on this situation the issue of people becoming separated should be solved by attempting to find an ideal solution.

6.2.3 Results

According to what the interviewees mentioned and information from other sources, we have constructed an initial idea about the situation in Mecca in several terms such as: methods that pilgrims use to find each other, an idea about the paths / corridors that people use them to enter into Haram and exit from it, and other important information about the Haram environment. Furthermore, through those interviews with people we have extracted some ideas which could help us to build an initial system for this issue. Comments and suggestions of interviews are depicted in table (6-1).

Table 6-1 shows the interviews comments and suggestions

Interview participants	Comments and suggestions
17 out of 20 participants (85%) argued that	There is not any technology in navigation used to indicate people to the right direction. People find it difficult to navigate from one place to another. Also, there are not any particular systems to guide people and let them know about the pillars of Hajj such as places and start points.
19 out of 20 participants (95%) mentioned that	The ways that people use to stay together through their Tawaf rites or other rituals are very poor and not useful, as many pilgrims have tried them. Unsuccessfully.
10 out of 20 Participants (50%) commented that	Negative aspects such as crowdedness, stress, and confusion made it easy for people to lose each other, especially inside the Haram.
20 out 20 participants (100 %) explained that	There are a lot of gates / doors around the Haram, pilgrims use them to enter and exit, each door/gate has a name. However, those doors all look the same.
All participants (100%) stated that	The common way they use to remain together while they are inside the Haram is to hire someone to guide them and indicate to them the right direction. However, this leader might disappear at any time.
All participants (100%) confirmed that	The area of Haram is difficult to understand, as many columns, doors and places are very similar and people are easily lost at any time, some pilgrims think that they agreed to meet at particular column of door but they never meet because all of the columns look the same.

All participants (100%) claimed that	A person may find it difficult to move inside the Haram alone, especially for those people who are attending Mecca for the first time, because no means are available to guide them in the right direction such as the exit or any other places, they could ask other people but usually no one has time to answer questions.
18 of 20 participants (90%) emphasised that	No clear signs are installed inside the Haram, some signs exist outside the Haram and all of them are written in Arabic or English which is not understandable to other pilgrims who are not Arab or do not understand the English language. Consequently people ignore them.
13 out of 20 participants (65%) argued that	All traditional ways used to deal with the Haram environment to perform rituals or move around the Ka'bah are increasing the crowds.
16 out of 20 participants (80%) commented that	They think that installing displays may help people perform their duties in safety and in peace.
5 out of 20 participants (25%) mentioned	A lot of stories which occurred for people while doing their hajj rituals. Those stories are about how and where pilgrims lose each other. These examples were presented in the evidenced example section.
All participants (100%) explained in detail about	Mecca's properties and constraints (e.g. different culture, language, hajj conditions). They also mentioned about the environment in Mecca (e.g. that there are many similar places, limited space, and a lack of navigation information).
All participants (100%) believed that	Mobile phones are not useful inside the Haram, they said that it is difficult to use for many reasons (e.g. the place is very noisy and hard to hear the output of them).

From the comments, suggestions, and information that we gathered from the people who we interviewed, we obtained a complete idea about Mecca's Haram structure (area of Tawaf, gates and corridors), and the properties and constraints of Mecca, i.e. a large number of people with different cultures and languages. Afterwards, we started designing an initial system which considered all the information that was obtained and discussed through the interviews sessions. The next section gives full details of the initial system design.

6.3 Design approach

After gathering a lot of information and ideas about the situation in Mecca, from interviews, we then designed an initial system that might be able to provide help for pilgrims to find each other in crowded places at Mecca's Haram. Our initial system has been presented in the focus groups session to get feedback in order to improve the system. Focus groups' participants provided us with significant comments and important suggestions and ideas which helped us to redesign the system to be more useful and effective. When we felt that the system included the basic requirements, then we evaluated the final design through a lab-based study in a simulated environment.

6.3.1 Initial design description

In order to design the initial system we have taken into account all the considerations that we have gathered from the interviews. Based on the facts which indicate that the Mecca area structure is already divided into eight sectors (wedges), (see Figure 6-4), each wedge has a corridor which pilgrims use to enter into the Haram and exit from it. Therefore we used eight colours and considered that each wedge represents a particular colour.

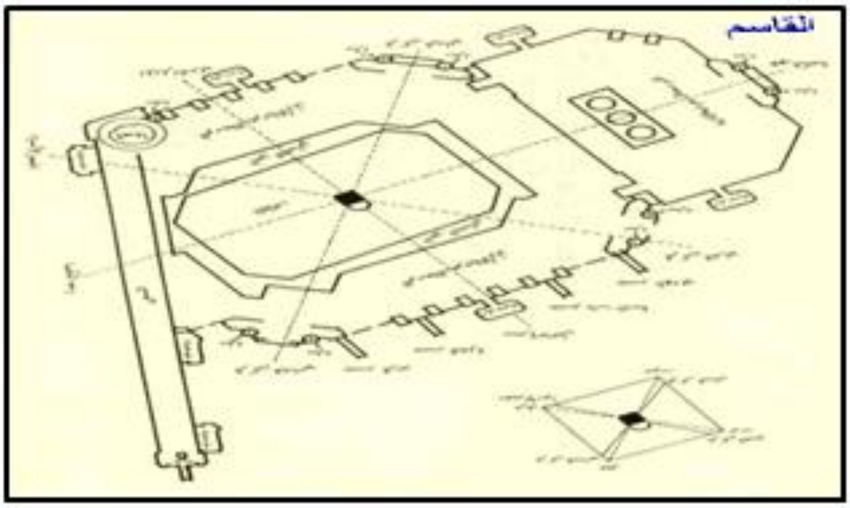

Figure 6-1 the layout of Mecca's Haram structure (eight wedges) [78]

The initial system consists of a dynamic display which is installed at each gate, a large static sign which is placed at the beginning of each corridor from the Ka'bah side, and a number of static signs distributed throughout each corridor. We proposed two options which can be shown via public displays: dots and symbols. Figure 6-2 shows some examples of them. As mentioned before pilgrims attend from different cultures, languages and backgrounds, therefore we proposed the colours / symbols as common factors that all human beings can understand regardless of their culture and languages.

Dynamic display proposed

Dynamic displays are intended to be displayed at gates (i.e. each gate will be included a dynamic signage). Pilgrims will read this while passing a gate into the Haram to perform their rituals (e.g. Tawaf) and memorise the background colour and a number of dots/symbols shown on the display at that moment.

Dots condition: We proposed eight dots, so eight signs will show on the screen display, each sign will remain shown for 30 seconds (30 seconds is initial proposed time, it might update based on gates situations, e.g. crowds) and then disappear, the first sign will show one dot on a particular background. Then the dot incremented by 1, once the number of dots reaches 8, and then a new background colour will appear with one dot shown on it again and so on until dots have been shown on all backgrounds we proposed. Figure 6-2 shows some signs of the dots condition. For example, Figure 6-2 (a) shows the one dot on blue background, this sign will stay for 30 seconds and then disappear, then two dots appear on the same background (see figure 6-2 (b)), once the number of dots reaches to 8 then new background appears and so on until 8 backgrounds have appeared.

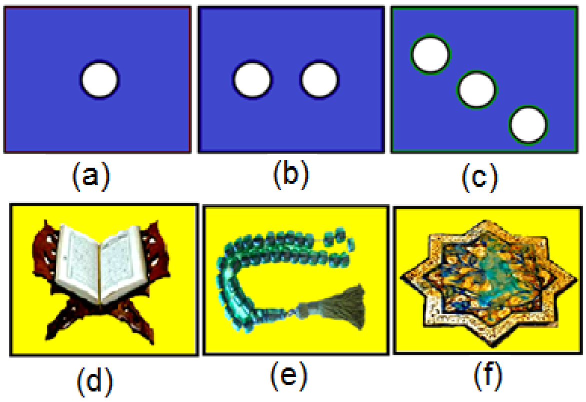

Figure 6-2 show one example of each condition (dots and symbols)

Symbols condition: in this approach we will use symbols instead of the dots that we used in dots condition (i.e. some Islamic symbols are used to show on the coloured backgrounds), each sign shows a symbol on a coloured background then another symbol and so on. Suggested symbols are: Mecca, Quran, Rosary, Prayer carpet, Menber, etc. Figure 6-2 (d) shows Quran image on the yellow background, Rosary on yellow background see (e), and Islamic star shown on yellow background in (f). So this background will show 8 symbols, then a new background will appear and another 8 symbols will show on it and so on. Figure 6-3 illustrates how pilgrims deal with the dynamic display which is placed at each gate of the Haram while passing it.

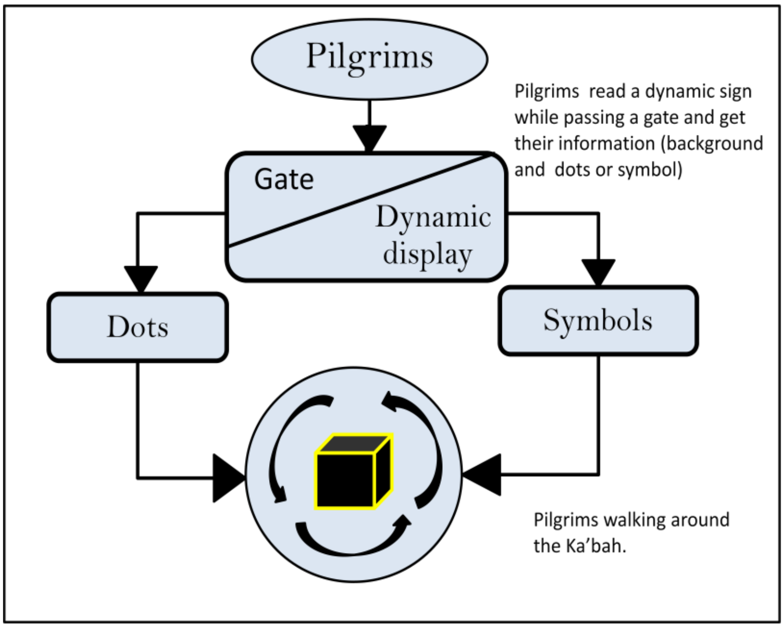

Figure 6-3 people read the dynamic sign located at a gate.

Firstly, pilgrims will read a dynamic display which placed at a gate and identify a colour (background) and dots or symbol that are shown on a screen display while passing through a gate. Groups, family, friends, or relatives should all memorise the same information (e.g. 'blue and 5 dots' or 'yellow and Ka'bah image'). As they will use this information later once they deal with static signs. Secondly, pilgrims start doing their rituals inside the Haram and at the same time they keep in mind the information they gathered from the dynamic display (at a gate), after they have completed their tasks (e.g. Tawaf) they have to find static signs which are placed at the beginning of each corridor. Here we have to identify the second part of our system, it is static signs and how pilgrims can deal with them by using the memorised information.

Static signs proposed

Two types of static signs have been proposed: the first type is a huge sign which will be placed at the beginning of each wedge to indicate to pilgrims about their wedge, each static sign will be divided into two parts, the upper part will show the wedge colour (background), and the lower part will be divided into 8 rectangles, each rectangle in a particular colour and associated by directional arrow, excepting the colour which is indicated as the current wedge, (illustrated in Figure 6-5).

These kinds of signs will help people to know where their wedges are, so pilgrims will find those signs at the beginning of each wedge/path/corridor.

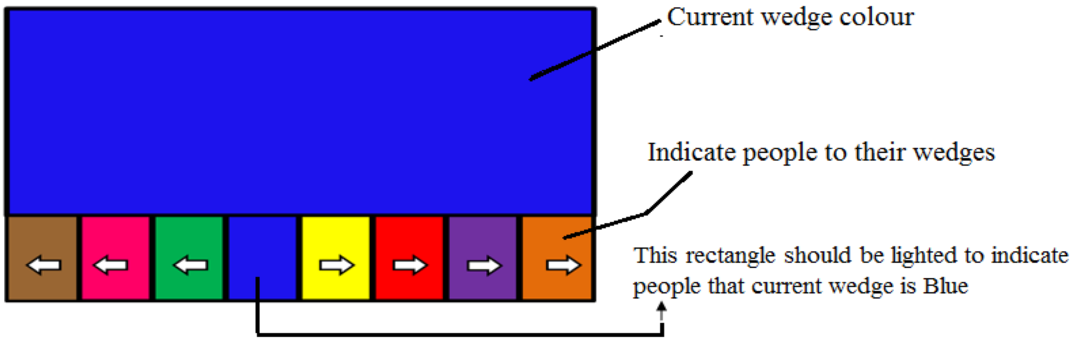

Figure 6-4 the static sign which will be installed at the beginning of each wedge from Mecca side (Blue wedge)

The second type of static sign is a number of signs distributed in corridors (the existing columns in a corridor might be used to mount them), each static sign will be divided into two parts, the upper part will show the background colour and a number of dots or one of the symbols, and the lower part will be divided into 8 rectangles, each rectangle has particular colour, some of them associated by directional arrow to indicate people in the right direction. Once a person has found a sign which includes the same information that he/she has memorised then they have to wait in that place until his/her relative comes and meet at that point.

Figure 6-6 shows how people move to the corridor after they have completed their rituals around the Ka'bah. Pilgrims try to find their wedge by using a static sign which available at the beginning of each corridor from Ka'bah side.

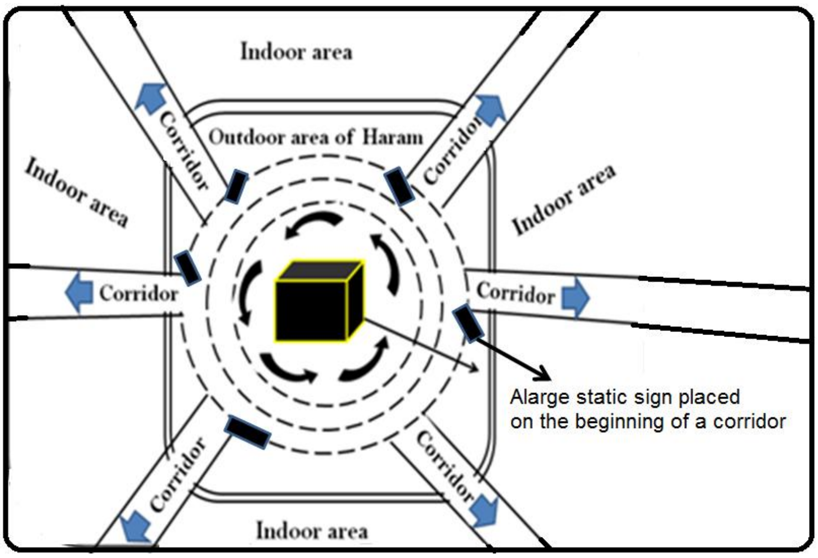

Figure 6-5 Layout of indoor and outdoor of Haram and static sign in the beginning of each corridor

The second step; once a pilgrim has identified his corridor by colour, then he/she should enter into that corridor and walk until they find a static sign which contains their exact information (colour and dots/symbols). Once they have found this, they should wait until their friends arrive, meeting points are shown in Figure 6-6.

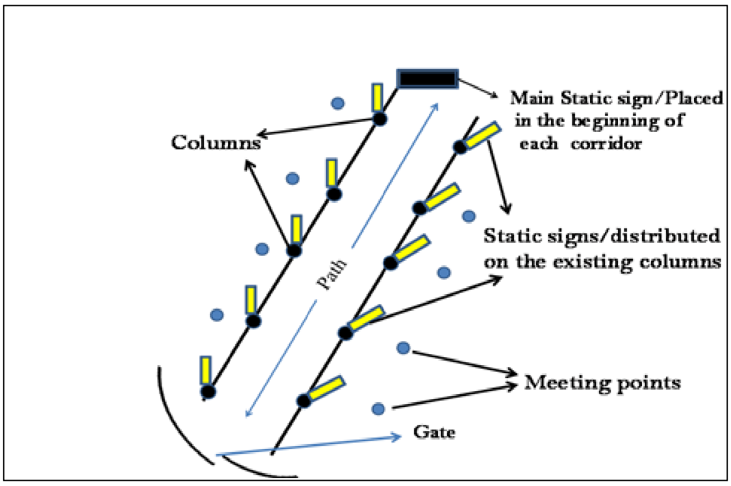

Figure 6-6 Layout of a corridor involving static signs and meeting points

So, Figure 6-6 shows the layout of a corridor structure and how static signs and meeting points are distributed in it. For example, a person deals with a large sign: once he or she has found a sign, they have already memorised their information background colour and dots/symbol. A sign is divided into parts: the upper part refers to the current wedge colour and the lower part is also divided into 8 colours (stated above) each colour is associated with a directional arrow to indicate people to their wedges. So a person should try to find a sign and try to find his/her colour on it. Once they have found the colour they looking for then they should enter into that corridor and try to find their information (number of dots / symbol and coloured background). So, that was the initial idea which built based on the interviews comments and suggestions. After that we presented the initial system on the focus group sessions to gain feedback about. Next section describes the focus group case.

6.3.2 Focus group and initial design

In order to gather feedback and more information about the system and how it can help in Mecca conditions, we decided that we should present our initial design to people who have experience of Mecca and discuss with them several aspects which could help us improve our system design in "focus group sessions".

6.3.2.1 Participants

Twelve people have been invited to this session (5 female and 7 male) from different nationalities: (Malaysia, India, Egypt, Pakistan, and Saudi Arabia). All focus group members had completed a pilgrimage before; three of them had been on a pilgrimage more than once. Some of the focus groups members were working at Newcastle city and the other were students at the Universities: Newcastle, Sunderland, and Durham. We invited them by sending emails via Islamic societies and posters at Newcastle Mosques.

This session took place at the Islamic society centre in Newcastle city. We started the session by saying "Good afternoon, thank you for taking the time to meet with us". We asked them if anyone would mind if we tape recorded the session for our records. Nobody had a problem with this. We mentioned that our primary point is to gather information about issues that face pilgrims at Mecca when they perform pillars of Hajj. This information will help us to design a suitable system that could solve the pilgrim's issues. In addition, we informed them that all the information we collect is confidential. For example, we will not disclose who actually participated in this focus group nor will our final report make any attributions for quotes. We hoped that this would encourage participants to speak freely. We offered the participants an opportunity to ask any questions before we started.

6.3.2.2 Focus group sessions

In the beginning we mentioned to them about the purposes of our study and why we had undertaken it. We provided a brief introduction regarding public displays and how today maybe providing information about users locations could help them move between places. We provided them with some examples about the technology and how mobile guides and augmented displays developed and provided navigation information for pedestrians in different settings. Based on that, they asked us many questions relevant to the technology used in pedestrian navigation. Then we started the session by asking them questions, as following:

The first question was "*could you please tell us about the issues that face pilgrims once they perform pillars of Hajj*?" They answered: there are a lot of issues facing pilgrims, the main problem faced by people is Tawaf pillar rounds (pilgrims find it difficult to remember / count Tawaf rounds), they mentioned this problem in detail, all the points they mentioned here we knew about as they are similar to those we addressed in looking at the Tawaf system (Chapter 4). Then they said that another big problem for pilgrims is losing each other once they have performed Tawaf around, Saai, Zamzem place, and Arafat Mountain. They mentioned that the pilgrims suffering from this problem lose contact with their groups such as relatives, friends, wives, or other group members.

Based on that we asked them question "*Does this problem occur only in the Haram around Ka'bah or there are other places*? If so, *could you please tell us in which places pilgrims could lose each other*?"

The answers suggest that there are many places people could lose each other, including, Mecca's Haram such as the Saai area, Tawaf area, and Zamzem place. Also people could lose each other at the Arafat Mountain (outside of Mecca area). But they stressed that the Ka'bah area is significantly crowded and many people lose each other in there. Then we asked them "*how can pilgrims can overcome this problem and* *find each other in such situations? i.e. what are the ways / methods pilgrims use to find each other*?" The answers revealed that there are many gates for people to use to enter into the Mecca's Haram. Each gate has special name pasted on it. For example, Salaam gate, King Abdul-Aziz gate, etc. So one of the methods pilgrims use is, before entering the Haram, they make an agreement that if they lose each other then they will meet at King Abdul-Aziz gate for example. However, pilgrims may find it hard to find that gate because all the areas look like similar and it is difficult to recognize a particular gate.

A further way pilgrims can overcome this problem is when a group agree that if they get lost then will then meet at their accommodation. Participants mentioned that this way has several disadvantages, such as some pilgrims are not able to read signs and are unable to ask other people to find help because they do not speak the same language. They added, some people are able to go back to their accommodation alone but this also causes a minor problem (i.e. pilgrims as a group need to help each other, e.g., remind each other of some things such as: prayer time, important places, discuss some rites, enjoy time together). So if they lost each other then they would feel sad and worried and this is could impact on their Hajj rites.

Another way deal with this issue is that there are many people who work inside the crowded area, and their job is help people who are lost, for example when they find any lost person they try to get him/her to a particular office and ask them some questions and try to take them to their accommodations. However, these people often cannot understand them because sometimes they speak a different language.

Then we asked them the following question "*Could you please give us some examples which illustrate how pilgrims suffer from these issues*? i.e. *did you have a problem such as this or do you know someone who has experience in this issue*?" They have mentioned a lot of examples about how pilgrims suffer from this issue. An important example that one participant mentioned is "There were two people, a man and his wife. While they doing the Tawaf pillar the man lost his wife and he tried to find her but with no success. He thought that he would never find her. That man suffered from diabetes and after one hour he collapsed and ended up spending one day in hospital. Regarding his wife, the police found her after 5 hours and took her to her accommodation. She was lucky because the police understood her and she was able to remember her accommodation address". Another story mentioned an old man who, while performing Tawaf with his group looked and suddenly he could not find his group, he asked police for help but they did not understand what he looking for, furthermore he could not remember his accommodation address, so the police could not help him so he stayed in the Haram for two days, after that his group found him by coincidence somewhere around Ka'bah. They added that the main problem is people do not have a common language, so some people could not understand information on signs, could not ask police, or could not remember their address. People also ask police for help when they have lost each other, this method has many drawbacks such as police members can come from other cities and therefore they do not have full information about those crowded area (e.g. gates names). Some of them understand the area but they could not understand a person's language (usually police speak one language (Arabic), a few police understand English).

One participant informed us that he was in hajj with his friend, he said "before we started Tawaf we agreed that we will meet beside main door of Zamzem if we got lost, in the third round I lost him, after I completed Tawaf rounds I walked to the Zamzem gate, unfortunately I did not find him, I stayed there for about 2 hours and after that I went back to my hotel. I did not find him there, finally I met him at 12 am (night), he said that I had been confused and I could not recognize the place that we agreed about."

Key aspects which have been concluded from the focus group participants

Table 6-2 presents all focus group participants important aspects of Mecca

Participants	Descriptions
10 out of 12 participants (83%) claimed that	Mecca's Haram (around Ka'bah, Saai area, and Zamzem) is more crowded than other places; pilgrims are losing each other in these places more than in other places.
6 out of 12 participants (50%) argued that	Arafat Mountain also a place where people could lose each other. As understood from participants of this session, there are no gates to control people, i.e. people can get there from anywhere (there are a large number of tents around the Arafat Mountain). The advantage however, is that once people arrive at the Mountain (a particular tent) they stay in it throughout the day (not moving from it until sunset). They can pray and do some rites inside the tent. That means that the percentage of loss is very little.
11 out of 12 participants (92%) mentioned that	Pilgrims use some traditional ways to overcome issues when they lose each other, as stated above.
All participants (100%) said that	Different nationalities, languages and cultures increase the problem. As a result pilgrims find it hard to deal with available means such as police, other people, and leaflets/booklets.
10 out of 12 participants (83%) mentioned that	All the places around Ka'bah look like the same, so pilgrims found it hard to detect the right way.
8 out of 12 participants (67%) argued that	It is difficult to stay with your relative (wife, friend, others) throughout day. This left them worried and consequently this will impact on their Hajj rites performance. Some example stories mentioned above illustrated how pilgrims feel when they have lost relatives or groups.

We then asked a further question; "*Are there currently any systems (e.g. static signs, dynamic signage, or directional arrows) available to help pilgrims find each other*?" They answered that currently there is not any technology used there. The majority of participants said that they did not see any digital public displays to help people navigate from one place to another. They said there are some static signs outside of the Haram used to indicate people to some places. The majority of people ignored them because they are incomprehensible and not enough information is shown. They added that there are some signs in Jeddah airport which are used to indicate pilgrims to Hajj places, those signs are also written in the Arabic language; consequently non-Arabic pilgrims have ignored them.

Also we asked the question; "*Do people use their mobile phones in the Haram, i.e. if there are some instructions shown on the mobile screen such as go left for 20 m, turn right, and so on. Is this a situation where this could be useful and help people to meet at a particular point"*? All participants of this session argued that mobile phones do not help at all at in the Mecca area because there are several issues that limit their suitability. For instance, it is difficult to hear mobile phones output (e.g. vibration or audio); it is also difficult to access a network where a huge number of mobile phones are working at the same time. A further example mentioned by two participants stated (eyewitness), "*One day after we finished our Tawaf rounds, while we were outside, we observed a policeman with a person. The policeman called us and told us that this person was from Africa and did not understand Arabic. He asked if we could please try to speak with him to understand what he wanted. My friend & I speak English but when we tried to talk to that person in English he did not understand us, but we understood some of his words to be similar to the French language. During that time the policeman had left us and asked us to please help him if we could. After that, we found someone from Tunisia who understood French. When he tried to speak with him he told us that this person does not understand the French language either. Finally we took him to the information office, and asked someone there how they could help this man. The man who worked in that office said that this person could stay there until they found someone who understood his language or somebody from his group came and ask about him*"(sic).

The other question we asked was: "*Do you think that there are religious barriers for the use of technology such as public displays in the Great Mosque at Mecca or any other holy places*?" The majority of participants think that there is no religious objection to use of technology at Mecca. They did not provide any evidence to prove that, however some of them pointed out that CCTV cameras which are installed inside the Haram is also technology.

Further question posed was; *"What are the changes that you would like to see in the Mecca situation?"* All session members stated that they want to see substantial changes in the current situation of Mecca; the following table presents some people's wishes:

Table 6-3 comments of participants about what they like to see at Mecca in near future

Participants	What they like to see at Mecca in near future
10 out of 12 participants (83%) mentioned that	They wish to see technology applied at Mecca to organise pilgrims' movement inside Mecca's Haram. They would like to see all pilgrims doing their rituals in safety and fewer crowds.
2 out of 12 participants (17%) commented that	We wish to see everything organised by technological methods. This will allow pilgrims to perform their rituals in safety and peacefully, also we hope the Hajj becomes easy and relaxed, with no worries or nerves, and no overcrowding. Nowadays people through Hajj feel worried and uneasy because they think that they will lose each other at any time.
1 out of 12 participants (8%) said	"*a lot of people would like to perform their Hajj pillars together with their wives without any interruption could be occurred in anywhere at any time*" (sic).
All participants (100%) argued that	If a person has lost his relative in the Great Mosque this would impact on their pillars where the pilgrims should pay full attention in the pillars.

6.3.2.3 Focus group feedback on Dots condition

In order to gather feedback about the ideas of a 'Dots condition', we explained to focus group participants in full detail about this idea and showed them draft documents which illustrate the design of both condition essentials (dynamic and static signs). Moreover we mentioned to them how dynamic signage works to provide people with information and how people obtain background colour and dots, which appear while they pass a gate. Then we mentioned how people should keep in mind that information to use later (static signs). Participants have provided us with many significant comments and suggestions.

In general; they have suggested several important points that we should modify to improve a significant and essential part of the system. We summarised the comments and suggestions regarding the Dots condition and depicted them in the following table.

Table 6-4 presents comments and suggestion s about Dots idea

Participants	Comments and Suggestions
All participants (100%)	Were very interested and satisfied with the initial design.
10 out of 12 participants (83%) suggested that	The large static signs which we proposed to install at the beginning of each corridor should be removed from the system, and we should use static signs inside a corridor only. Using those signs at the beginning of corridors will increase crowding as people will stop to look at each of them to find their wedges. Increasing crowds will make the situation more complicated. Once pilgrims have completed their rituals around the Ka'bah, they should enter the closest corridor and search for their colour and dots on the static signs which are installed in that corridor.
9 out of 12 participants (75%) suggested that	If we reduce the number of dots it will be better, for example the maximum number of dots is 6 (i.e. a dynamic display which is installed in a gate will include no more than 6 dots). The number suggested is to avoid confusion and should be easy to remember. So they suggested that six dots will be easy to memorise.
All participants (100%) mentioned that	There are many paths (corridors/routes) that pilgrims use to enter into Haram and exit from it, each wedge could include one path. They suggested that we could install static signs in these paths and pilgrims can meet through the corridor or alongside it.
4 out of 12 participants (33%) noted that	The width of each path is approximately 6 meters and paths are surrounded by columns. So, signs could be mounted between the columns in the corridors.
8 out of 12 participants (67%) agreed that	This system will improve the situation of the pilgrims and allow them to do their pillars in safety and peace.
11 out of 12 participants (92%) said that	Colour and visual codes proposed in the dynamic and static signs were very clear and easy to distinguish between.

Possibility of using such a system at Mecca

We asked participants this question "*Do you think that installing public displays (such the one we showed you in this session) in the Haram is allowed*?"

All participants believed that this technology is allowed to be used in the Haram and other holy places, they added that many times religious people have stated (Saudi Arabia) via TV channels (Iqraa) and Mecca Islamic centre, that technology should be used to solve issues that face pilgrims in all Hajj (e.g. Tawaf rounds, finding each other, Arafat day, etc.). They encourage people who are interested and experienced in the technology field to produce an optimal system to help people perform their pillars, especially inside the Haram, and frequently request them to do that as soon as possible because the crowds continue to sharply increase and as a result the situation has become more complicated.

Another question which has been asked is; "*Do you think that installing public displays (such the ones we showed you in this session) in the Haram will help people find each other once they lost?"*

They were very interested and happy to see this idea and agreed that it will improve the situation of Hajj and a large number of people will benefit from this system. We hope this idea encourages other experts to work and produce a suitable system to solve the issues which face more than 2 million people who meet in one place at the same time.

6.3.2.4 Focus group feedback on the symbol condition

Focus group participants have received full details regarding the symbol condition idea. Moreover, we showed them our draft initial design and explained to them how it works and how people interact with displays. We have gathered some comments and suggestions about the system, their comments and suggestions are listed as following:

All participants were very satisfied with the second idea and they said that this system is very interesting; it will provide a considerable contribution towards solving one of the main issues of the pilgrimage situation. Their suggestions and comments are presented in table 6-5.

Table 6-5 comments and suggestions about the symbol condition idea

Participants	Suggestions and comments
All participants (100%)	Were very satisfied with the symbol idea and said that this system is very interesting; people at Hajj could understand and use it easily. It will make a considerable contribution towards solving one of the main issues of the pilgrimage situation.
10 out of 12 participants (83%) said that	The key to this condition is that all Muslim people know the Islamic symbols so it will be very easy to remember and simple to learn how to use.
8 out of 12 participants (67%) claimed that	The symbols that will be shown on the static signs in each wedge should be very obvious and the background of signs for each wedge should be clear as well.
2 out of 12 participants (17 %) suggested that	The symbols used should be the same in all wedges. The difference will only be in the background of static signs. This will make the situation more easy and clear.
All participants (100%) said that	It might be good if you use famous symbols such as (Quran image, Ka'bah image, etc.), where all Muslim people can recognise and memorise them easily. Some Islamic images look the same so it will be better to avoid those, to prevent confusion.
7 out of 12 participants (58%) claimed that	Both ideas could be used together (dots and symbols), but in this case you should reduce the number of dots and symbols. A combination of dots and symbols could work. (e.g. dots from 1 to 4 and 4 symbols only).
4 out of 12 participants (33%) noted that	The width of those paths is approximately 6 meters surrounded by columns; signs could be mounted between those columns of a corridor. Pilgrims would find it easy to meet in those corridors and alongside them.
9 out of 12 participants (75%) suggested that	Dynamic displays which will be installed at the gates should be placed in a proper place to be obvious to everyone. These allow pilgrims to extract their information successfully.

6.3.2.5 Summaries of focus group participants about two conditions

After we received all comments and suggestions from the focus group session regarding both conditions; we concluded the important points that could be used to improve the system. Table 6-6 includes summaries of focus group comments and suggestions:

Table 6-6 shows the summary of the comments and suggestions about both ideas

Participants	Suggestions and comment
All participants (100%) argued that	Both ideas are very interesting and could be useful, and pilgrims will benefit if they are applied in Mecca particularly in the Haram area.
All participants (100%) believed that	It would not be possible to use huge static signs which we proposed to install at the beginning of each corridor from Ka'bah side. These signs might make the area more crowded.
10 out of 12 participants (83%) suggested that	Only six dots in the first condition should be used to avoid confusion.
11 out of 12 participants suggested that	Only famous symbols should be used in the second condition to help understanding and ease of use.
9 out of 12 participants (75%) said that	Background colours in both conditions should be clear and easy to use to distinguish among colours used (primary and secondary colours could be enough in this context).
4 out of 12 participants (33%) stated that	Using corridors/paths/routes which already exist in each wedge. The key advantage is that corridors are famous and all people know them.
3 out of 12 participants (25%) claimed that	Both ideas could be used together (dots and symbols), but in this case you should reduce the number of dots and symbols. A combination of dots and symbols would work. (e.g. dots from 1 to 4 and 4 symbols only).
All participants (100%) noted	The width of those paths is approximately 6 meters surrounded by columns; signs could be mounted between those columns of a corridor. Pilgrims would find it easy to meet in those corridors and alongside them.
11 out of 12 participants (92%) suggested that	Dynamic displays which are installed at the gates should be placed in a proper place and size to allow people extract their personalised information correctly.

All comments and suggestions of the focus group participants have been taken into account while we redesign our system which will include both ideas individually. The system conditions can be evaluated by running a user study to see whether this system is feasible at Mecca or not and which condition provides more help to pilgrims while performing Hajj rituals.

A usage scenario which describes exactly how we design solves the problem of helping people re-group after being separated.

The approach that we proposed to solve the problem of helping pilgrims re-group after being separated consists of two main components: dynamic signage displays and static sign displays. The dynamic signage which is supposed to be placed at the gates of Mecca's Haram, (i.e. install dynamic signage at each gate, pilgrims read it and gather their information while passing a gate to enter into the Haram to perform their rituals). These dynamic displays present backgrounds and dots (Dots condition) or backgrounds and symbols (Symbols condition). For example, a group of people while passing the gate read a sign (blue background and 3 dots, in the dots condition) or (yellow background and Quran symbol, in the symbol condition). See Figure (6-2) shows the structure of public dynamic signage for two conditions (dot, upper side) and (symbol, lower side)

So in this stage pilgrims (groups, friends, relatives, or families) read a dynamic display and memorise the information that they see. Then they enter into the Haram to start directing their actions, e.g. the Tawaf rite. In the case of a group, family, or friends being separated while performing rituals around the Ka'bah, i.e. each one being in different place, they have to remember the information that they read when passing a gate. Then each one of them (group, friends, or family) should enter into the close corridor/path to find the static signs.

Static signs are the second component of the system; these signs are distributed in all corridors/paths of the Haram, each corridor includes specific sign colours. For instance, in one corridor all signs have a red background; in the next corridor all signs have a brown background, and so on. Each static sign is divided into parts: the upper part shows the background of the current corridor to refer pilgrims to this corridor colour. The lower part is consists of eight colours to indicate to pilgrims the other corridors' colours.

A person who is lost will compare their memorised information to the information shown on a static sign, once he/she finds the same information then he/she should wait until the other group members come. If the information is not the same he/she should move to the next sign and so on, in the worst case they will find their information in the end of that corridor (last sign). This is always true if a person is lucky and finds himself in the corridor that he/she looking for. Whereas if a person found herself in different corridor (i.e. a person is looking for the red colour but he entered into blue because it was the closest corridor to her position). In this case she should look at the lower part of a sign and follow the directional arrow drawn on the colour she is looking for; this will direct her to the next corridor and so on. If she finds the colour but without a directional arrow, she must move to next sign and check it and so on. In the worst case she will find the colour associated with a directional arrow in the last sign in that corridor.

The next story explains how pilgrims interact with the system displays and extract their personalised information which support pilgrims and re-group them after being separated.

Kareem, Saleem and Nadeem three people (a group of friends) decided to visit Mecca to perform the pilgrimage pillar. They have not visited Mecca before. While they are passing a gate they read the display (dynamic signage), placed at a gate (i.e. they read and remember what the dynamic signage displayed at that moment). The information shown at that time was blue and 3 dots, so they agreed that the common information is blue background and 3 white dots. Every one of them has kept that information in mind to use it later. Then they entered into the Haram to perform their rituals. Many things must be done in this stage around the Ka'bah, e.g. Perform the Tawaf, pray, visit the Zamzem place and Saai between Safa and Marwa.

Kareem, Saleem, and Nadeem start Tawaf rounds and suddenly they are separated, each one of them being in different places. In this case, every one of them should complete his circuits of Tawaf (seven times). Then each one of them should enter into the closest corridor to find a static sign which shows the information corresponding to their information (blue plus 3 dots that they agreed about before being separated. For example, Kareem was lucky because he entered into the blue corridor, in this state he just wants to find a sign which shows 3 dots and wait there until his friends come. Saleem has entered into the red corridor, so he must find a sign which shows information about the blue background (i.e. all background colours are shown in the lower part of each static sign) Then he must follow the directional arrow to reach the blue corridor, sometimes only the colour is shown on a sign, in this case he must continue walking to the next sign and check it and so on until he finds a directional arrow to direct him to the blue corridor, sometimes the next corridor is not the blue corridor. Here he should move from one corridor to another until he finds the blue one. When he finds it then he should try to find three dots and wait there. The same is true with Nadeem, who has entered the yellow corridor. Directional arrows will lead him to the blue corridor. Then they will meet in the blue corridor next to a sign displaying three dots and become a group again. So any group, friends, or family members should read the dynamic signage and remember the information shown at that moment and use it and the static signs distributed in the corridors of the Haram.

6.3.3 System Design

Once we have obtained all the information regarding the issues that we are addressing from many sources we will redesign our system. We have obtained information by conducting a series of semi-structured interviews with people who had already completed a pilgrimage before and had investigated the properties and constraints of the environment at Mecca. In addition we have gathered many comments and suggestions from the focus group session about the initial system that we proposed. Based on all these considerations we have redesigned our system in both approaches (dots and symbols). Existing solutions that pilgrims use to perform their rituals are not very useful and the previous systems which are used to provide navigation information are not feasible to use at Mecca. We therefore developed the augmented displays to provide an optimum solution that would work for every pilgrim without any of the drawbacks of the approaches that are currently used.

The next sections will describe the system design of both conditions (dots and symbol).

6.3.3.1 Dots condition design

This condition has two essential parts; dynamic and static signage. Dots and coloured background will be used in both dynamic and static signs.

6.3.3.1.1 Dynamic signage design

Dynamic signage has been designed based on the focus group suggestions, where all focus group comments and suggestions have been taken into account. One of the focus group suggestions is that no more than 6 dots should be used. We have 8 colours which will be used as backgrounds to represent the wedges and 6 dots. The screen display will show the dynamic signage that involves (background and dots). The screen display will dynamically show 48 signs. These number of signs results from 6 dots x 8 colours/wedges = 48 signs. We assumed that each wedge of Haram includes one corridor or path.

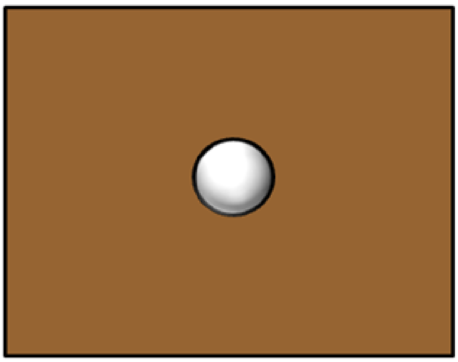

Figure 6-7 Dot Dynamic Signage Design

The content of the dot dynamic signage system we developed in response to those considerations is shown in Figure 6-7. It consists of a coloured background with one white dot shown in the centre. The screen display which is placed at a gate will automatically show a number of signs; each sign will remain showing for 30 seconds and then disappear. It will start with a particular coloured background (e.g. Brown background), it will start with one white dot and after 30 seconds a new sign will appear with the same colour but the white dot will be incremented by 1 (two white dots), and so on. Once the number of dots reaches six then a new background colour will appear with one white dot and the number of dots will continue changing every 30 seconds, until six dots are complete on this colour, then the next background colour will show. As a result each background colour will show (from 1 to 6 dots). So, 48 signs will be shown in order on the screen display and then will start from the beginning to show first background colour again (as loop). Figure 6 – 8 illustrates the underlying mechanism.

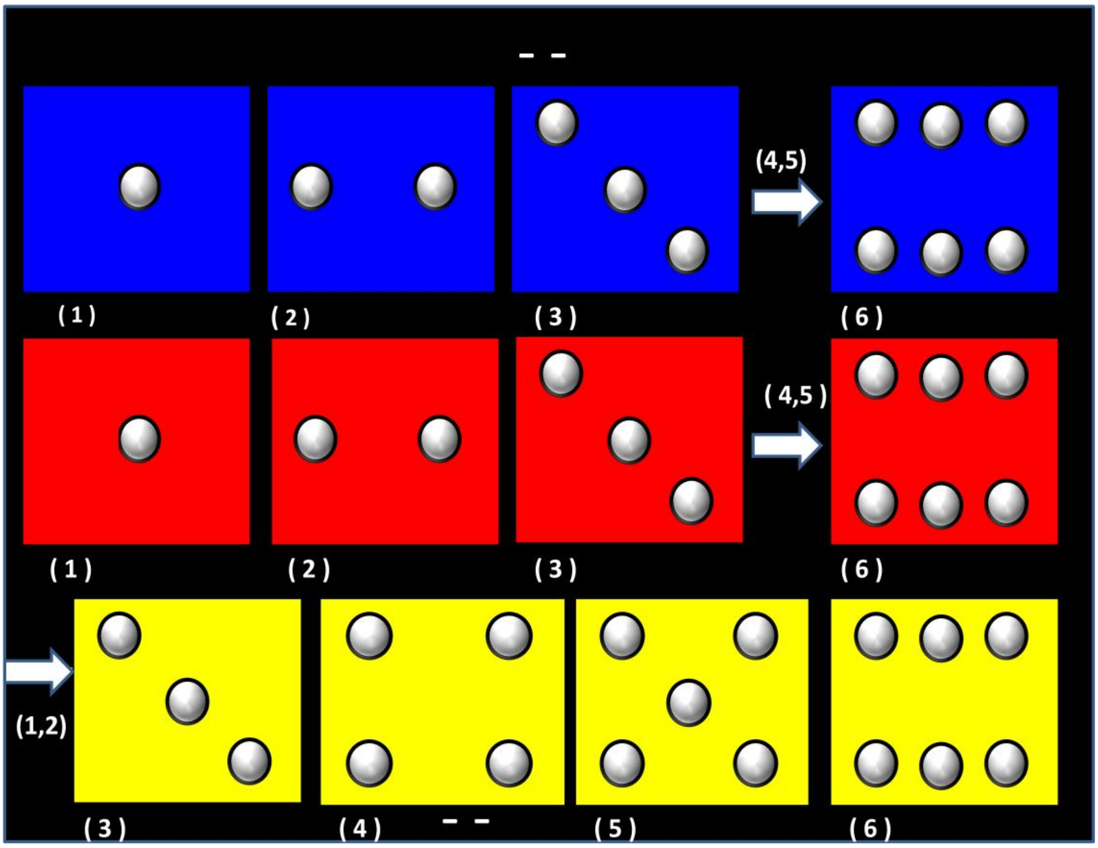

Figure 6-8 Change over time of the dot dynamic signage

Figure 6-8 shows only three cases of dot dynamic signage as an example to illustrate how signage shows. The first row shows the blue background state changing; a single white dot has been added until it reaches six dots. Then the same situation is shown in the second row (red background). The third row shows signs with a yellow background. At the Mecca's Haram, a large dynamic display will be placed at each gate and pilgrims should read a dynamic signage while passing through a gate to remember a coloured background and the number of dots shown on it. Then they walk to the Haram to perform their rituals. They should keep in mind two things: background colour and the number of dots shown on it. For example, they might remember "blue 3" (i.e. blue background and three white dots), "green 5" or "red 2".

6.3.3.1.2 Static signs design

Static signs were designed in line with the focus group's comments and suggestions. These static signs are designed to be installed in the corridors of the Haram and pilgrims will identify them by the information they have obtained from the dynamic signage at the gate while they entered into the Haram. Figure 6-9 shows the content of the static sign with description about the design of it.

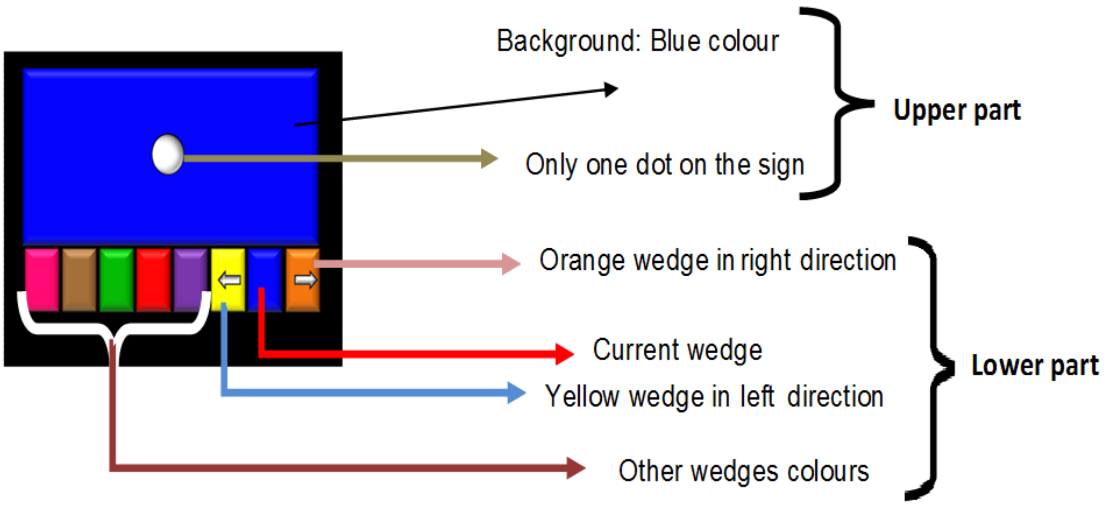

Figure 6-9 The structure of static signs

As shown on Figure 6-9, each static sign is divided into two parts: The upper part refers to a wedge colour; people will be directed by it to their wedge. The lower part refers to the other wedges colours. This part of the sign is designed (ribbon colours) to represent all 8 colours. So the lower part contains 8 different colours: some colours are supported by arrows to indicate people to a wedge of another colour. For example the first colour (in the right corner) attached with an arrow is to indicate to people that the orange colour (orange wedge) is in the right direction, the second position is used to indicate to people the current wedge colour, and the third position is used to show the first wedge colour on the left side. Other positions are not supported with arrows which mean that no information is available about their colour in this sign. In this case a user should continue walking to the next signs which may include the relevant information, in the worst case a person will find their information in the last sign in the current corridor.

How static signs work: when a person gets lost inside the Haram, they should have already memorised the information which they obtained from the dynamic signage at a gate, and then a person should enter into the closest corridor to him/her and start searching for a static sign which guides him/her in the right direction. Once they have found a sign they should look at the upper part of it and compare it with their colour, if the colours are the same then they are in right place, otherwise (e.g. different colour) they should look at the lower part of a sign and try to find their colour, if they found that their colour is associated with a directional arrow then they should follow that direction to reach their destination (they will find a sign which contains the same information that they memorised, e.g. 'blue 5'). It might be found that their colour is without a directional arrow; in this case they should continue walking in the same corridor until finding other signs and checking them to find the corresponding information. So a person could find their information in that corridor or maybe the signs will refer him/her to walk to the next corridor.

6.3.3.2 Symbols condition design

In this condition 6 famous symbols (focus group suggestions) will be used in both dynamic and static signs. The idea of a symbol condition is similar to the previous idea (dots condition). Here, we used symbols instead of dots. The next section describes the both essential parts of the symbol condition.

6.3.3.2.1 Dynamic signage design

The symbol condition is the second idea in our system; the initial design has been discussed in a focus group session and many suggestions and comments have been taken into account when designing the symbol dynamic signage. The majority of participants argued that using famous symbols might make the system easy to use and easy to remember. It's very important for pilgrims to memorise the dynamic display content.

Similar to the dots condition, we have decided to use six symbols in this approach to indicate people to their meeting places. The dynamic screen display will show 48 signs. This number of signs results from (6 symbols x 8 colours/wedges) = 48 signs. We assumed that each wedge of the Haram includes one corridor or path. The next table presents the symbol name, symbol shape, and a brief description.

Table 6-7 symbols used in the symbol condition

Symbol Name	**Symbol shape**	**Description**
The Quran		Quran: the sacred writings of Islam revealed by God to the prophet Muhammad during his life at Mecca and Medina.
The rosary		Rosary: it is a personal tool, people use it after they pray, there are some sentences that should be spoken with each bead of the rosary.
Ka'bah		Ka'bah: is the important holy place of Muslims, located in the Great mosque. Muslim people should walk around it seven times when they arrived there.
Islamic Star		Islamic star: one of many images that is allowed to be used even in holy places like Mosques.
Menber		Menber: it is used in Mosques, it is like a desk, the Imam when giving a lecture should sit or stand on this Menber, it is usually used on a Friday.
Prayer carpet		Prayer carpet: its use is for prayer. People stand on it while praying, or sit on it after praying to say some particular sentences.

Figure 6-10 Basic design of the dynamic signage system

Figure 6-10 shows an example to explain how the dynamic display shows coloured background and Symbol. Also here is the dynamic signage which will be installed at each gate. Pilgrims while passing a gate should identify the background colour and symbol shown. Every 30 seconds the screen display will shows a sign, each sign includes a colour and symbol. Each background will remain until all six symbols have been shown, then a new background appears on the screen display, the six symbols will then be shown on it again. So, the six symbols will be shown on each background, i.e. six symbols with eight background colours will be shown on the screen display (48 signs will be presented on the screen display). Figure 6-11 illustrates the underlying mechanism. Pilgrims as groups (friends, relatives) will identify their information while passing through a gate.

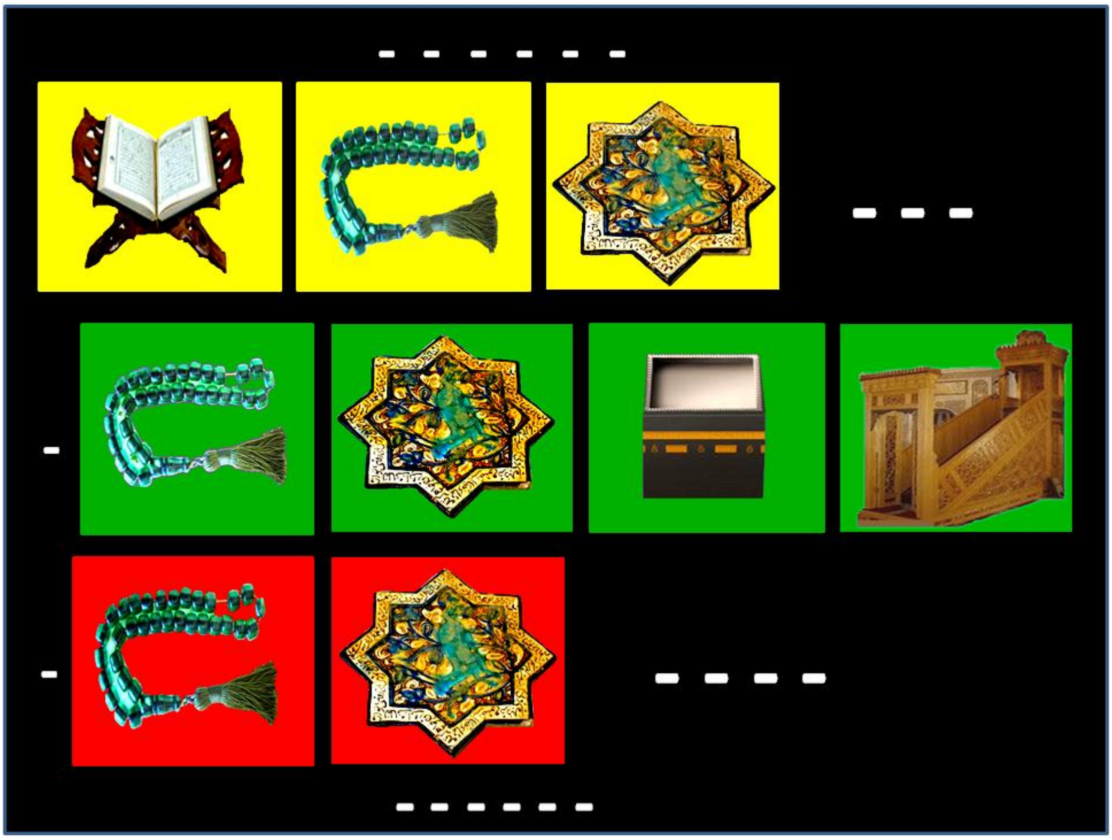

Figure 6-11 symbol dynamic signage change over time

States of symbols in dynamic signage are shown in Figure 6-11, where the symbol of the Quran is shown on the yellow background, this context will appear on the screen display for (30 seconds) and then disappear, at that time pilgrims read the sign and keep it in mind (e.g. Yellow background and Quran), and continue walking to the Haram. When all six symbols have been shown on the same background (yellow in this case), then a new background colour will appear again on the screen display, all symbols will shown on it in the same order. We assume that 30 seconds was enough for users to identify signage content and view information available at that moment while they pass through a gate into the Haram. In the actual area (Mecca city), it would be useful to preview the environment and choose an appropriate amount of time. The information gathered from the dynamic display will be used later when the pilgrims interact with static signs. For example, pilgrims keep in mind "blue Quran", "red rosary" or "green mat" and start their pillars inside the Haram; it might take 2 to 3 hours to complete their tasks. During this time they must keep their information in mind, otherwise they will not benefit from the system.

6.3.3.2.2 Static signs design

According to the suggestions and comments of the focus group about the initial design of the symbol dynamic signage, we have improved this part of our system (static signs). The common comment from the majority of participants was "*Famous symbols should be used in this condition; this allows people to easily recognise and remember them*".

The design of static symbol signs is similar to the design of static dots signs, Six Islamic symbols have been used; the interface of this design is also similar to the dots interface design. Figure 6-13 shows the symbol signs design.

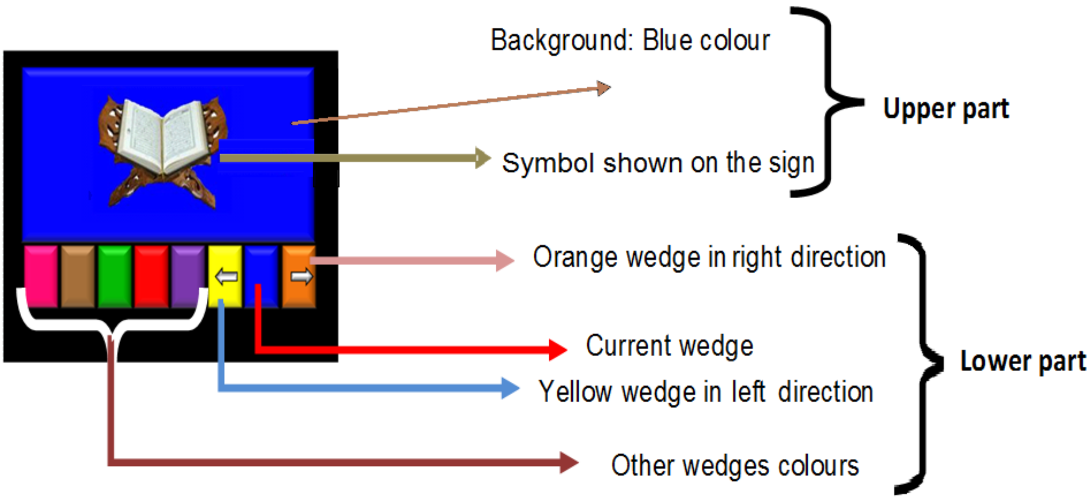

Figure 6-12 Symbol sign structure

After reading the symbol dynamic signage which is placed at each gate, Pilgrims should keep that information in mind. Once a person has lost his/her group, they should enter the nearest corridor and search for static signs, when a sign is found they should look at the upper part of sign and match it to the colour taken from the dynamic signage at the gate, if it is the same then a person should continue trying to compare the symbol as well. If a colour is not the same as the colour they obtained from the dynamic signage at a gate, then he should continue walking until finding other signs and checking them. As a result they will find their information in the current corridor, this information could be enough to meet in or indicate them to next corridor.

6.4 Evaluation

Our system has been redesigned based on the considerations that were extracted from a focus group session. Once we had completed the system design we then needed to test it and evaluate the effectiveness via a group of people (user study participants). Running such a system at Mecca was infeasible for many reasons, e.g. government rules, Mecca authority, i.e. requires a holy places work permit, a further reason is that our approach is in the early stages of development. Therefore, we ran the study through a lab-based user study.

In order to evaluate our approach we ran a user study in an environment simulating some aspects of the actual setting at Mecca.

6.4.1 Aims of the study

The main goal of the study was to gather feedback from potential end users and to observe their interaction with the system in both conditions. Also we tried to gain significant results which might be obtained in order to provide more help in such situations in many terms (e.g. easy to use, simple to learn how to use, and feasibility of use at Mecca). More specifically, we were interested in finding answers to the following questions:

(a) Does the current user interface of dynamic and signs meet their needs, can they use it, or are there any issues that need to be addressed?
(b) Do end users find the idea of installing such a system at Mecca acceptable?

6.4.2 Participants

We recruited 20 participants of Newcastle city societies. 10 of them were male and 10 female, aged between 25 and 56 years. Two of them are long-sighted and three of them have short-sighted vision: (based on the results that we gathered about them, we found that they were wearing glasses and their performance was normal, no any errors or disorientation occurred while doing any study tasks). Their cultural background was varied with people originating from Northern Africa, India and Asia. 50% of participants had been on a pilgrimage to Mecca before, the other participants claimed to be knowledgeable in terms of the pilgrimage but they had not been to Mecca before.

6.4.3 Stimuli

As it was infeasible to run the study at Mecca, we tried to set up an environment in the lab that shares certain key properties with the area around the Ka'bah.

Both conditions: dots and symbols signs were shown on the 50" screen colour display, it was mounted on a metal stand (total height: ca. 1.70m). This was connected to a laptop computer and the computer running the system was hidden behind the walls.

To make the situation similar to a realistic environment, we attempted to make the dynamic signage which we used in the experiment somewhat similar to the one which will be placed at a gate of the Haram. As in the real situation the dynamic signage will be placed at the gates of the Haram and pilgrims will extract their information while passing a gate. Therefore we designed the dynamic signage to appear on the centre of the screen display initially in a small size gradually enlarging until it takes up the full screen. People perceive things from far away to be small and when they become closer to those things they find that they appear larger. So we tried to simulate the opposite by making the symbols on the display grow in size and asking the user to walk on the spot instead of the user approaching a fixed screen display from a distance. Users were asked to walk on a certain spot in the front of the screen display and extract their information while the signage was growing in size. This simulation was designed to mimic the user approaching the screen display. We simulated the following: The dynamic signage shows a coloured background with white dot(s) or a symbol at the centre of the screen display; a background with a dot/symbol firstly appears in a small size on the centre of the screen display and slowly grows until it becomes full screen size, then disappears. A background including dots / symbol takes 15 seconds to become full screen size, the amount of time for a sign staying on the screen display was proposed based on a pre-test had done by three participants. This time allows a user to recognise the screen content and memorize it (i.e. while the content of the display is growing larger a user reads the display content and keeps it in mind). After the previous background has disappeared, another coloured background will appear on the screen display and a number of dots / new symbol will be shown on it (e.g. three dots (in the dot condition) or new symbol (in the symbol condition)) and so on. Each trial will show eight coloured backgrounds and different dots / symbols. A user is asked to memorise the last signage information in each trial. This simulation (the method that we used to present the signage content) has been done in this way to let a user imagine that he/she is approaching the screen display to extract their information. This is to simulate the real situation: it seems that a person walking towards the screen display can read it and accurately identify information shown at that moment. Each participant took part in all study tasks (dots and symbols), i.e. six trials for each condition, each trial contains (dynamic signage, distraction tasks, and static signs tasks).Figure 6- 13 shows some photographs of the experimental area.

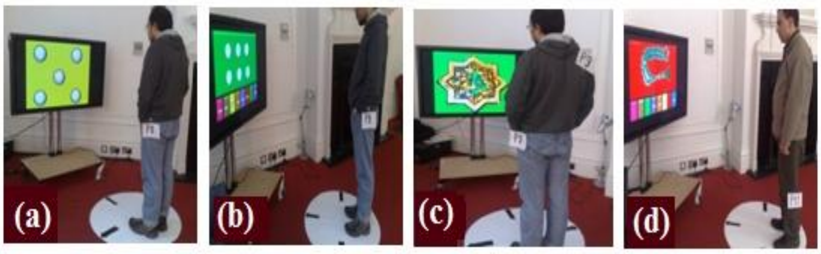

Figure 6-13 Photographs of the experimental showing: (a) dot dynamic signage, (b) dot static sign, (c), symbol dynamic signage and (d) symbol static sign

Distraction tasks: Once participants completed their first task of locating the dynamic signage and memorising their information (colour and dots / symbols). We asked them to complete distraction tasks. These tasks are designed to clear the participant's memory. We designed several slide shows; each slide presents a sentence and an image, all images and sentences related to the Hajj situation. We showed slides randomly, where some of them are matching and some not. Each slide remained for 15 seconds and then disappeared. For example, a sign shows the sentence "Tawaf definition and Tawaf image". Participants were asked to view both and say 'YES' if they were matching and say 'NO' if they were not.

By developing these tasks we attempted to clear participants memories to test if they easily forgot their information or not. We tried to encourage them to imagine that they are at Mecca and doing some rituals. Figure 6-14 shows an example to illustrate the distraction task.

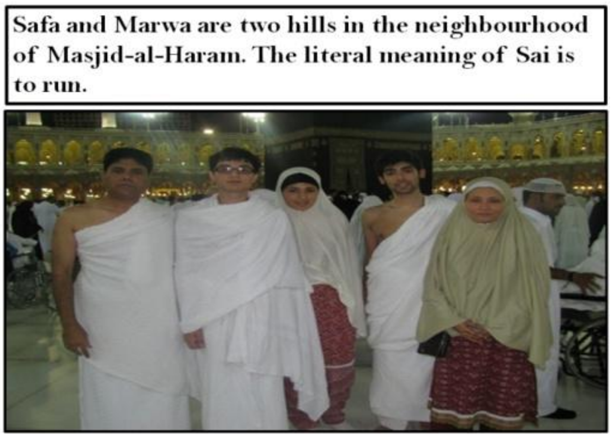

Figure 6-14 an example of distraction tasks: an image not corresponding to a sentence (photos from Wikimedia commons-http:// commons.wilki.org)

In this example the sentence and image are not matching, so the user should say "No" to indicate to us that the image does not correspond to the sentence attached. Whereas in the next figure (6-15) the image and the sentence are matching, so a user should say "Yes".

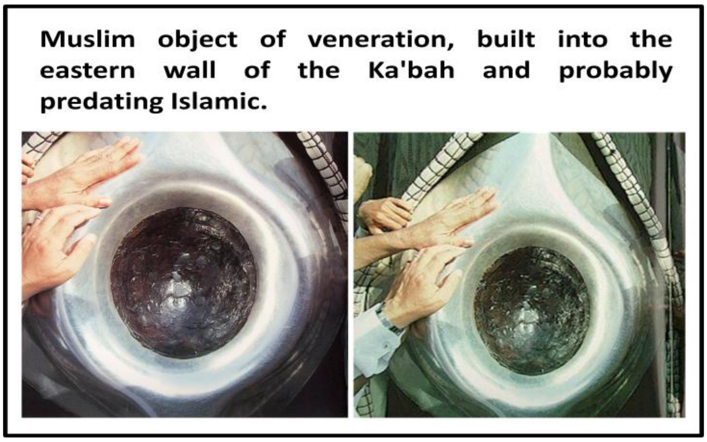

Figure 6-15 an example of distraction tasks: an image corresponding to a sentence (photos from Wikimedia commons-http:// commons.wilki.org).

Results reported that none of the participants had disorientation and no errors occurred while they performed the tasks. Even though they completed distraction tasks, they were still able to memorise their information.

6.4.4 Procedure

Each participant first had to fill in a brief questionnaire, which contained questions about the (cultural) background of each user and about basic demographic properties such as the participants' age.

We then briefed participants about the task they had to perform (walking to the same place in the front of the display and looking at the dynamic display), participants should identify the information on the display (e.g. blue 3, i.e. blue background and 3 white dots or yellow background and Rosary). We asked them walk in place to simulate the experience of approaching the sign on foot. The entire study was recorded on video.

In the second phase, subjects had to perform the distraction tasks; subject were asked to look at the screen and try to match sentences and images showing on it, each participant had to try and match 8 signs per trial, each sign remained on screen for only 15 seconds and then disappeared, subjects should says "Yes" in the case of a match, otherwise saying "No".

In the third phase (static signs tasks), subjects were asked to stand on the circle available in the front of the screen display, with three directional arrows drawn on it. Each sign remained showing for 15 seconds and then disappeared. Subjects were asked to move their foot to indicate the correct direction, depending on the data that they obtained from dynamic display at a gate. As we recorded all trials on video, and used the footage to take the following measurements: disorientation events (no direction selected within the 15 seconds a sign is displayed), errors (selection of an incorrect direction) and completion time (time from the appearance of a sign until on foot made contact with one of the marks corresponding to the directions).

Afterwards, participants were asked to answer a question about the data that they obtained from the dynamic display. The question was "*could you please tell us what colour the background is and how many dots did you obtain from the dynamic* *display?*" This process is designed to measure the errors rates of dynamic signage. So after each task of viewing static signs, participants were asked that.

Subjects moved again to the next trial and performed the same steps, each participant completed six trials. At the end of each trial the subject was asked to state the information that he/she had obtained from the dynamic signage at gate. For example, 'Red 4' which means red: for background colour and (4) for a number of dots existing on that background, this regarding the dots condition. While for the symbol condition, subjects should say, for example, 'Blue Quran' which means that they identified a blue background and the Quran symbol. This helps us to measure the error rate in dynamic signage tasks (each participant has a sheet on which to fill in their answer).

In order to determine an appropriate time for showing signs time in our set up, we invited three students to participate in a test run prior to the main study. We instructed them to slowly walk to the same place in the front of the screen display and measured the time it took them to complete the task. We found that the average time per trial was 15 seconds, based on that, each sign appeared on the screen display for 15 seconds and then disappeared.

In last phase, subjects were asked to fill in a final questionnaire after completing all tasks for each condition, for example when a subject completed the dots condition tasks he/she filled in a final questionnaire on it, then started doing the symbol condition tasks, once finished they then filled in a final questionnaire on this condition.

6.4.5 Results

In the initial questionnaire, all the participants reported that they were familiar with the pilgrimage in general, and 10 of them had visited Mecca. Participants listed a number of sources, from which they had acquired their knowledge about the pilgrimage: TV, books, family, the Internet, and mosques were the most frequent ones.

Regarding the subjects who had completed a pilgrimage, we asked them to fill in a questionnaire before starting the experiment. We issued them with series of negative and positive statements about crowded situations, issues, current means available to help pilgrims, and how easy it was to find each other. We asked them to indicate whether they agreed with these statements. We used a five points Likert scale, where a value of five corresponded to “strongly agree” and value of one to “strongly disagree”. In the following we report on the participants responses, which analyse all questions relating to the same category.

When we asked them about the crowding situation, there was a strong agreement that the area of the Haram was very crowded and it was easy to lose each other there, (1 of 10 participants agreed and 9 of 10 strongly agreed), average: 4.9, standard deviation: 0.32. Subjects also strongly agreed that the places inside the Haram are the same and it is difficult to identify a particular place (7 of 10 strongly agreed and 3 of 10 agreed), average: 4.5, standard deviation: 0.53. When asked to consider the statement, “pilgrims inside the Haram do not receive much help (e.g. through signage)”, participants were strongly in agreement that there are no any signs to indicate pilgrims to known places or to help them find each other in the case of becoming separated. (9 of 10 participants were strongly agreed and 1 agreed), average: 4.9, standard deviation: 0.32. Subjects were strongly in disagreement with the statement “it was easy to find someone who is lost at Mecca’s Haram”, (average: 1.5, standard deviation 0.42). Participants also were strongly in disagreement about the statement, “many means were available in the Haram to help pilgrims find each other”, (average: 1.2, standard deviation 0.53).

With regard to the other questions that were posed to all participants who had been on a pilgrimage and those who hadn’t. The three most frequently mentioned elements were: the large number of people in a limited space; people losing each other inside the Haram and that there are no systems available to guide people and organise their movement. In terms of helpful aspects participants only mentioned one item: some people are available to help pilgrims find each other, however, sometimes they could not provide any help for pilgrims for many reasons such as: different languages and people who do not remember their accommodation addresses.

6.4.5.1 Time completion Task and error rate of static signs Tasks

Firstly, we categorised the subjects of this study into two groups: (pilgrimage: “had visited Mecca” and non-pilgrimage: “have not been to Mecca”) in both conditions.

Dynamic signage error rate: Once a participant has completed one trial (dynamic signage, distraction task, and static sign) we asked them to answer a question about the data that he/she obtained from the dynamic display. This process is designed to measure the errors rates of dynamic signage. We have prepared two sheets (one for the dots condition and one for the symbol approach) for each participant to register their answer. Results reported that no errors occurred from any of the participants when comparing their answers to the dynamic display tasks which were recorded on video.

Dots static signs: The average time that pilgrims took to complete all six trials of each group in the Dot static signs condition is shown in table 6-8. For the pilgrimage group the average task completion time was 11.63 with a standard deviation of 0.44, for the non-pilgrimage group the average time and standard deviation are 11.45 and 0.38 respectively.

Table 6-8 Descriptive Statistics for the Dot Condition on all Six Trials Completion Time

Group	Mean	Std. Deviation	Std. Error Mean	p value
Pilgrimage	11.63	.44	.14	0.328
Non-Pilgrimage	11.45	.38	.12	

Again an independent sample t test was use to find out if there was any significant difference between the averages of task completion time. Results show that 11.63 was the average time of the pilgrimage group with a 0.44 standard deviation and the average time and standard deviation of the non pilgrimage group was 11.45 and 0.38 respectively, this with a t statistics of 0.66 and P value was 0.328 ($P > 0.05$). Results suggested that there was no significant difference between the participants (in both groups) in tasks completion time. Figure 6-17 shows the average tasks completion time for the dots condition.

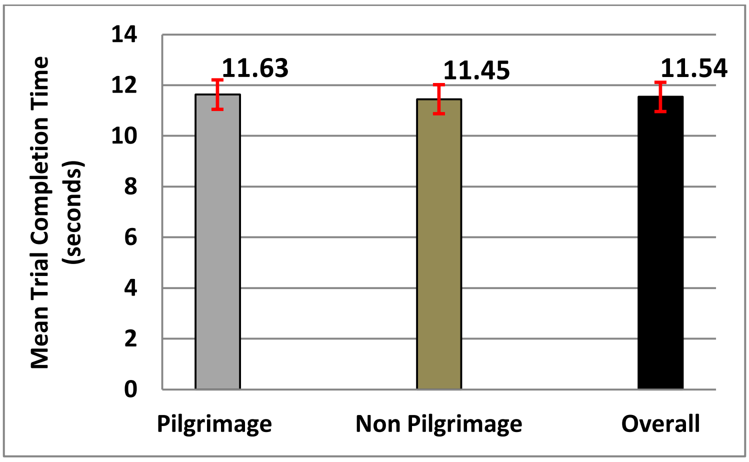

Figure 6-16 Dots condition: the average tasks completion time of Pilgrimage, Non-Pilgrimage Groups, and overall

Symbols static signs: for the pilgrimage group the average task completion time was 11.80 with a standard deviation of 0.28, for the non-pilgrimage group the average and standard deviation are 11.65 and 0.31 respectively. The non-pilgrimage group took slightly less time than pilgrimage group.

Table 6-9 Descriptive Statistics for Symbol Condition on all Six Trials Completion Time

Group	Mean	Std. Deviation	Std. Error Mean	p value
Pilgrimage	**11.80**	**.28**	**.09**	**0.271**
Non-Pilgrimage	**11.65**	**.31**	**.10**	

An independent sample t test result indicates that there is no significant difference in time between the two groups, where P value was 0.271 ($p > 0.05$). The average time of the pilgrimage group was 11.80 and 11.65 for the non- pilgrimage group with t statistics of 0.76. Based on that, we can therefore conclude that on average there is no difference between the groups in completion time. Participants in both groups completed their tasks in a suitable time, which is illustrated in Figure 6-17.

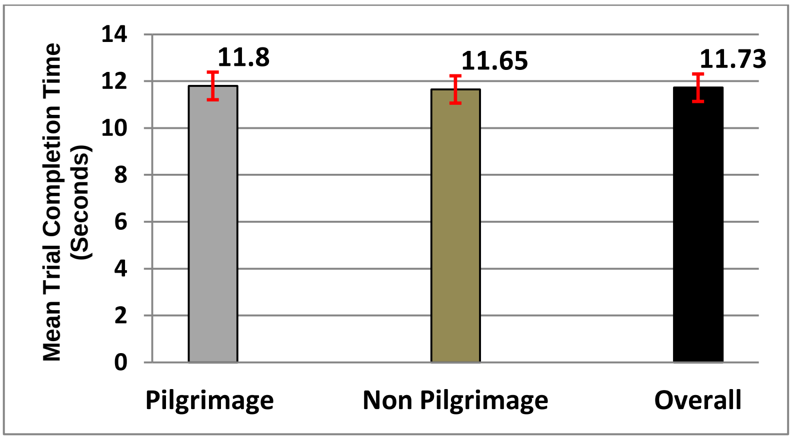

Figure 6-17 symbol condition: The average of tasks completion time using of pilgrimage and Non-pilgrimage groups, and Overall.

Comparison between Dot and Symbol Conditions in task completion time

For the pilgrimage group using static signs in the Dots condition the average of the task completion time was 11.63 while in the Symbol condition it was 11.80. Independent sample t test indicates that there is no significant difference between them with a t value of -1.01 and p value of 0.325 (> 0.05).

For the non-pilgrimage group using static signs in the Dots condition the average of the task completion time was 11.45 while for the Symbol condition it was 11.65. Independent sample t test indicates that there is no significant difference between them with a t value of -1.31 and p value of 0.206 ($p > 0.05$).

For the dot condition participants (pilgrimage and non- pilgrimage) using static signs the overall average of the task completion time was 11.54 while the symbol condition it was 11.73. Independent sample t test indicates that there is no significant difference between them where p value of 0.329 ($p > 0.05$).

Overall, one can say that the participants (pilgrimage and non- pilgrimage) in both conditions completed their trails in less than the time available for each sign (15 seconds).

6.4.5.2 Usability Satisfaction

Dots condition: The results of selected questions from the IBM Computer Usability Satisfaction Questionnaire [53] are depicted in Figure 6-18 which shows the average results of all participants.

Overall, independent sample t test was used to find out if there was any significant difference between the averages. The results of t test shows that there was strong evidence to indicate that the participants of the pilgrimage group were satisfied and strongly agreed with all the questions that we selected more than the participants of the non-pilgrimage group. Where in the pilgrimage group the range was very close to 5 (strongly agree), in the non-pilgrimage group the range was very close to 4 (agree). That was based on t test results where the average was 4.71 for the pilgrimage group and 4.29 for the non-pilgrimage group, and p value of 0.001 ($p < 0.01$).

In general, we could conclude that the participants of both groups were satisfied with the usability of the dot condition. Where the range was between 4 (agree) and 5 strongly agree).

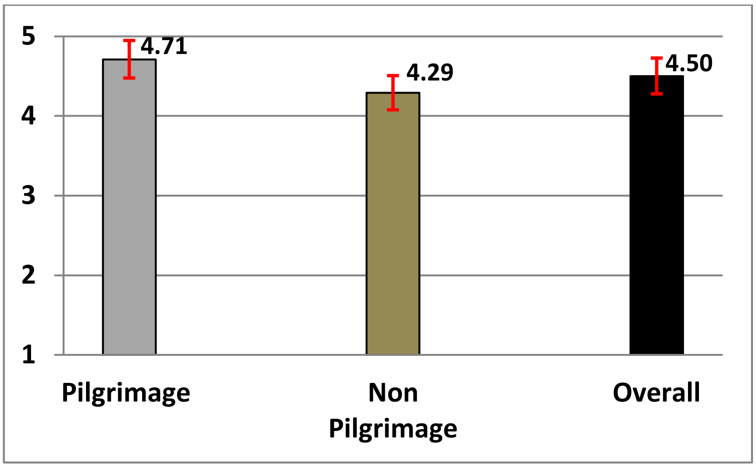

Figure 6-18 Dot condition: Average results regarding usability satisfaction (scale: 1 – strongly disagree, 2 – disagree, 3 - neither agree nor disagree, 4 – agree, 5 – strongly agree) of pilgrimage and non- pilgrimage groups, and overall

With regard to the Symbol Condition: Unlike the dot condition, the pilgrimage group rated the questions for the symbol condition consistently lower than the non-pilgrimage group for all 12 statements of IBM Computer Usability Satisfaction Questionnaire. This indicates that the non- pilgrimage group is more in agreement with the questions than the pilgrimage group.

For the symbol condition the average for the pilgrimage group is 4.27 with a standard deviation of 0.08 while the corresponding figures for the non- pilgrimage group are 4.63 and 0.10 respectively.

Table 6-10 shows statistics of Symbol condition

Group	N	Average	Std. Deviation	Std. Error Average	p-value
Pilgrimage	10	4.27	.08	.02	0.001
Non- Pilgrimage	10	4.63	.10	.03	

Independent sample t test was used again and illustrated that the participants of the non- pilgrimage group were satisfied and strongly agreed with the selected questions more than the participants of the pilgrimage group. The range was very close to 5 (strongly agreed) in the former, and the range was very close to 4 (agree) in the latter.

We can therefore conclude that on average the non- pilgrimage group strongly agreed more than the pilgrimage group. Figure 6-19 the bar chart shows this clearly.

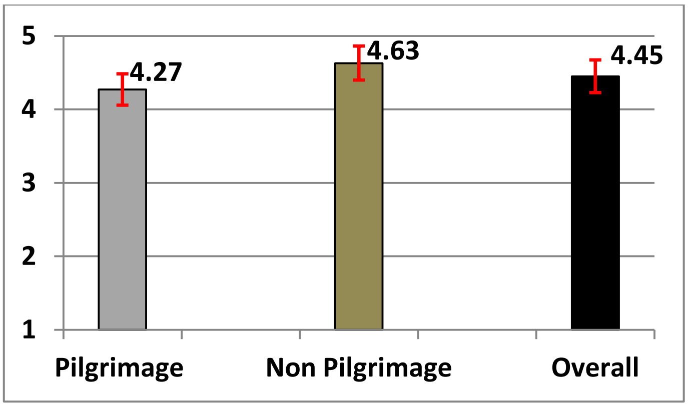

Figure 6-19 Symbol condition: Average results regarding usability satisfaction (scale: 1 – strongly disagree, 2 – disagree, 3 - neither agree nor disagree, 4 – agree, 5 – strongly agree) of pilgrimage, non- pilgrimage groups, and overall

Comparison between Dots and Symbol conditions regarding Usability and satisfaction

For the pilgrimage group using the dot condition the grand average was 4.71 while for the symbol condition it was 4.27. An independent sample t test indicates that there is a significant difference between these numbers with a t value of 11.82 and p value of 0.001 (<0.01). The results showed that the dot condition is favoured more than the symbol condition.

For the non- pilgrimage group using the dot condition the average was 4.29 while for the symbol condition it was 4.63. An independent sample t test indicates that there is a significant difference between these numbers with a t value of -7.24 and p value of 0.001 ($p < 0.01$). So here the results illustrate that the symbol condition is favoured more than the dot.

For the non- pilgrims and pilgrimage groups using dot condition the average was 4.50 while for the symbol condition the average was 4.45. An independent t sample test indicates that there is no difference between these numbers as p value (> 0.05). So here the results illustrate that the participants were very satisfied with the usability of the two conditions. As in dot condition the average (4.45 was closer to 4 agree) and in symbol the average was 4.50 which closer to 5 strongly agree).

6.4.5.3 Workload

Dots condition: The results of all questions of the NASA Task Load Index TLX [37] are depicted in Figure 6-20 and show the average results of all participants. For the pilgrimage group the average was 1.42 with a standard deviation of 0.20 for the non-pilgrimage group the average and standard deviation are 1.86 and 0.25 respectively.

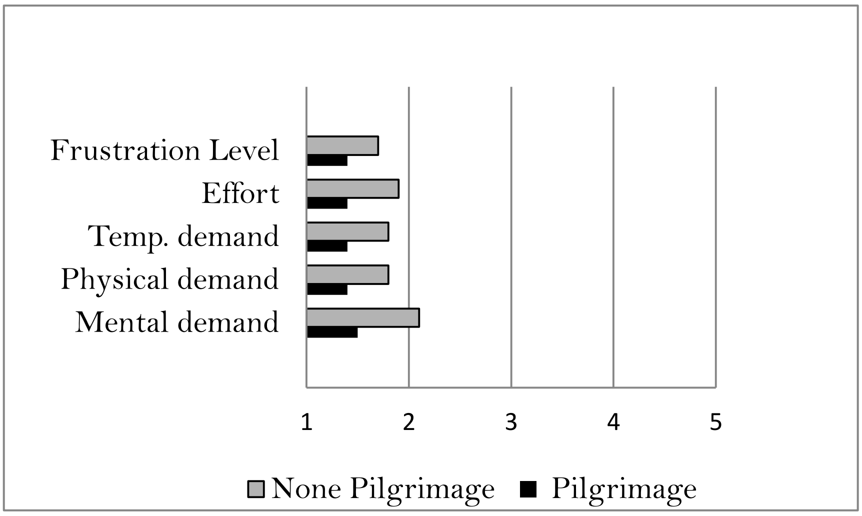

Figure 6-20 Dot condition: Average results regarding workload (scale: 1 – very low, 2 – low, 3- unsure, 4 –high, 5 – very high).

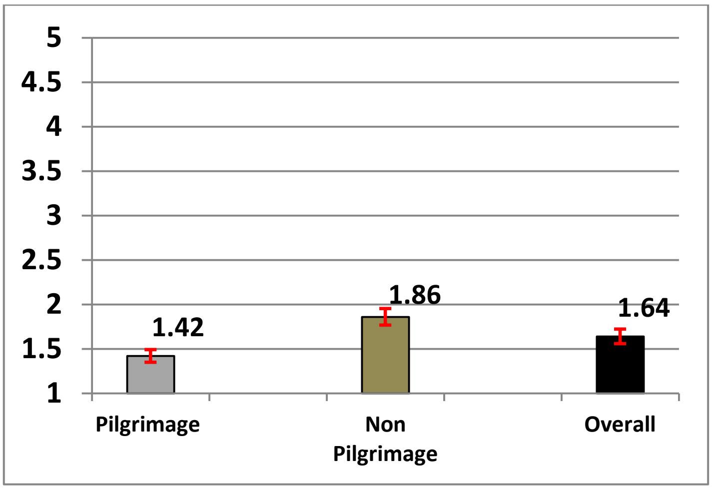

Figure 6-21 Dot condition: Average results of pilgrimage, Non--Pilgrimage, and overall for both conditions regarding workload (scale: 1- very-low, 2 – Low, 3- unsure, 4- agree, and 5- strongly agree

An independent sample t test shows a significant difference in the NASA Task Load Index, where the average value of 1.42 for the pilgrimage group was significantly different from the average of 1.86 for the non- pilgrimage group with t statistics of -4.35 and p value of 0.001 ($P < 0.01$). We can therefore conclude that the pilgrimage group gave a lower average rating to the NASA Task questions compared to the non-pilgrimage group. Here it can be said that the results for both groups in the dots condition are, for most part, in the range between 1 (very low) and 2 (low).

Symbol condition: The results of all the questions of the NASA Task Load Index (TLX) show the average results of all participants. For Q2 “Physical demand”, Q3 “Temporary demand”, and Q5 “Frustration” the pilgrimage group gave a lower load average rating while for Q1 “Mental demand”, and Q4 “Effort” the non- pilgrimage group gave a lower load average rating. Compared to the dot condition where for all questions the pilgrimage group gave a lower average rating than the non- pilgrimage group, in the symbol condition the average rating was different.

In the symbol condition the variance between the pilgrimage group and the non-pilgrimage group was equal; an independent sample t test was used again to find out if there was any significant difference between the grand averages. There is no evidence to indicate that the average value of 1.58 and standard deviation (0.20) for the pilgrimage group is significantly different from the average of 1.52 and standard deviation (0.19) for the non- pilgrimage group with t statistics of 0.68 and p value of 0.503 (> 0.05). We can therefore conclude that there is no difference between the groups and both found the tasks low in terms of load.

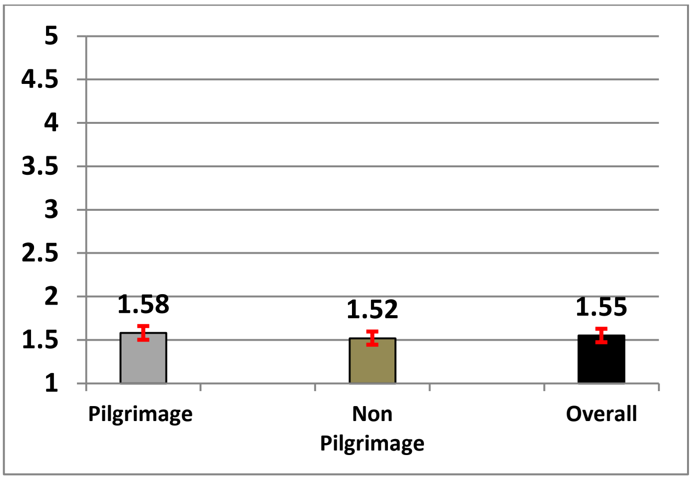

Figure 6-22 Symbol condition: Average results of pilgrimage, Non--Pilgrimage, and overall for both conditions regarding workload (scale: 1- very-low, 2 – Low, 3- unsure, 4- agree, and 5- strongly agree

Comparison between Dot and Symbol Conditions

For the pilgrimage group using the dot condition the average was 1.42 and while using the symbol condition it was 1.58. An independent sample t test indicates that there is no significant difference between these numbers with a t value of -1.78 and p value of 0.089 (> 0.05). Here, it can be said that dots tasks were less in terms of load than the symbol condition tasks.

For the non- pilgrimage group using the dot condition the grand average was 1.86 and while they were using the symbol condition it was 1.58. An independent sample t test indicates that there is a significant difference between these numbers with a t value of 3.40 and p value of 0.003 (<0.05). The result indicated that the symbol condition tasks were lower in terms of load than the dot condition tasks.

For the dot condition participants (non- pilgrimage and pilgrimage) using static signs the average regarding the workload was 1.64 while the symbol condition (for both groups) it was 1.55. Independent sample t test indicates that there is no significant difference between them where p value of 0.329 (p > 0.05). The results showed that the both conditions tasks were low in terms of load, as the workload in both conditions with both groups was in range close to 2 (disagreed). That means that overall for both conditions tasks were low in terms of load.

6.4.5.4 Qualitative Feedback

One aspect we asked participants to comment on was whether they think it would be acceptable to install displays (such as the ones used in the study) in Mecca, e.g. dynamic displays on the outer gates of the Haram and static signs in corridors. For this question respondents were asked to select Yes, No or Unsure. Respondents were given the opportunity to give a brief description for their chosen answer.

Dot Condition: Regarding the above question not a single respondent answered No in either the pilgrimage or non- pilgrimage group. The majority (80%) of the pilgrimage group were happy for the use of displays and signs. Some of the descriptions they gave to explain their answers are:

One participant said "*It is acceptable because we have heard many times that the Islamic Research Centre encourages people who specialise in the technology field to design systems which could help organise pilgrims' movement inside the Haram and reduce overcrowding*".

Another said "*I have seen a lot of CCTV cameras in the Haram, however it's not allowed for anyone to carry a personal camera to take photos. I asked someone (organiser inside the Haram) about that and he said that taking photos is not allowed because of privacy (as some pilgrims do not like photos to be taken). Regarding the many CCTV cameras installed in the Haram, he said, 'That's for safety reasons, such as monitoring the Haram for fire, for example'. This suggests that the use of technology is acceptable. This system could be helpful in many aspects such as organising pilgrim's movement and reducing overcrowding*".

Another participant said "*11 years ago (in 1999) I was in Hajj and I attended a conference regarding the efforts made to make the Hajj easier. One participant at the conference stated: "It is necessary to use technology at Mecca. Today technology is available to help people in many of their activities, so why is technology still not applied here in this Great Mosque?"* This also suggests that we can believe that this system could be accepted in the Haram and provide much needed help in Hajj situation.

Only 20% were unsure, the concern was that it may affect the style of Haram and therefore lead to changes. For the non- pilgrimage group 60% were happy with displays and signs while 40% were unsure. One participant who was happy with displays said “*I had a conversation with my father in law who has competed Hajj two times and he said that no technology was there and that people were suffering as pilgrims are expected to move without any guidance. He also added that the use of technology would be useful particularly to people who are there for their first Hajj*.” The 40% of the non-pilgrimage group who were unsure did not provide any comments.

Chi-Square test was used to find if there is a significant difference in the proportion of those who support displays/signs and group. Even though a higher proportion (80%) of the pilgrimage group support the use of displays and signs compared to the 60% for the non- pilgrimage group, there is no statistical significant difference between these proportions with a Chi-square value of 0.95 and p value of 0.329 (> 0.05). The results showed that the majority of participants (80% of pilgrims group and 60% of non-pilgrims) were confirmed that the public displays provide personalised information in at Mecca situation.

Symbol Condition: Again not a single respondent answered No in either the pilgrimage or non-pilgrimage group. All the participants of the pilgrimage group were happy for the use of displays and signs at Mecca. All participants who had experience with hajj before agreed that the system is acceptable to install in Mecca, the common suggestion was that “the displays on this system are in-keeping with the Mecca style, where the images shown on screens are familiar to pilgrims already”

For the non- pilgrimage group only 20% were happy with displays/signs while the majority (80%) were unsure. One of those who was unsure about the possibility of installing displays/signs at Mecca said “*it is useful and will make the situation of Hajj very easy but am not sure whether acceptable inside the Haram or not*” *(sic)* Another participant said *“a lot of electronic tools are installing around the Ka’bah such as cameras, and I think its allowed to install other electronic tools which could be* *providing extreme help for people there, but am not fully sure is allowed to install such system or not"(sic)* According to that, it can be said that the use of technology in Mecca is not clear yet, where there is no evidence to illustrate that technology could be accepted at Haram. All our participants throughout different stages (interviews, focus groups, user study) agree that the use of displays could solve many issues faced by pilgrims and make the Hajj easier.

Comparison between Dot and Symbol Conditions

For the pilgrimage group for the dot condition the proportion of participants who said yes to displays/signs is 80% while for the symbol condition the proportion was 100%, a difference of 20%. There is no significant difference between these proportions with a Chi-square value of 2.22 and p value of 0.139 (>0.05).

For the non- pilgrimage group the corresponding proportions are 60% and 20% respectively, a difference of 40%. Even though the difference is twice that of the pilgrimage group, Chi-square indicates that there is no significant difference between these proportions with a Chi-square value of 3.33 and p value of 0.068 (>0.05).

Another question we asked was "*Is it possible to understand and use the system (displays) without being given instructions*?"

Dots condition: A large percentage of the users felt positive that the system would be usable with little or no instructions. 14 of 20 participants (70%) agreed and they believed that the displays of the system could be used without instructions whereas 6 of 20 participants (30%) disagreed. The average was 3.45 and standard deviation was 1.28. The subjects who agreed were: 6 of 10 participants who had completed a pilgrimage and 8 who had not undertaken a pilgrimage. The subjects who disagreed were: 4 of 10 non- pilgrimage participants and 2 who had been on a pilgrimage.

Symbol condition: The majority of participants (85%) argued that the system displays contents were very clear and that people would not need to have instructions to use the system. 17 of 20 participants agreed and only 3 of the 20 participants (15%) disagreed. The subjects who agreed were: 8 of 10 participants who had been on a pilgrimage before and 9 who had not yet undertaken a pilgrimage. The participants who disagreed were: 2 of 10 who had not visited Mecca before and only one who had done Hajj before. Typical comments include "*it can be said that in the beginning user should have instructions (written or verbal) which help them deal with displays, after that maybe they can use it without instructions..*." (sic). Further comments include; "*the instructions are not necessarily for any person but it might be help for some people especially when they use the system first time*" (sic). In terms of conveying instructions on how to use the system, subjects suggested leaflets or large (static) signage outside of the great mosque. Further to this we asked participants to comment on whether they think that installing displays (such as the ones used in the study) in Mecca would help pilgrims find each other.

Dot System: Respondents were asked if installing display signs will help pilgrims. In general the pilgrimage and non- pilgrimage groups agreed that displays would be useful. The grand average for the pilgrimage group is 4.7 while that for the non-pilgrimage group is 4.3. The average for the pilgrimage group is bigger than that for the non- pilgrimage group. However, there is no evidence to suggest that the averages are significantly different with a t value of 1.52 and p value of 0.145 (> 0.05).

Symbol Condition: For the symbol condition, the respondents gave similar answers as for the dot condition. The majority agreed that displays will help pilgrims. The grand average was not that different at 4.4 and 4.3 for the pilgrimage and non-pilgrimage groups. Moreover, there is no evidence to suggest that the averages are significantly different with a t value of 0.37 and p value of 0.714 (>0.05).

Comparison between Dot and Symbol Conditions

For the pilgrimage group using the dot condition, the grand average was 4.7 while for the symbol approach it was 4.4. There is no significant statistical difference.

For the non- pilgrimage group using the dot condition, the grand average was 4.3 while for the symbol condition it was also 4.3. Again, there is no significant difference.

6.4.5.5 Preferences

At the end of the study, the participants were asked to state their first and second preference. The results are depicted in Figure 6-23. The results are depicted in Figure 6-23. The resulting score for dots condition was 1.5 and 1.4 for Symbols condition.

12 out of the 20 participants (60%) ranked the symbol condition as their first choice, 11 participants (55%) ranked the dots condition their second choice.

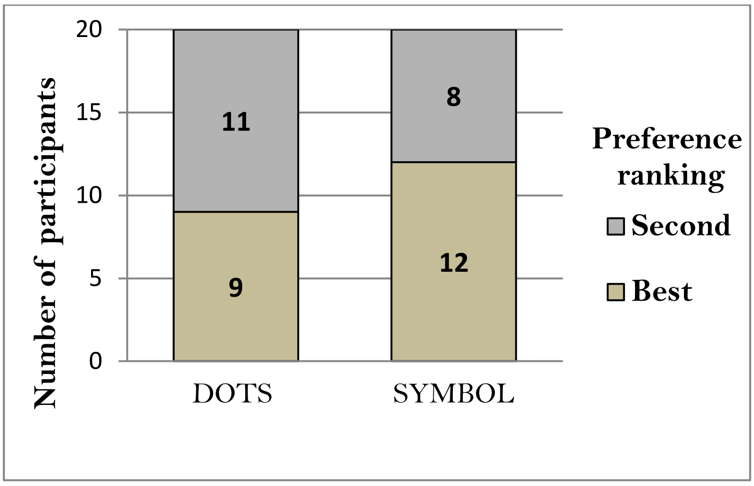

Figure 6-23 Preferences of the participants

The results showed that 11 out of 20 participants preferred the Dots condition and ranked it as the second choice and 12 out of 20 participants ranked the Symbol condition as the first choice. This occurred because 13 out of 20 participants (65%) had chosen both conditions as the best (double ticking by participants).

6.4.5.6 Summary findings

In order to determine whether the designs of augmented displays conditions (dynamic and static signs) would be acceptable and support pilgrims find each other at Mecca while perform their rites around the Ka'bah and to gain feedback from potential end users, we conducted a lab-based study comparing two conditions (dot and symbol conditions). More specifically, we were interested in finding answers to the following questions: whether or not the use of augmented displays (static and dynamic) can help pilgrims find each other inside Mecca's Haram and regroup them after becoming separated and the question of whether pilgrims can understand the displays' content and are able to extract their personalised information in crowded situation inside the Haram. In addition, how do the two conditions (Dot and Symbol) compare two groups (pilgrimage and non--pilgrimage participants) in terms of task completion time, errors, disorientation event, usability, satisfaction, and workload?

The results provided us with some initial insights into whether people can use augmented displays. We recorded all trials on video, and used the footage to take the following measurements:

Disorientation events: were counted when no direction selected with 15 seconds a sign is displayed, overall, no disorientation at all occurred when using the two conditions.

Errors: were counted when a participant selected an incorrect direction, no errors at all occurred when using the conditions.

Timing: both augmented display conditions (Dots and Symbols) ,Overall, participants were fast in the both conditions: in the dot condition, the average time for pilgrimage group was (11.63 seconds) and the average time for non-pilgrimage group was (11.45 seconds).while in the symbol condition the average task completion time for pilgrimage group was (11.80 seconds) and the average time was (11.65 seconds) for the non-pilgrimage.

Workload: The combined NASA (TLX) scores for the different conditions were as follows: in Dot condition, the average results of pilgrimage group was 1.42 and for the non-pilgrimage was 1.86. Results indicated us that pilgrimage group gave a lower average rating to the NASA tasks questions compared to the non-pilgrimage group. Regarding the Symbol condition the results showed that the variance between the pilgrimage and non-pilgrimage groups was equal, where the average for the pilgrimage group was 1.58 and 1.52 for the non-pilgrimage group. We can therefore conclude that there is no difference between the groups and both found the tasks low in terms of load.

When compared the Dot condition (both groups pilgrimage and non-pilgrimage) with the Symbol condition (both groups pilgrimage and non-pilgrimage) in terms of workload. The results showed that the both conditions tasks were low (average was 1.55 for Dot condition and 1.64 for Symbol condition) in terms of load, as the workload in both conditions with two groups was in range close to 2 (disagreed). Which means that overall for both conditions tasks was low in terms of load.

Usability and Satisfaction: The results of selected questions from the IBM Computer Usability Satisfaction Questionnaire showed that in all four categories (Usability, Satisfaction, Ease to use, and Ease to learn): the two conditions were rated best. For the non-pilgrims and pilgrimage groups using dot condition the average was 4.50 and for the symbol condition the average was 4.45.it could be said that the average results for both conditions are, in the range between 4 (agree) and 5(strongly agree). From this, one could conclude that the participants (pilgrimage and non-pilgrimage) were satisfied with the usability of both conditions tasks.

The outcomes of this study provided initial evidence that augmented signage display can be used successfully at Mecca to help pilgrims find each other after becoming separated. In general, the results showed that the two conditions were easy to use and the participants were able to read the system (displays content) and extract their personalised information, which support considerably larger numbers of people around the Haram. The Dot (background and dots) and the Symbol condition (background and symbols) were consistently rated best in almost all tests. In addition, compared to existing systems, the proposed approach offers a number of benefits. It does not require users to carry a mobile device, it works well with static signage, and it maintains the original purpose/function of the signs. The use of colours and/or symbols also makes the system accessible to people, who do not speak the local language or who cannot read at all.

6.5 Discussion and reflection

In general the results that we gathered proved to us that people can use public displays and extract personalised information to navigate from one place to another. However some shortcomings limited us from gaining full results from the study. For example, run the study in a lab instead of in a realistic environment, and the lack of crowds when we undertook the large scale user study.

Results in many terms suggested that augmented displays could be helpful in the Hajj situation. Our results showed that users completed their tasks in an appropriate time and memorised the dynamic display information. Even though we tried to clear their memories by utilising distraction tasks, they completed all tasks on the static signs successfully. Results illustrate that no errors or disorientation events occurred while they interacted with the static signs.

To make sure that the participants memorized the information they obtained from the dynamic signage, we asked each participant after they completed each task. There were no errors recorded.

In terms of satisfaction and usability, the results we obtained indicated to us that for both conditions the system was easy to understand: the content of displays was very clear, easy to use, easy to learn how to use, and simple to use. Our user study includes two long-sighted participants and three short-sighted participants. They were wearing glasses to fix their vision and completed their tasks successfully. We did not receive any negative comments from them regarding the system interface. This could lead us to say that the system may be useful for all people even those who wear glasses for any reason. A further aspect that should be mentioned here is that the lack of crowdedness might make the study tasks easy.

Workload: results showed that the participants found the tasks too easy in both conditions. In general both were accepted by all participants in all tests done. In terms of preference, participants' results illustrate that they ranked the symbol condition as the best; however a lot of them commented that they ranked both approaches the same. Some of the participants told us the Quran; however, they did not provide any evidence to support that.

We have already mentioned that the Hajj organisers used balloons with different colours to guide people to their accommodation. This evidence could lead us to the fact that technology might be used in the near future at Mecca to help pilgrims navigate from one place to another.

The other advantage of this system is that users can interact with displays without requiring any personal devices. Mobile phones are impossible to use at Mecca for several reasons (e.g. difficulty of recognising output of personal devices, access to networks, etc.).

6.6 Summary chapter

In order to find a solution for people who lose each other at Mecca while performing pilgrimage rites, we have designed a dynamic and static signage system to help in this context. It is based on a dynamic public display and static signs, from which individuals can extract personalised information. We evaluated our approach in two conditions: dots and symbols against the constraints we identified and through a lab-based user study in a simulated environment.

The results suggest that augmented display could be a promising option to improve the situation of hajj (especially when groups become separated). By installing such dynamic signs at the gates of Haram and static signs in the corridors of Haram as well, such signs at Mecca may be acceptable to pilgrims.

Becoming separated from friends and family in the Haram is one of the problems facing pilgrims (specifically at Tawaf and Saai), and the solution we proposed may help in addressing it. There is however a number of further issues such as pilgrims unable to count / remember the number of Tawaf rounds when performing the Tawaf rite: walking seven times around Ka'bah. This issue has been addressed by the Tawaf system which is mentioned in Chapter 4. In the next chapter (Discussion) we discuss several significant aspects which have been presented chapters 4, 5 and 6. For example, Mecca properties and constraints: large displays placed properly to help people perform Hajj rituals in different situations. Finally, technology devices could be used to measure some places such Tawaf area and average speed of pilgrims while walking around the Ka'bah (e.g. GPS).

Chapter Seven Discussion

7. Discussion

Finding one's way in an unknown or not very familiar environment is a common task that people experience regularly throughout their lives. A number of supporting tools are available, from conventional paper maps to modern location based services such as electronic navigation systems. Those systems provide considerable help to people in many different settings. However, almost all of these systems do not work in crowded places, for instance it can be difficult to hear mobile phone output (e.g. vibration or audio). As public displays occur more and more in public spaces, they can be used to provide personalised navigation information in crowded situations. Using augmented displays might overcome some issues that are evident in previous systems.

In this thesis we have investigated the question of whether the use of public displays can help people in crowded places *(e.g.* navigation from one place to another and assistance to pilgrims performing their tasks at Mecca), also we have investigated how people can understand the augmented display's content and their ability to extract relevant personalised information. Through the three studies that we have done, we have concluded that augmented displays may provide considerable help for people in different settings. For example, the participants of all studies were on average 'somewhat satisfied' in terms of task completion time, work task load, error rate and disorientation events, usability and satisfaction. In addition, we concluded that people can use and understand the content of displays easily; results showed that participants in all studies performed their tasks successfully. We can say that an augmented display can be used for the provision of personalised navigation information to people in different situations.

Through this chapter we will also discuss some important positive and negative points of the thesis such as results, comments and suggestions relating to our three studies, participants, and other significant aspects which were extracted when the results were analysed. We have researched and investigated many sources to increase our understanding about the environment in Mecca such as interviews and focus groups with people who have experience with Mecca, It could be said that Mecca has very specific and unique properties and constraints. The sources provided us with knowledge of several key proprieties and constraints, which allowed us a better understanding of the situation. The results that we gathered from all our studies provided us with evidence that the dynamic signage and public displays might improve the situation at Hajj in terms of reducing the crowds, helping people to remember and count the rounds of Tawaf, and to allow people to meet again after they have become separated. The evidence has been extracted from several aspects such as participants' feedback via questionnaires, video observation, and qualitative feedback. The augmented signage study was a good example which shows that augmented displays can help people in their navigation; results in this context illustrated that people can understand dynamic signage content, extract their personalised navigation information and reach their destination easily. This led us to the realisation that colour coding via augmented displays may help people move confidently around an unfamiliar space or help them to perform their activities in different settings.

Generally, our three studies provided some initial insights into whether people can use augmented signage in different settings. There are some shortcomings that limit the generality of the results we obtained. One of these issues relates to the lack of realism: participants of studies had to physically move to perform the tasks. 27 participants walked seven times around the simulated Ka'bah (the cube shape that we built), this amount of walking was very small compared to the actual amount of walking in Mecca around the real Ka'bah. In actuality, the number of people at Mecca reaches 2 million. We would have preferred to test both Mecca studies in the actual environment, as crowdedness and other aspects were lacking in the lab studies. Many reasons (mentioned previously) prevented us from running the systems there. In addition, another eighteen participants had to physically move to select a direction while they dealt with the signage (arrow/base, colour, and symbol) In case study 2, this movement was very small compared to the amount of walking that would be required if this system were deployed in the real world. The difference is particularly related to the lack of crowdedness, which is hard to emulate in the lab. We varied the overall complexity of sign within very narrow boundaries (i. e. between five and nine items per sign), whereas in the real world, sign complexity can vary more widely, (e.g. in terms of the layout, number of items and directional indicators being used).

While a real-world test with an actual deployment would overcome these issues, there are some considerable safety implications that this would incur. It can be said that all three studies were done as lab-based user studies and all participants had to physically move to perform the tasks.

The interfaces we proposed for the our scenarios rely on people extracting personalised information from the augmented displays content by themselves, based on their relative location at the time of interaction with the system. These approaches can be generalised to the principle of *'manual' context-driven personalisation of public display content*, where users effectively adapt what they see on the screen based on readily observable contextual factors such as time or location. For example, in the Tawaf system, the screen content in turn is designed to facilitate mapping to the real world scenario – in our case; we visually mirrored both the layout of the deployment location and the motion of people around the Ka'bah. While we will further explore the applicability of this idea in the context of other problems we identified for the Hajj, we believe that it can be applied to a broad range of interfaces for large crowds, with some beneficial side effects compared to alternative solutions.

A dynamic timetable display at a train station is a very simple example, where this principle can help people. Travellers can extract personally relevant information from the public display using the contextual factor 'travel destination'. (In this example, the visual 'congruence' with the real world setting is however limited).

A more complex scenario would be a system to minimise waiting times and navigation effort to different attractions in a theme park. In this case, upon entry to the park, visitors could 'acquire' an individual colour-number key similar to the one we used in our approaches. Contextual factors used in this scenario are 'time of entry' and possibly 'location of entry'. This key could be printed on the ticket and then be used by public displays to distribute people more evenly over all the attractions, e.g. by providing fast-track access to specific attractions for a group with a specific colour-number key, or by directing specific groups to particular locations.

Other aspects regarding our three studies will be discussed in detail in the following sections.

7.1 Summary of *design issues* and hypotheses and how they developed across the three case studies

Three key requirements emerged from our background research. Systems supporting pilgrims while perform their rituals around Ka’bah would need:

1) To be usable by a large number of pilgrims simultaneously, who also vary greatly in terms of their cultural background and abilities.
2) To be easy to learn (as almost all users would be first time users, i.e., pilgrims on their first pilgrimage to Mecca).
3) To interfere as little as possible with the main (spiritual) task. Due to the religious significance of the site, it is also desirable to minimize any modifications or changes to the site.

Based on these considerations, we created initial designs for both Mecca systems. When we presented the initial design to the focus groups, it attracted positive comments regarding the use of an augmented display (dynamic signage case study 1 and dynamic / static signs in case study 3) as the basic means of delivery and also with respect to using colours and dots/symbols to relay the round count in case study 1 and regroup pilgrims in case study 3. The main critique that emerged from the focus groups of the case study 1 was the overall complexity (i.e., the large number of colours, wedges combined with the continuous rotation), which participants considered problematic. This feedback was expected, as we were assumed that the initial design of the Tawaf system was complicated.

In response to the feedback, we modified and simplified the design. The resulting system was subsequently evaluated through a lab-based user study. With regard to the case study 3, the main critiques that emerged from the focus group were: the large static signs which we proposed to install at the beginning of each corridor should be removed from the system, and we should use static signs inside a corridor only. Using those signs at the beginning of corridors will increase crowding as people will stop to look at each of them to find their wedges. Increasing crowds will make the situation more complicated. Once pilgrims have completed their rituals around the Ka’bah, they should enter the closest corridor and search for their colour and dots on the static signs which are installed in that corridor.

The second critique was, eight dots will be shown on displays of this system, this number could be confused and be difficult to remember, to avoid that they suggested that the maximum should be six dots, in the Dot condition. Regarding the Symbol condition, only one comment was about symbols, they suggested that famous symbols should be used. All focus groups suggestions and comments were taken into account. Our hypothesis regarding case study 1 was ‘ we assumed that the dynamic signage rotating on screen display will help participants to keep track by remembering the round count without any external cues while they walking around the cube ‘simulated Ka’bah’. With regard to case study 3 our hypothesis was ‘all participants (both groups: pilgrimage and non-pilgrimage) will interact with the system in both conditions (Dot and Symbol) and remember the dynamic signage information and matching them with the static sign information successfully.

Furthermore, we thought that the pilgrimage group will be more interested than the non-pilgrimage while using the symbol condition, as they had visited Mecca before and had seen such symbols around the real Ka’bah. Generally, the results of both Mecca studies supported our hypothesis, where all participants of both case studies completed their tasks successfully as expected. However, in case study 3, the result was contradicted the hypothesis in the case of pilgrimage and non-pilgrimage, where the results obtained that the non-pilgrimage were more interested than the pilgrimage group when using the symbol condition and the non-pilgrimage group was more interested than the pilgrimage group while using the dot condition.

Regarding case study 2, the study provides some initial insights into whether people can use augmented signage, but there are some shortcomings that limit the generality of the results we obtained. One of these issues relates to the lack of realism: while participants had to physically move to select a direction, this movement was very small compared to the amount of walking that could be required if the system were deployed in the real world. Another issue related to this is the lack of crowdedness, which is hard to emulate in the lab without compromising the safety of participants. Finally, we varied the overall complexity of sign within very narrow boundaries (i. e. between four and nine items per sign), whereas in the real world, sign complexity can vary more widely, e. g. in terms of the layout, number of items and directional indicators being used.

A real-world test with an actual deployment would overcome these issues but could also incur considerable safety implications in case of dense crowds. A more realistic simulation environment could thus be a sensible intermediate step. In general the result supported our hypothesis that 'we assumed that both augmented signage designs can provide personalized directions to any number of users, their scalability is limited by the number of simultaneous destinations they support. The coloured circle design allows for as many destinations as there are colours'. The result supported our hypothesis and showed that the coloured circle is the best choice for the user study participants, followed by coloured symbols.

Generally all the methods that we used in the three studies worked well and provided good evidence that augmented displays can be used for supporting navigation for large and heterogeneous crowds in different settings.

7.2 Discussion of the strengths and limits of the experimental methods

The design and evaluation of the interface to support large crowds during the Tawaf ritual posed several challenges. After our initial investigations into the scenarios, it was clear that the density of the crowd was a key factor to consider. This raised the question how we could simulate that aspect convincingly without compromising the safety of our participants and without having to recruit large numbers of subjects. Our approaches were to scale down the location so that we could achieve a relatively high density of people with a relatively low number of participants. In the case studies (1 and 3) we attempted to make the studies environments similar to the real area. Several shortcomings we faced such as lack of crowds, small experimental area compared to the actual situation, and real atmosphere of the real situation (i.e. participants who had pilgrimage at Mecca informed us that there is special feeling while walking around the Ka'bah). For example, our investigation of the Tawaf scenario (case study 1) and the user study we conducted to evaluate our design also yielded some insights with respect to the design of system to support navigation for large crowds. We identified the approach of context-driven personalization of public display content as a promising way to provide adaptable support for very large numbers of diverse and concurrent users. In addition, we highlighted some issues pertaining to the evaluation of interface for large crowds, i.e., the difficulty of creating a realistic simulation in the lab and how to best progress from small-scale tests such as focus groups to larger scale studies prior to real-world deployment. The same is true with case study 3, we highlighted some issues such as the difficulty of creating a realistic simulation in the lab, i.e. the issue of the lack of realism, while participants had to physically move from the area of Tawaf walking to the corridors to find their information on the static signs, this process was small compared to movement in the real environment.

In case study 2: augmented signage, there are some shortcomings that limit the generality of the results we obtained. One of these issues relates to the lack of realism: while participants had to physically move to select a direction, this movement was very small compared to the amount of walking that could be required if the system was deployed in the real world. Another issue related to this is the lack of crowdedness, which is hard to emulate in the lab without compromising the safety of participants. Finally, we varied the overall complexity of sign within very narrow boundaries (i. e. between four and nine items per sign), whereas in the real world, sign complexity can vary more widely, e. g. in terms of the layout, number of items and directional indicators being used.

Regarding the actual use of the systems, the results suggest that augmented signage may be a promising option for improving safety during Hajj and that the installation of such signs around the Ka'bah may be acceptable to pilgrims.

Case study 1 emphasized the importance of the rotational speed of the dynamic sign, and we discussed several options to achieve a high degree of synchronicity between the people circumambulating the Ka'bah and the sign (e.g. (e.g., using GPS-based tracking of a few pilgrims).). Losing track of the round count is only one of the problems facing pilgrims (specifically at Tawaf and Saee), and the solution we proposed may help in addressing it. With regard to case study 3, we discussed some ideas about how the displays might be installed in the gates of the Haram (dynamic signage) and distributed through the corridors of the Haram (static signs). We suggested that the displays should be installed in an appropriate place at a gate, so everyone could read them when passing the gate. We could use video analysis to determine how long each sign stays showing on the screen display. In addition, we could use a few pilgrims to investigate whether or not the static signs distributed through the corridors were placed correctly and that people can extract their information easily.

Install Public Display at Mecca: based on the results that we obtained from the participants of both Mecca case studies, we can say that the majority of participants suggest that it might be possible to install public displays inside the Haram. Many comments regarding this idea have been gathered. These results support the results that we gathered from comments in interviews, and focus group suggestions, as they also suggested that installing displays at Mecca is acceptable. For instance, the subjects' trialling the Tawaf system commented that "there are a lot of CCTV cameras installed in different places inside the Haram which are used for keeping people safe, this might indicate the possibility of using augmented displays (navigation technology) to assist pilgrims inside the Haram".

We have asked some people who specialise in the Islamic religion (e.g. Mosques Imams) about the possibility of installing systems such as these at Mecca (after we explained to them the purpose of our systems and how these systems could provide help to pilgrims to solve/overcome some issues such as Tawaf circuits or finding each other once they had become separated while they are in Mecca's Haram), almost all of them concurred that nothing in the Quran prevented the use of technology inside holy places especially those tools which provide help to people in performing their pillars. The people we asked about this context are currently working in Newcastle city mosques (as Imams) and they are staff members of Newcastle Islamic centre, as in this city there are more than 10 mosques, some of them associated with the Islamic centre.

We investigated with four Imams and they were agreed that technology such as is evident in our systems will provide considerable improvements at Mecca and will make the situation of the Hajj easier. They also believe that the use of systems such as these would be accepted. One of them provided us with an example to illustrate this situation, he said "technology is acceptable for use in holy places to help people doing their rituals, for example we usually use digital display in Mosques when giving lectures and presentations". Currently, in almost all of the mosques there are one or two large displays, because the Friday prayer is so crowded, some mosques use the second and third floor for prayer. People sit there to perform Friday prayer; in this prayer the Imam must give a speech to those in attendance. So the displays are used to allow those who sit on the first floor and other floors to watch and listen to the speech.

A further comment was "anything which helps people to perform Islamic pillars is acceptable. From the religious side it is accepted but installing them at the great Mosque may require a lot of approvals".

It can be said that we received many indications that installing displays such as the ones that we used in our studies is acceptable. We investigated this with many kinds of people, as we interviewed a large number of people to collect data about Mecca. We asked them about this and they all believed that it would be acceptable. The same was true with the focus group members who discussed our studies. In addition, the user studies subjects' comments suggest that displays could be used displays inside the Haram. The information that we gathered from different people led us to believe that the displays could be placed at Mecca and might provide considerable help to pilgrims there.

Regarding the people to whom perhaps the display could represent an unwelcome distraction, our investigations which resulted from different sources (interviews, focus groups, Imams of the mosques, and some people who expert in religions) indicated that pilgrims will be satisfied and perform their rites through these systems. However, our opinion about this situation is different, as we think that there are some pilgrims will not satisfied with these technologies and they consider the displays is a kind of distraction and take pilgrims away from the spirituals of the Hajj.

7.3 Discussion of Measurements

Timing: Based on the questionnaire and video analysis of all three studies, we noted and observed that the completion time of all tasks were suitable except for a few participants using the arrow condition of augmented signage. As we noted and observed, the completion times for both augmented conditions (colour and coloured symbol) were lower than the non-augmented case. These results were expected and confirmed to our hypothesis. In addition, a few participants commented that the rotation speed of the system was not optimal while performing the tasks in the Tawaf system 'case study 1'. This is a critical aspect though, as the function of the system hinges on the sign being synchronised with the movement of the pilgrims around the Ka'bah. Ideally, the system would sense the movement speed of the pilgrims but for the study, the speed was set manually based on measurements from a pre-test with a small number of participants.

An interesting alternative approach would be to investigate whether the system could actually be used to 'induce' a particular walking speed (thereby potentially contributing towards increasing the overall safety). Several technologies could provide a means of measuring the speed at which pilgrims walk around the Ka'bah. For example, a video camera could observe the area around the Ka'bah and compute the speed based on difference images and/or flow rates. Alternatively, a small number of employees could be fitted with tracking devices (e.g. GPS-enabled mobile phones) and be tasked to continuously walk around the Ka'bah with the crowd. Their movement could be transmitted to the dynamic signage system in real-time to adjust the rotation speed.

Due to the large size of the area, it is possible that the average 'angular' speed at different distances from the centre varies considerably (although we did not find clear evidence of this when reviewing available video footage). One possible solution to this problem is to install several displays at different distances to the Ka'bah (e.g. above head-height along the starting line), which rotate at different speeds (i.e. corresponding to the pilgrims walking at a particular distance from the centre). However, this approach might lead to cluttering the area with displays and could thus be perceived as obtrusive. Alternatively, a single display could be used but instead of showing a single circle divided into wedges, the screen could display a number of concentric bands. These could each be subdivided into wedges (where dots appear upon completion of a rotation). The bands could rotate at different speeds, which correspond to the average walking speed at different distances from the Ka'bah. A drawback of this solution would be an increased complexity of the screen content.

In order to design a version that could be deployed at Mecca, the next step is to gain a better understanding of how pilgrims move during busy times. Once more detailed information about the walking speed is available (including patterns of motion and change over time), the interface of the dynamic signage system can be adapted accordingly. Consequently, the results were supported by our hypothesis, as we assumed that the participants' speed while walking around the cube will correspond to the dynamic signage rotating speed.

Through the video of case study 2 we showed that participants completed their tasks relating to the colour condition in an optimum time (10.8 seconds) compared to the other two conditions (Arrow and Symbol). The typical comment was “users interacting with Arrow/base signs spent more time finding their information, as they needed to read all the information available, especially when their information appeared at the end of a sign”. From this, one can conclude that the users found the colour condition faster than the symbol or arrow to use, as in the case of the colour condition a person is just searching for colour (e.g. blue) regardless of the text (as in the Arrow condition) or symbol name (as in the symbol condition). In other words, we can say that the symbol condition was faster than the arrow; this means that the participants completed their tasks using colour and symbol approaches (which used augmented signage) in an optimum time (10.8 sec and 12.64) respectively, while they took much longer (16.33 seconds) to complete their tasks when using the arrow condition. Furthermore, there may be a case where a user is navigating in an unfamiliar environment and wants to check their destination on a sign. So the dynamic display-based colour codes would be the best choice for obtaining their information quickly and easily. The results suggest that the coloured circle was the fastest condition, followed by a coloured symbol, and the Arrow condition. This confirmed and support our hypothesis that the augmented signage conditions (coloured circle and symbol condition) will support people in their navigation in terms of delay and saving time. Also we presumed that the arrow condition would be the worst condition.

Through the video analysis we noted that the participants of the third study completed their tasks in an optimal time compared to the sign’s determined time (15 seconds). The tasks average completion time when using the dot condition was 11.6 seconds for pilgrimage participants and 11.4 seconds for non-pilgrimage participants. For the symbol condition it was 11.8 seconds for pilgrimage participants and 11.6 seconds for non-pilgrimage participants. In terms of task completion time, we noted that there is no difference between people who had completed a pilgrimage before and those people who had never visited Mecca before; the task completion time for all participants using both systems was lower than the sign time suggested. This led us to the fact that the system (both systems) was very easy to use and simple to extract personalised information from. A further key factor we noted was that the participants who had not visited Mecca before performed their tasks in the same amount of time as those people who had completed a pilgrimage before. This indicated to us that a person who will use this system does not need to be familiar with the situation at Mecca (i.e. new pilgrims visiting Mecca for the first time can easily use the system). Through the measurement of the task completion time, we noted that the result was supported our hypothesis in term of task completion time. As we expected that the participants of all case studies will perform their tasks in ideal time.

Workload: We observed that there was a very low workload across all three studies with the exception of two conditions in case study 2 (Arrow and Symbol). Through the comments that we have obtained about the tasks for the Tawaf study, we noted that all participants were able to perform the tasks easily, suggesting that the workload is very low. Based on the comments and video observation of the Arrow/base condition, we found that the majority of participants commented that the content of the Arrow signs requires more thinking than the augmented Colour and symbol approaches. The typical comment was “when users interact with Arrow signs they have to spend more time finding their information, as they need to read all the information available on the sign, this is especially relevant when their information is listed at the end of the sign”. It was difficult to find the information that a person was looking for. It can be seen that the colour condition outperforms both the Arrow and Symbol approaches considerably when considering the amount of mental demand. The results of a NASA TLX questionnaire showed that using the Arrow condition requires a higher mental demand than both the colour and symbol approaches. However, pertaining to mental demand, the results for the symbol condition was slightly better than for those using the Arrow case. For the Arrow condition the range was a bit higher in some sections of the NASA questionnaire, for example, scoring 4 (high) in frustration and mental demand. Results obtained that the load level of the case study 2 tasks was somewhat satisfied. This supported our hypothesis, as we hypothesised that augmented signage conditions tasks will be perform in low load and the Arrow condition will be a bit high load.

With regard to the both conditions of case study 3, the load average was in the range between 1(very low) and 2 (low), as we hypothesised From this, one could conclude that the participants scored workload as ‘low’ in the majority of the studies’ tasks.

Error rate and disorientation events: The results showed that with the exception of two errors that occurred in the case study 2, no other errors have been recorded for the subjects completing tasks in the three case studies. Both errors were observed in participants using the symbol condition, and we observed one disorientation event during the symbol approach in the augmented signage study. We expected that few errors or disorientations event could be occurred when using the symbol condition of case study 2, as a lot of symbols and colours might be confused the users. In addition, only one participant of the Tawaf study became confused while he was walking around the simulated Ka'bah (cube shape) and he immediately recovered, he later commented, "*I started my walking and memorised my colour and dots and everything was going well, suddenly I forgot how many rounds that I had completed, I continued and did not stop walking, when I arrived at the display I found six dots on it, then directly remembered that I had completed six rounds.*" It could be said that the subjects of the studies have completed all tasks successfully. So we can argue that this is a result of the ease and clarity of the approach' interfaces which allowed users to interact with them and easily access their personalised information.

Generally the number of errors (situations in which the participants left the predefined destination) was very low in all three studies. In total, only 2 errors occurred when the symbol in augmented signage was used (second study). No errors at all occurred when participants completed the tasks of Tawaf and also the third study. Disorientation events were counted when the participants stopped or were stuck for a predetermined time. This occurred once when trialling the symbol approach in augmented signage (we only observed one participant unable to select a direction within the 20 seconds that each sign appeared on the screen) and never occurred when participants completed tasks in other studies. In addition, the results showed that users can be easily guided from one place to another via dynamic signage supported by colour and visual codes. This indicated us that the augmented displays may provide considerable help to people in different situations. Pedestrians can obtain their personalised information by remembering a particular colour then use it to perform their activities (e.g. navigating from one place to another until reaching their destination).

In order to count the error rate of the participants while reading the dynamic signage of the third study we prepared a sheet for each participant to register the information that he/she obtained from the dynamic signage. This occurred once they had completed the static signs tasks. Through reading those information sheets and comparing them with the video (as the study was recorded audio and video) we did not register any errors, all participants had memorised the data that they got from the dynamic display while completing the dynamic signage tasks. Despite taking part in distraction tasks, they still remembered the information. This indicated to us that the information shown on the dynamic display was easy to understand and simple to memorise, even for long periods of time.

Based on this we can say that augmented signage might be useful to pilgrims at Mecca, as once people enter into the Haram they have to spend a lot of time doing their rituals. In general, after we investigated all three case studies, a few errors and a few disorientations within these studies provided us with good evidence that a colour code might be of assistance to people in different places and supply them with explicit cues to perform some particular activities such as performing Hajj pillars at Mecca or when navigating from one place to another in a public space. In other words we can say that the results lead us to the fact that people can understand the augmented display content and benefit from them in their navigation in different settings.

Usability and satisfaction: Through the results we gathered from all our case studies, it was very clear that the participants of all the case studies were very satisfied while they interacted with the interfaces. The majority of participants emphasised that the systems were very easy to use and simple to learn how to use. The content of the systems' displays were very understandable, the ratings in the different USE questionnaire which we used in case study 1 'Tawaf system' and case study 2 'augmented signage system' were high, the same is true for the third study where the IBM computer usability satisfaction questionnaire was used. Many comments illustrated that the participants of the Tawaf system were satisfied, for example, "display content was very easy to use and simple to learn how to use", another comment states, "it was easy to distinguish between colours and the size of white dots was reasonable". In contrast we have discovered a few negative comments through reading the participants' observations which were relevant to case study 1 and case study 2. A common observation of participants taking part in case study 1 was "the size of white dots and display should be appropriate to the situation" and a typical comment regarding the augmented signage (case study 2) was "the symbol condition was fun and a good idea but the use of the same colour with more than one symbol was a bit confusing, e.g. yellow star and yellow cross". Some other comments mentioned that "when a user finds a particular colour repeated in many items of the sign, this make the sign a bit complex, as a user will try to check all of them until they find their symbol". This issue may be resolved by using more colours (i.e. each symbol has particular colour). One of our considerations was using primary and secondary colours to avoid user's confusion and enable them to easily distinguish between symbols; therefore we have used only certain colours. One participant commented that "a lot of the same colour on one sign made me a bit confused whereas different colours such as the sign used in the colour was much easier to follow and easy to recognise, where a user directly identifies his/her colour, there is no need to remember the symbol". A further comment which was gathered from the majority of participants was "the arrow signs were very boring and not attractive". Here we can said that these results were confirmed our hypothesis, as we expected that the usability and satisfaction of coloured circle condition (case study 2) will be high with slightly better results for coloured symbol.

Seven participants who were categorised in the non-pilgrimage group commented that "the size of the white dot which was shown on the dynamic signage should be a bit larger to be clear to all people". All pilgrimage participants emphasised that symbols used should be recognisable and understandable by all people and avoid using the similar symbols. One participant commented that "Islamic symbols are more appropriate to use in the environment of Mecca than dots, where many symbols already exist in some positions of the Haram".

In terms of improving the Tawaf system, the users' comments suggest that the underlying concept of extracting personalised information from a public display based on their relative position can be understood and used but the actual implementation (choice of colour, size of wedges, and size of the screen) might have to be adapted. The comments and suggestions from the third study were generally about colour choice and symbols selected and that it could be easily adapted. Three participants commented that it is very important to give instructions (on how to use the system) to the user before they start to use the system. As well as this a few participants mentioned that instructions are necessary when using the symbol condition of case study 2 and that it is not necessary to have instructions when using the colour condition. Almost all of the Mecca case studies participants suggested using advertisements to let people know about the systems and how people can deal with them. They emphasised that pilgrims should know about the system before starting the Hajj. We therefore proposed that “the people who intend to visit Mecca should have full information about the systems before travelling there, e.g. by leaflets or guidebooks which mention how the system works and how a person starts to use it. A further option proposed is that it could be distributed as a leaflet among pilgrims while they are travelling to Mecca on airplanes or ships, as well as some explanation about how they can use the system by people who are experienced in using it. Another option is that many advertisements via several displays are installed around Mecca city, Jeddah airport, and Elmadina city to show the steps of how the system works. In general, it could be said that the average results for all studies are, for the most part, in the range between 3 (neither agree nor disagree) and 5 (strongly agree). From this, one could conclude that the participants were on average ‘somewhat satisfied’ with the usability of the three studies interfaces.

Video observation: Regarding the participants behaviour in all case studies, the video recording of case study 1 showed that that 7 - 10 (out of 27) stopped at the display for two or three seconds, a few participants (5 out of the 27) looked back to make sure of the number of white dots which appeared on the coloured wedge, and some participants (10 out of 27) talked to each other whilst walking. This can be seen as a disadvantage of the Tawaf system as it is easy to avoid those behaviours by following the instructions given before starting the tasks. In contrast, we did not observe any participant exiting before his tasks were completed. Also no-one became confused about which direction to walk in, i.e. all participants were observed walking in the correct direction (counter-clockwise as pilgrims walk at Mecca around the real Ka’bah), also we observed that the participants used the next gate to exit once they had completed the correct number of rounds, and did not turn back to a gate to exit. This can be seen as an advantage of this situation. Regarding the case study2, we did not observe any irregular behaviour, except for two participants. One of them tried to point his pen to the screen to indicate to us that he had found his destination, this occurred only one time. We also observed another participant who voiced his destination aloud; this behaviour was observed once only. We do not consider these as disadvantages because their results were successful and no any errors or disorientations were recorded. We also observed that 6 out of 20 participants in the case study3 stopped for a little time (2 to 3 seconds) after they read the sign and then moved their foot to indicate a particular direction. This action was noted only in the first and second trials of both conditions (symbol and dot). Also we observed that 3 participants didn’t move their foot but they moved their whole bodies to the right direction. (i.e., they walked one step in the direction that they perceived to be correct). In general, we can say that happened because the participants did not follow the instructions which were given to them before the studies started. In addition, those few irregular actions did not influence on their performance, as they all completed the studies’ tasks successfully.

Generally, all the three case studies provided initial evidence that augmented signage can be used successfully with little training and without incurring large penalties in terms of delays, workload, errors or disorientation. In general, the majority of the case studies participants performed their tasks successfully and they were satisfied. In addition, the results that we gathered through the three case studies were supported and confirmed with our hypothesis.

7.4 Chapter Summary

As a conclusion we can say that there are a few negative comments which have been found through reading the participants comments. For instance, a few participants of the Tawaf system trial noted that their walking speed did not correspond to the display rotation. The use of GPS-enabled mobile phones is one of the options that have been mentioned which can be used to measure pilgrims’ speed and resolve this issue. Also some comments mentioned that the Arrow condition for the augmented signage study was boring and a waste of time while users extracted personalised information. A few participants (3 out of 20) stated that they became confused between symbols while using the symbol approach during the sign study.

We attempted to overcome some drawbacks of static signs which we mentioned previously in this study. The results indicated that the colour condition has the highest priority in terms of usability satisfaction, workload, and task completion time. It could be said that the participants were on average ‘somewhat satisfied’ with the usability of the other two conditions. The majority of participants commented that a system such as this could be used in a public space to improve pedestrians’ navigation. A typical comment was “the colour condition could improve the pedestrian situation clearly because it is very easy to use and simple to learn how to use". The other suggestion which was provided by many participants was that the augmented signage supported by colours and symbols was a very good idea to enhance pedestrians' navigation field and could overcome the issues associated with conventional signs and aid people in getting up-to-date personalised information quickly, and easily.

Pertaining to the third study, only one participant commented that "it would be better for pilgrims to reach their corridor quickly", he suggested that if we placed a big coloured sign on the top of each corridor from the Ka'bah side, each sign should have a particular colour, e.g. blue to direct people to the blue wedge / corridor and so on. Here, we can say that we considered this idea and presented/discussed it in the focus group sessions, however they rejected this idea. They said that the area (where we decided to place the large static sign) was always crowded and it would not be possible to see that sign. In this context it would make the area more complicated, as everyone who is looking for his/her wedge would stop in that position to try to read a sign. Generally, the results that we gathered such as no errors and no disorientation events recorded provided us with good evidence that the participants understood and memorised the information they obtained from the dynamic signage.

In general, based on the results we have gathered from many sources such as a series of interviews, several focus group sessions, and user study subjects, we can say that our three approaches have provided considerable help to people in different situations. Moreover, results which were gained from all three studies suggest that the augmented signage supported by a colour code could help people in crowds and in unfamiliar environments.

The next chapter relates to the conclusions. It presents some results from the studies that we have done, then introduces the major and minor contributions of these systems and how they can improve crowded situations in different settings. Afterwards we discuss future work; talk about some other situations that involve crowds and look at how we could develop augmented displays to solve related issues.

Chapter Eight Conclusion

8. Conclusion

In order to provide support for large and heterogeneous crowds in different settings, we have developed and evaluated three approaches via augmented displays and colour coding. All three studies have used augmented displays which are supported by visual and colour codes. One of our research goals is in developing systems which help people navigate in crowded environments regardless of their cultures and languages, i.e. designing a system interface which can be understood by anyone even those people who are unable to read. In case study1 we designed a dynamic signage system which helps pilgrims to keep track of Tawaf rounds while walking around the Ka'bah. We designed the system based on the environment at Mecca (proprieties and constraints), and based on the analysis of interviews and focus groups' feedback which we undertook with people experienced in pilgrimage. So, the dynamic signage was divided into eight different coloured wedges and rotates on the screen display. A white dot appears on that coloured wedge once it has completed a 360o rotation which indicates to a person that he/she has completed their first round (details are mentioned in Chapter 4).

In case study 2 we again created two designs for the augmented signage using visual and colour coding but with different interfaces to support large and heterogeneous crowds navigating in unfamiliar space. We compared these two augmented signage conditions to a base/arrow condition in several areas such as tasks completion time, error rate and disorientation events. In addition, by designing this study, we hoped to overcome the issues of existing systems (e.g. static signs or mobile guides issues). The coloured-circle condition was designed by adding coloured circles to items which are shown on a sign. Each colour refers to specific destination, a user is just required to remember the colour and then follow the arrow shown next to the entry regardless of whether that entry reads or not (here also a user does not need to be familiar with a specific language). So a user can reach his/her destination based on colour and arrow directions shown on a sign. The coloured-symbol condition contains both symbols and colours; in this case a user should remember two things: a colour and a symbol (e.g. yellow star or green moon) and follow the arrow shown next to the entry in order to reach their target destination. Then we evaluated and contrasted these two designs against a base condition which was designed as a conventional sign (entries followed by arrows). The system was compared in a user study with conditions presenting the destination information on an augmented display, i.e. we introduced a scalable signage-based approach and presented results from a comparison study contrasting two designs for augmented signage with a baseline case. People can use the visual codes to extract individual directions from signs. The suggested approach addresses some drawbacks of existing systems such as the requirement for everyone to carry mobile phones or the limited scalability in terms of the number of simultaneous uses.

With regard to case study 3, again we developed an augmented display using visual and colour coding but with new interfaces to support and help pilgrims to be a group after being separated. These two augmented conditions have been designed to support large and heterogeneous crowds to navigate around the Ka'bah. We compared these two augmented signage conditions through two groups of people: pilgrimage and non-pilgrimage in terms of tasks completion time, error rate, disorientation events, and workload. In addition, by designed this study, we intended to overcome the drawbacks of traditional methods that pilgrims follow to perform their rituals around the Ka'bah (e.g. human guide.). This system consists of two conditions (dot and symbols), each condition includes dynamic and static signs.

In the actual environment at Mecca, a dynamic signage will be installed at each gate of the Haram, and pilgrims will read a sign while passing a gate. Dynamic signage is designed to show dots (in dot condition) or symbols (in symbol condition) on particular background, e.g. a blue background and number of dots or symbols. In the dot condition a sign will show a particular background and a number of dots, it might be 1, 2, 3, 4, 5, or 6 dots each time. In the symbol condition a sign will show eight different backgrounds, each background will show a symbol (six Islamic symbols will be used in this condition). A user will read the dynamic signage and memorise the information that they gathered to use in the second part of this system (static signage).

The second part of the system is static signs and these will be installed in the corridors of the Haram. Here the static signs again include two conditions (dot and symbol), dot condition (background and a number of dots [from one to six] per time) and symbol condition (background and one of the six Islamic symbols each time). Each static sign is divided into two parts: the upper part shows the background colour and the lower part shows eight colours, some of them are associated with arrows and some are not. A user will utilise the dynamic signage information and match it with the static sign information.

In experiments when they had found the same information shown on static sign they had to put one of their feet onto the mark around the edge of the circular mat that corresponds to the direction. If a user found only the colour without an arrow direction on the lower part of a static sign then a user should move their feet forward. In the real situation when a person found a colour without an arrow, then s/he should continue walking along that corridor to find the next sign, in the worst case they will find their information on the last sign of the corridor. Here one can say that in all three systems we developed augmented displays via visual and colour codes. Results showed that users can easily understand the contents of displays and extract their personalised information quickly, easily and successfully. This led us to the fact that augmented display via colour codes can be developed and used in different settings to help large and heterogeneous crowds to extract their navigation information individually. As in all systems that we designed, a user is only required to remember a specific colour and a visual code (e.g. blue and 3 dots in the first and third case studies, or a colour and a symbol in the second and third case studies).

We can conclude that the augmented display has been developed to show different interfaces to support large and heterogeneous crowds in different settings. All interfaces used colour and visual codes to help a large number of people in different situations, as colours and visual codes are easy to understand by all kinds of people regardless of their cultures and languages. Moreover, the signs should be placed in an appropriate setting to allow all people to read them and extract personalised information. Additionally, the signs' content should reflect the immediate environment. All these key aspects together, enable people individually in crowds to extract information that is relevant to them. The three systems were conducted in a lab user studies, as it was infeasible to run the Mecca studies in the actual setting, for several reasons which we stated previously.

The results of all studies provide clear evidence that augmented displays could be useful for the provision of navigation information in different situations. In addition, results suggested that augmented displays might solve the issues that pilgrims are suffering from, such as losing count of Tawaf rounds and the inability of finding each other when becoming separated in the Haram. As we identified previously there are not currently any systems used at Mecca to help people perform their rituals inside the Haram. The proposed approaches address several shortcomings of the traditional methods that pilgrims use to perform pilgrimage pillars such as people collecting seven stones and throwing one away once they have completed one round of the Tawaf rite or people who agreed to meet at a particular place and then find that they are unable to meet again as all places look the same. Regarding case study 2 the results showed that the colour condition was the best in all tests, and this was followed by the coloured-symbols approach. The base/arrow condition was rated the lowest of all three conditions of case study2. Furthermore, the results that we gathered from all three case studies were provided good answer for all our research questions that we attempt to find answer for them through the user studies.

8.1 Contributions

8.1.1 Major contributions

(a) We analysed properties, constraints, and key issues facing people that take part in the yearly pilgrimage to Mecca. In order to improve the safety of pilgrims while they are performing their rituals (e.g. Tawaf), we developed augmented displays to help people navigate around the Great Mosque in the context of extreme crowdedness. It is based on a dynamic public display, from which individuals can extract personalized information using their relative position with respect to the Ka’bah. As we identified that the scenario of Mecca should be divided into two main parts: the environment at Mecca which concerns the city properties and constraints (the spatial segmentation of the environment) and associated symbolic representation using dynamic representation. So, we attempted to solve the crowd through this combination. For example, we designed a dynamic signage system to help people perform Tawaf rite (case study1). We also designed a dynamic and static signs which working in a combination to provide support for people who getting separated and unable to find each other (case study3). Our investigation of the Tawaf scenario and the user study we conducted to evaluate our design also yielded some insights with respect to the design of system to support navigation for large crowds. We identified the approach of context-driven personalization of public display content as a promising way to provide adaptable support for very large numbers of diverse and concurrent users. In addition, we highlighted some issues pertaining to the evaluation of interfaces for large crowds, i.e., the difficulty of creating a realistic simulation in the lab and how to best progress from small-scale tests such as focus groups to larger scale studies prior to real-world deployment.

(b) In creating a system to support pilgrims navigate around the Ka'bah during Tawaf, we considered the continuous involvement of users essential not only to expose designs to potential users early on but also to ensure that the designs are acceptable from a ''religious'' perspective. We first identified the properties, constraints, and most pressing issues pertaining to the application scenario by surveying existing literature and other sources such as material published by the Saudi Arabian ministry in charge of the Hajj or guide books for people planning to go on a pilgrimage. Then we designed initial systems and presented them to the focus groups to gather feedback about them.

Once we were satisfied that the systems met the basic requirements we had identified through this process, we evaluated the final design through a lab-based study with user participants in a simulated environment. Contrary to the previous steps, in case study 1 we recruited people of Muslim faith who had not been on a pilgrimage before since we wanted to test the system on people, who were potential future users (i.e., pilgrims who will visit Mecca for the first time).

In case study 3 we used both user pilgrimage and non-pilgrimage users to test the system on both situations (people who had made the pilgrimage and those who had not). In the systems that we have designed, pilgrims need to remember only a single combination (colour and dots /symbols) while performing their rituals around the Ka'bah. This combination of a colour and dots/symbols are shown on the sign to facilitate recognition. Previously, people had to keep track by remembering the round count and incrementing it after every full circuit without any external cues (case study 1), people confirmed that they will meet at particular place by remembering that place without any support (case study 3).

We thus argue that our designs are cognitively less demanding and more resilient to error, and therefore, should interfere very little with the spiritual experience. In order to evaluate the augmented display systems in a realistic context with potential users, we carried out user studies in an environment simulating some aspects of the actual setting at Mecca. We evaluated our approaches against the constraints we identified and through lab-based user studies in a simulated environment. We employed new simulation methods such as a simulated Ka'bah (case study 1) and the simulation method which was applied in the dynamic signage / distraction tasks (case study 3).

Existing methods were infeasible to apply in our context, as our study's environment required a special design based on the properties and constraints of Mecca; therefore we designed new simulation methods. The results suggest that augmented signage may give promising options for improving safety during the Hajj and that the installation of such signs around the Ka'bah may be acceptable to pilgrims. The studies also emphasized some significant points such as the importance of the rotational speed of the dynamic sign (case study 1); we discussed several options to achieve a high degree of synchronicity between the people walking round the Ka'bah and the sign. Losing track of the round count and people getting separated are the main problems facing pilgrims (specifically at Tawaf rite), and the solutions we proposed may help in addressing them.

8.1.2 Minor contributions

(a) The results were gathered while analysing both the video of all studies (showing the usage of the interaction techniques by the participants) and by analysing the comments of the participants made whilst filling in the questionnaires. As we attempt to answer the research question ''Does the current user interface of augmented displays meet their needs, can they use it, or are there any issues that need to be addressed?' results showed that users were satisfied while using of three studies tasks. This led us to the fact that simulation methods worked well.

(b) One key consideration relates to the international nature of the crowd people come from many different countries and cultures. Our design takes this into account by not using any textual components, it relies on colours and dots / symbols, which are largely independent of particular cultures and languages, and thus ''readable'' by a broad range of people (though not by visually impaired people). Learnability should also benefit from the simplicity of basic principle and design. Another key benefit of our approaches is that they do not require users to carry/use a mobile device in order to obtain personalized information. It thus increases the number of potential users and can also help to address the issue of scalability in the case of very large crowds.

Our three systems dynamically change the content of the signs to enable a large number of users to extract relevant information from the display based on their current location simultaneously.

8.2 Future work

As mentioned previously the results of the case study 1 (Tawaf system) showed that, for a few users, their walking speed did not correspond to the dynamic signage speed. As in the study, the dynamic signage speed was set manually, based on measurements from a pre-test. In the actual situation (at Mecca), one option which could be used to measure the pilgrims' speed is a video camera which could observe the area around the Ka'bah and compute the speed based on difference images and/or flow rates. Alternatively, a small number of employees could be outfitted with tracking devices (e.g. GPS-enabled mobile phones) and be tasked to continuously walk around the Ka'bah with the crowd. Their movement could be transmitted to the dynamic signage system in real-time to adjust the rotation speed.

In addition, there are a number of issues related to the other places of Mecca which have not been addressed by this thesis. These could also form the basis of future work. For example, outside the Haram, there is a large space which pilgrims use for shopping and refreshment after they have completed Tawaf and Saai inside the Haram. This place is usually crowded and people again face the same issues that we addressed in the third study (losing each other). One of our interests is to find a solution for this issue. By using the system which we designed to solve the problem inside the Haram; we could attempt to develop the displays of the system to be used to enable people to meet again after becoming separated. This system could use the signs which are installed in the Haram corridors.

The initial results of our systems has increased our understanding about how augmented displays can be developed and utilised to assist large and heterogeneous crowds in different situations and has posed a number of challenges such as further developments of augmented displays to use in variety of different crowds situations. We also plan to increase the realism of the lab-based studies such as simulating movement in a more convincing way or by using semi- immersive imagery.

Our designs are mainly based on the technological approach of providing different interfaces through augmented displays to support people in different settings. As we mentioned in several places in this thesis, the results of almost all tests provide initial evidence that an augmented display is usable, easy to learn and enjoyable without incurring large penalties in terms of usage time, error rates or disorientation events.

The findings described in this thesis will hopefully encourage more research on the usage of augmented displays in this context and might lead to the deployment of such systems in a practical context. On the other hand, it could be use new conceptual perspectives such as distributed cognition or crowd psychology to offer different design solutions. Based on our research we concluded that there are some aspects of distributed cognition that could be suited to the approaches that we proposed to support pilgrims at Mecca while performing their rituals. For example, the distributed cognition approach emphasises the distributed nature of cognitive phenomena across individuals, artefacts and internal/external representations in terms of a common language of representational states and media. In addition, other concepts coming from the social sciences are utilised to account for the socially-distributed cognitive phenomenon. So, new conceptual perspectives might provide different design solutions which improve the crowds' areas such as the Mecca environment in general and inside the Haram around the Ka'bah specifically.

This conceptual perspective could be of benefit in different settings such as sports stadia, especially those prepared for the Olympics which include a large number of people who come from different cultures and backgrounds. Several aspects are common with the Mecca situation aspects. Our solution is intended to work and provide support in several circumstances such as general situations, in crowds on the move, in crowds where mobile phones are not usable, and in crowds where is no common language.

Furthermore, these systems could be deployed and used in other crowded places, as augmented displays via colour coded systems could assist people and guide them to their destinations quickly and easily. For example in large shopping centres, people can get leaflets from the entrances which include a set of coloured circles followed by destinations to direct people to their destinations. Each circle has particular colour, people just follow those colours.

Also it might help in emergency situations. In a football stadium, a colour code could be printed on the tickets so that people just follow the colour printed to reach their seats. Tickets could include another colour for emergency exits and fires. This idea might be useful to allow friends to enjoy watching their favourite football teams together in a stadium. Football gives people a good reason to get together with friends and family by having social event centred around the game.

A further advantage of these systems is that users do not require a mobile device in order to obtain personalised information. This in turn broadens the number of potential users and also overcomes the issue of scalability in the case of very large crowds. While nowadays mobile phones are ubiquitous, software compatibility, communication costs and network scalability (in particular for Bluetooth and WLAN) limit the applicability of systems targeting large crowds that depend on mobile phones for public display interaction/personalisation.

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9. References

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Appendixes

Appendix A

Case study 1

Supporting Pilgrims in Navigating Densely Crowded Religious Sites

A.1 Consents Forms

Two consent forms: users asked to read them and signature before start the study tasks. One copy submits to a participant after signed by the investigator and the other copy keep by investigator.

Consent Form

Newcastle University

School of Computing Science

Overview of Tawaf study

Participant / Investigator Copy

First of all, thank you for agreeing to participate in this study. The purpose of this form is to inform you about our experiment as a research volunteers.

Please read the form carefully, and please ask any question that you have now and any question come to your mind when you read a form. . For any reason you can get out from the experiment.

There is no deception involved in this study. So, again, please ask any questions that you may have about the study, what you will be asked to do, and so on.

Principal investigators: Fathi Hamhoum, assisted by Esmail Mohamed

Purpose of the research: we will ask volunteer for a usability study to investigate dynamic signage to improve pilgrimage situation particularly in Tawaf pillar.

The aim of this research is to investigate new way to support pilgrims perform Hajj particularly in Tawaf pillar. Basically, we are going to run experiment simulation to investigate a usability of dynamic signage to improve pilgrimage situation particularly in Tawaf pillar. Dynamic signage will show the system (a circle subdivided into several wedges with different colours, the circle rotates on a screen (360^o).

The aim of this experiment is to evaluate and examine the system, and you as research volunteers will perform these tasks. We are collecting data from approximately 30 participants to help us evaluate users interaction with dynamic signage during they walking around the model seven times, they have start walking from particular point. The experiment will takes place in space 4 / 5, culture lab building, on Friday 30 Jan, 2009.

Procedures: There are three main steps of this experiment: Firstly, you will fill out initial questionnaire, secondly, start running the experiment tasks, and then you will fill out final questionnaire. You will do tasks individually, it will be four gates of the area of walking, and you will enter into the area from different gates and different times. Each one of you will works alone and interact with the dynamic signage to perform his tasks. Once you have completed tasks (seven times) you can get out of the area of walking or stay to do other duties such prayers. The seven rounds should be continuously .i.e. there is no rest until completed seven times around the model. However, you can get out if you are unable to complete walking. i.e. for any reason you can get out from the experiment area.

Foreseeable Risks or discomforts: We will inform the participants about the routes getting to experiment place and emergency exit routes. In addition, we will put some direction signs on the corridors of building to illustrate the experiment place. The experiment will be audio and video recorded. The camera will start recording with participants start running tasks simultaneously. The probability of risk is very little, however if any emergency happens, we will do our best to help volunteers as they needed. If the system failed the experiment will terminate.

Benefits: The expected benefit from this study is to examine and evaluate usability of public display (dynamic signage) and ubiquitous computing to improve pilgrimage situation particularly in Tawaf pillar. In addition, get users feedback will help us to improve our system.

Compensation: Volunteers will be given refreshments (biscuits and drinks) at Culture Lab after experiment completed.

Confidentiality: All results which obtained from the experiment will use only in our research and it will remain secret. All things which related to volunteers experiment study such as names, pictures, and behaviour will not be publicly accessible. Basically, we will write papers about this research but, we will do not use the participants personality information in our research publication.

Contact Person: If you have any questions about this research, call or write:

Fathi Hamhoum, PhD student

Culture Lab, School of Computing Science

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f.a.a.hamhoum1@ncl.ac.uk

Signatures: Volunteers will receive a signed copy of this form.

Your signature below indicates that the investigators have answered all of your questions to your satisfaction and that you consent to volunteer for this study.

☐ Please tick this box if you are happy to use this study in our scientific publication.

Participant's signature: ________________________________ Date: / /

Investigator's signature: ________________________________ Date: / /

A.2 Questionnaires

The questionnaire consisted of two types' initial questionnaire and final questionnaire. The first questionnaire comprised the identification data related to the participant, such as age, and previous experience with pilgrimage to Mecca.

The second questionnaire consisted of seven questions related to interface issues and general acceptability, and related to negative and positive aspects of the system. This questionnaire was answered after study completed.

Some questions relating to possible future install displays in the area of Mosque in Mecca. And other questions about possible future this system will help to reduce the crowded and risks of the pilgrims in Tawaf area.

A.2.1 Initial Questionnaires

Thank you for taking the time to fill in this questionnaire; it should only take about ten minutes. Please return your completed questionnaire to one of investigators. Your answers will be treated with complete confidentiality. If you have any question about this questionnaire, please ask one of the investigators.

Q1.Please tell us your age [Please tick only one]

☐ 18-25

☐ 26-33

☐ 34-41

☐ 42-49

☐ 50-57

☐ 58-65

☐ Over 65

Q2. Is your vision affected by colour-blindness? [Please tick only one]

☐ Yes ☐ No

Q3. How would you describe your eyesight? (If you are wearing glasses or contact lenses, please describe your vision when wearing glasses or contact lenses.) [Please tick only one]

☐ Short-sighted

☐ Farsighted

☐ Neither short-sighted nor farsighted

Q4. Are you familiar with the pilgrimage, which Muslims perform in Mecca every year? [Please tick only one]

☐ Yes ☐ No (please continue with Q5)

If yes, please tell us how you learned about it. [Please tick all that apply]

☐ Books

☐ School

☐ Mosque

☐ Television

☐ Internet

☐ Family / Friends

☐ Other (please specify) ………………………………………..

Q5. Have you already gone on a pilgrimage to Mecca? [Please tick only one]

☐ Yes ☐ No (please continue with Q6)

If yes, how would you describe your experience while performing the Tawaf Pillar, which involves walking around black building (Kaaba) seven times? Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with each statement:

Statements	
It was easy to recognise where to start each round.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It was difficult to remember the rounds count.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
There is a lot of help available to pilgrims performing the Tawaf Pillar (e.g. signs).	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
Identifying where to start each round was difficult.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
The place was very crowded.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
Keeping track of the number of rounds was easy.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
Pilgrims performing the Tawaf Pillar do not receive much help (e.g. through signage).	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
Only a few people are performing the Tawaf Pillar at the same time.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Please list three problems you were facing when performing the Tawaf Pillar:

Please list three aspects that helped you perform the Tawaf Pillar:

Q6.Did someone, who had been on a pilgrimage to Mecca, ever discuss his or her experience with you? [Please tick one]

☐ Yes ☐ No (please continue with Q7)

If yes, do you recall any of the positive or negative aspects they mentioned?

Please list three problems mentioned about performing the Tawaf Pillar:

Please list three helpful aspects mentioned about performing the Tawaf Pillar:

Q7. Do you have any further comments about the pilgrimage to Mecca or the Tawaf Pillar in particular? If you do, please use the space provided below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators now.

A.2.1 Questionnaires after experiment

Q1. Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with these statements about the display-based system that was mounted inside the study area.

Statements about the dynamic signage	
The screen content was difficult to understand.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It was easy to learn how to use it.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It helped me to remember the number of rounds.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
The rotation speed of the display corresponded to my walking speed.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It was difficult to tell the different colours apart.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I lost track of the rounds count.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
My walking speed and the rotation speed of the display were different.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It was difficult to learn how to use the system.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It is easy to distinguish between colours.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
The content of the screen was easy to understand.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Please list the three most negative aspects of the system:

Please list the three most positive aspects of the system:

Q2. Do you think it would be acceptable to install displays (such as the one used in the study) in Mecca, e.g. on the outer wall of the mosque where the Kaaba is located?

[Please select only one option.]

☐ Yes ☐ No

If no, please briefly describe why you think it is unacceptable:

Q3.Do you think that installing displays (such as the one used in the study) in Mecca would improve the experience of pilgrims performing the Tawaf Pillar? [Please tick one of the circles]

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Q4. Do you think that it is possible to understand and use the system without being given instructions? [Please tick one of the circles]

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Q5. Do you have any further comments about the display system or the situation of pilgrims performing the Tawaf Pillar? If you do, please use the space provided below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators now.

Appendix B

Augmented display study

Scalable Pedestrian Navigation support via Augmented (Dynamic) signage

B.1 Consent forms

Consent Form

Newcastle University

School of Computing Science

Pedestrian Navigation via Augmented display Study

Participant / Investigator Copy

Principal Investigator: Fathi Hamhoum, assisted by Esmail Mohamed.

Purpose of the Research: You are being asked to volunteer for a usability study to explore using a dynamic signage conditions to navigate between places. Approximately 20 people, recruited from Newcastle University and the city, will participate in a series of usability studies.

Procedure: The usability study will take place in Space 7, culture lab… building. The procedure will involve filling out a background questionnaire, completing the study, and filling out a brief questionnaire. Volunteers will complete the questionnaires individually. You be able to take short breaks as needed.

Foreseeable Risks or Discomforts: There is minimal risk involved in the participation of this study. This means that the probability and magnitude of harm or discomfort anticipated in the research are not greater than those ordinarily encountered in daily life during the performance of routine physical or psychological examinations or tests. However, if an emergency arises during the test, an investigator will assist the volunteer as needed. In the case of system failure, the study will be stopped and will be considered void.

Compensation: Volunteers will be given refreshments and snacks at Space 7, culture lab.

Confidentiality: All results of this usability study will remain confidential. Articles that reference and report research findings from this usability study will not use the names of any of the volunteers who participate in the test. Investigators are mainly concerned with reporting on the interaction phenomena and the performance measures, not the volunteers. Any comments concerning individual behaviour will not be identifiable. Records that identify the investigators will not be publicly accessible.

Injury/ Adverse Reactions: Reports of any injury should be made to Fathi Hamhoum, the co-principal investigator. Mr. Hamhoum can be reached through at 07799828153. Neither Newcastle University nor the principal investigator have provided for paying costs associated with any injury resulting from participating in this study.

Contact Person: If you have any questions about this research, call or write:

Fathi Hamhoum

Culture Lab, School of Computing Science

Newcastle University, Newcastle upon Tyne, NE1 7RU

07799828153

f.a.a.hamhoum1@ncl.ac.uk

Voluntary Participation/ Withdrawal: Research volunteers have rights. Taking part in this study is completely voluntary. If volunteers choose to not take part, they will have no penalty. Volunteers may stop participating in this study at any time with no penalty.

Signatures: Volunteers will receive a signed copy of this form.

Your signature below indicates that the investigators have answered all of your questions to your satisfaction and that you consent to volunteer for this study.

Subject's Signature: ____________________________ Date: __________

Investigator's Signature: _________________________ Date: __________

B.2 Questionnaires

B.2.1 Initial Questionnaire

In order to analyze the results from this study, it would be very helpful if you could provide us with some information about yourself. This information will only be used in the context of this study, and will not be passed on to a third party. If we publish the results of our research, we will thoroughly anonymous all personal information so that it will not be possible to identify the individual that produced it.

1. Please tell us your age [Please tick only one]
   ❍ Under 20 ❍ 20-29 ❍ 30-39 ❍ 40-49 ❍ 50-59 ❍ 60-69 ❍ 70 or older

2. Please tell us your gender.
   ❍ Male ❍ Female

3. Is your vision affected by colour-blindness? [Please tick only one]
   ❍ Yes ❍ No

4. How did you describe your eyesight? (if you are wearing glasses or contact lenses, please describe your vision when wearing glasses or contact lenses.) [Please tick only one]
   ❍ Short-sighted

   ❍ Farsighted

   ❍ Neither short-sighted nor farsighted

5. Do you sometimes rely on public signage when finding your way in unfamiliar environments?

   ❍ Yes ❍ No (continue with question 5)

6. If yes,

Please list the three helpful aspects about using public signage for navigation?
1-
2-
3-

Please list the three problems you were facing when using public signage for navigation?
1-
2-
3-

7. How could public signage be improved to make it easier for someone to find their way? Please use the space provided below.

8. This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should tick one of the circles to indicate your level of agreement with the statement.

Statement about Sense-of-Direction	
I am very good at giving directions.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I am very good at judging distances.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
My ”sense of direction” is very good.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I very easily get lost in a new city.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I enjoy reading signs.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I have trouble understanding directions.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I am very good at reading signs.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I don't enjoy giving directions.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
It's not important to me to know where I am.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I usually let someone else do the	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

navigational planning for long trips.	
I can usually remember a new route after I have travelled it only once.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree
I don't have a very good “mental map” of my environment.	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Thank you for filling in this questionnaire. Please hand it back to one of the investigators.

B.2.2 Questionnaires after experiment

B.2.2.1 Base/arrow condition questionnaire

Q1.Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with this statement about the signage of Arrows condition. *Note: Arrows condition means that the signs in this condition will not be supported by any extra cues, i.e. all signs will show only several entries indicated by several directions. "Arrows Condition"*

Statement about the Base condition		
It helps me to be more effective	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U
It is fun to use	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
It is easy to learn to use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
It is simple to use	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I am satisfied with it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
I can recover from mistakes quickly and easily	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I learned to use it quickly	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
I easily remembered how to use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
It meets my needs	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U
I can use it without written instructions	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I would recommend it to a friend	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
It saves me time when I use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U

Please list the three most negative aspects of Arrows condition:
1-
2-
3-

Please list the three most Positive aspects of Arrows condition:
1-
2-
3-

Q2. Please read the following statements carefully and then tick one of the circles to indicate whether and how Very you high/low with this statement about the signage of Arrows condition.

Statement about the Arrows condition	
Mental Demand: How mentally demanding was the task.	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Physical Demand: How physically demanding was the task	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Temporal Demand: How hurried or rushed was the pace of the task.	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Performance: How successful were you in accomplishing what you were asked to do How satisfied were you with your performance in accomplishing these tasks?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Frustration level: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low

Q3. Do you think that installing dynamic displays such as the one used in the study in public space would improve the experience of pedestrian's navigation system and allow them to get right direction quickly? [Please tick one of the circles]

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree.

Q4. Do you think that it is possible to understand and use the dynamic signage without being given instructions? [Please tick one of the circles].

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree.

Q6. Do you have any further comments about the dynamic signage system or the situation of pedestrian's navigation via signs? If you do, please use space provided below to write your comments:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators.

B.2.2.2 Coloured-circle Condition questionnaire

Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with this statement about the signage coloured circle condition.

Note: Coloured circle condition means that the signs of this type will supported by circle /different colour, i.e. all sign entries will followed by one or more coloured circle. "One symbol and different colours"

Statement about the Coloured circle condition		
It helps me to be more effective	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U
It is fun to use	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
It is easy to learn to use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
It is simple to use	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I am satisfied with it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
I can recover from mistakes quickly and easily	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I learned to use it quickly	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
I easily remembered how to use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
It meets my needs	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U
I can use it without written instructions	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I would recommend it to a friend	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
It saves me time when I use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U

Please list the three most negative aspects of **Coloured circle** condition:
1-
2-
3-

Please list the three most Positive aspects of **Coloured circle** condition:
1-
2-
3-

Q2. Please read the following statements carefully and then tick one of the circles to indicate whether and how Very you high/low with this statement about the signage of **Coloured circle** condition.

Statement about the Coloured circle condition	
Mental Demand: How mentally demanding was the task.	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Physical Demand: How physically demanding was the task	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Temporal Demand: How hurried or rushed was the pace of the task.	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Performance: How successful were you in accomplishing what you were asked to do How satisfied were you with your performance in accomplishing these tasks?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Frustration level: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low

Q3. Do you think that installing dynamic displays such as the one used in the study in public space would improve the experience of pedestrian's navigation system and allow them to get right direction quickly? [Please tick one of the circles]

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree.

Q4. Do you think that it is possible to understand and use the dynamic signage without being given instructions? [Please tick one of the circles].

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Q6. Do you have any further comments about the dynamic signage system or the situation of pedestrians' navigation via signs? If you do, please use space provided below to write your comments:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators

B.2.2.3 Coloured-Symbol Condition Questionnaire

Q1. Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with this statement about the coloured symbols condition.

Note: Coloured-symbols condition means that the signs in this condition will supported by different symbols / different colours, i.e. all sign entries will followed by one or more coloured symbols. “Coloured symbols condition”

Statement about the coloured-Symbols condition		
It helps me to be more effective	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U
It is fun to use	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
It is easy to learn to use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
It is simple to use	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I am satisfied with it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
I can recover from mistakes quickly and easily	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I learned to use it quickly	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
I easily remembered how to use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	L
It meets my needs	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U
I can use it without written instructions	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	E
I would recommend it to a friend	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	S
It saves me time when I use it	Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree	U

Please list the three most negative aspects of **Coloured Symbols** condition:
1-
2-
3-

Please list the three most Positive aspects of **Coloured Symbols** condition:
1-
2-
3-

Q2. Please read the following statements carefully and then tick one of the circles to indicate whether and how Very you high/low with this statement about the signage of **Coloured- Symbols** condition.

Statement about the Coloured -symbol condition	
Mental Demand: How mentally demanding was the task.	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Physical Demand: How physically demanding was the task	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Temporal Demand: How hurried or rushed was the pace of the task.	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Performance: How successful were you in accomplishing what you were asked to do How satisfied were you with your performance in accomplishing these tasks?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low
Frustration level: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?	Very High ❍ ❍ ❍ ❍ ❍ ❍ ❍ ❍Very Low

Q3. Do you think that installing dynamic displays such as the one used in the study in public space would improve the experience of pedestrian's navigation system and allow them to get right direction quickly? [Please tick one of the circles]

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree

Q4. Do you think that it is possible to understand and use the dynamic signage without being given instructions? [Please tick one of the circles].

Strongly Disagree ❍ ❍ ❍ ❍ ❍ ❍ ❍ Strongly Agree.

Q6. Do you have any further comments about the dynamic signage system or the situation of pedestrians' navigation via signs? If you do, please use space provided below to write your comments:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators.

B.2.2.4 Comparison Questionnaire

Please rank the three different conditions according to the following dimensions by filling in '**1' for the best**, **'2' for the second best**, and **'3' for the worst** condition.

Statements	**Arrow / Base**	**Colour**	**Symbol**	
It helps me to be more effective				U
It is fun to use				S
It is easy to learn to use it				L
It is simple to use				E
I am satisfied with it				S
I can recover from mistakes quickly and easily				E
I learned to use it quickly				L
I easily remembered how to use it				L
It meets my needs				U
I can use it without written instructions				E
I would recommend it to a friend				S
It saves me time when I use it				U

Please write any further comments below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators.

B.3 Procedure: How participants run the study trials

Participants divided into three groups as the following:

A B C 1	**A C B 2**	**B A C 3**	**B C A 4**	**C A B 5**	**C B A 6**
A B C 7	**A C B 8**	**B A C 9**	**B C A 10**	**C A B 11**	**C B A 12**
A B C 13	**A C B 14**	**B A C 15**	**B C A 16**	**C A B 17**	**C B A 18**

A --- Means Arrow/base condition,

B --- Means Coloured-circle condition,

C--- Means Coloured-symbol condition

Participant's no. (1, 7, and 13) follow the order [A B C]

Signs	Conditions order		
	Condition A destinations	**Condition B destinations**	**Condition C destinations**
Sign1	Sport Centre	Follow Orange circle.	Follow yellow Heart.
Sign2	Primary school	Follow Orange circle.	Follow Pink Square
Sign3	Sea front	Follow Green circle	Follow Green Star
Sign4	Pharmacy	Follow Orange circle	Follow Blue Heart
Sign5	General Hospital	Follow Pink circle	Follow Red Heart
Sign6	High street	Follow Brown circle	Follow Red Moon
Sign7	Train Station	Follow Blue circle.	Follow Blue Square
Sign8	Stadium	Follow Blue circle	Follow Blue Moon
Sign9	Post Office	Follow Yellow circle	Follow Green Triangle
Sign10	Fire Station	Follow Green circle	Follow Blue Star
Sign11	Church	Follow Purple circle	Follow Pink Heart
Sign12	Central Park	Follow Yellow circle	Follow Blue Triangle

Participants no. (2, 8, and 14) follow the order [A C B]

Signs	Conditions order		
	Condition A destinations	**Condition C destinations**	**Condition B destinations**
Sign1	Sport Centre	Follow Yellow Heart	Follow Orange circle.
Sign2	Primary school	Follow Pink Square	Follow Orange circle.
Sign3	Sea front	Follow green Star	Follow Green circle
Sign4	Pharmacy	Follow Blue Heart	Follow Orange circle
Sign5	General Hospital	Follow Red Heart	Follow pink circle
Sign6	High street	Follow Red Moon	Follow Brown circle
Sign7	Train Station	Follow Blue Square	Follow Blue circle.
Sign8	Stadium	Follow Blue Moon	Follow Blue circle
Sign9	Post Office	Follow Green Triangle	Follow Yellow circle
Sign10	Fire Station	Follow Blue Star	Follow Green circle
Sign11	Church	Follow Pink Heart	Follow Purple circle
Sign12	Central Park	Follow Blue Triangle	Follow Yellow circle

Participants no. (3, 9, and 15) follow the order [B C A]

Signs	Conditions order		
	Condition B destinations	**Condition A destinations**	**Condition C destinations**
Sign1	Follow Orange circle.	Sport Centre	Follow Yellow Heart
Sign2	Follow Orange circle.	Primary school	Follow Pink Square
Sign3	Follow Green circle	Sea front	Follow green Star
Sign4	Follow Orange circle	Pharmacy	Follow Blue Heart
Sign5	Follow pink circle	General Hospital	Follow Red Heart
Sign6	Follow Brown circle	High street	Follow Red Moon
Sign7	Follow Blue circle.	Train Station	Follow Blue Square
Sign8	Follow Blue circle	Stadium	Follow Blue Moon
Sign9	Follow Yellow circle	Post Office	Follow Green Triangle
Sign10	Follow Green circle	Fire Station	Follow Blue Star
Sign11	Follow Purple circle	Church	Follow Pink Heart
Sign12	Follow Yellow circle	Central Park	Follow Blue Triangle

Participants no. (4, 10, and 16) follow the order [B C A]

Signs	Conditions order		
	Condition B destinations	**Condition C destinations**	**Condition A destinations**
Sign1	Follow Orange circle.	Follow Yellow Heart	Sport Centre
Sign2	Follow Orange circle.	Follow Pink Square	Primary school
Sign3	Follow Green circle	Follow green Star	Sea front
Sign4	Follow Orange circle	Follow Blue Heart	Pharmacy
Sign5	Follow pink circle	Follow Red Heart	General Hospital
Sign6	Follow Brown circle	Follow Red Moon	High street
Sign7	Follow Blue circle.	Follow Blue Square	Train Station
Sign8	Follow Blue circle	Follow Blue Moon	Stadium
Sign9	Follow Yellow circle	Follow Green Triangle	Post Office
Sign10	Follow Green circle	Follow Blue Star	Fire Station
Sign11	Follow Purple circle	Follow Pink Heart	Church
Sign12	Follow Yellow circle	Follow Blue Triangle	Central Park

Participants no. (5, 11, and 17) follow the order [C A B]

Signs	Conditions order		
	Condition C destinations	**Condition A destinations**	**Condition B destinations**
Sign1	Follow Yellow Heart	Sport Centre	Follow Orange circle.
Sign2	Follow Pink Square	Primary school	Follow Orange circle.
Sign3	Follow green Star	Sea front	Follow Green circle
Sign4	Follow Blue Heart	Pharmacy	Follow Orange circle
Sign5	Follow Red Heart	General Hos.	Follow pink circle
Sign6	Follow Red Moon	High street	Follow Brown circle
Sign7	Follow Blue Square	Train Station	Follow Blue circle.
Sign8	Follow Blue Moon	Stadium	Follow Blue circle
Sign9	Follow Green Triangle	Post Office	Follow Yellow circle
Sign10	Follow Blue Star	Fire Station	Follow Green circle
Sign11	Follow Pink Heart	Church	Follow Purple circle
Sign12	Follow Blue Triangle	Central Park	Follow Yellow circle

Participants no. (6, 12, and 18) follow the order [C B A]

Signs	Conditions order		
	Condition C destinations	**Condition B destinations**	**Condition A destinations**
Sign1	Follow Yellow Heart	Follow Orange circle.	Sport Centre
Sign2	Follow Pink Square	Follow Orange circle.	Primary school
Sign3	Follow green Star	Follow Green circle	Sea front
Sign4	Follow Blue Heart	Follow Orange circle	Pharmacy
Sign5	Follow Red Heart	Follow pink circle	General Hos.
Sign6	Follow Red Moon	Follow Brown circle	High street
Sign7	Follow Blue Square	Follow Blue circle.	Train Station
Sign8	Follow Blue Moon	Follow Blue circle	Stadium
Sign9	Follow Green Triangle	Follow Yellow circle	Post Office
Sign10	Follow Blue Star	Follow Green circle	Fire Station
Sign11	Follow Pink Heart	Follow Purple circle	Church
Sign12	Follow Blue Triangle	Follow Yellow circle	Central Park

Appendix C

Using augmented signage to reunite groups in densely crowded environments study

C.1 Consents forms

Overview of the Study

(Participant / Investigator Copy)

Please read this form carefully. Please ask any questions that you have now or that come to mind as you read this form. The purpose of this form is to tell you about the experiment and to inform you about your rights as a research volunteer. If at any time you feel unable to continue participating in the experiment (for whatever reason), please inform the investigator and you will be released immediately. There is no deception involved in this study. So, again, please ask any questions that you may have about the study, what you will be asked to do, and so on.

Thank you for agreeing to participate in this study. We are collecting data from approximately 20 participants to help us evaluate the signs display system and our studies could not be completed without your help. The purpose of our research is to identify potential design features, benefits and drawbacks of a signage system to support people find each in crowded situations.

You will be participating in a study that involves three steps. You will first be asked to fill out a brief questionnaire at the beginning of the test. This questionnaire will ask general questions about your background and your knowledge about pilgrimage to Mecca. In the second part, you will be asked to run two conditions, each condition include a number of tasks. Your activities will be observed by at least one investigator, and will be recorded (audio and video). You may ask investigator questions about the test during this time only if you encounter a problem that prevents you from completing your task. In the event that you still cannot complete a certain task, you may exit the area and inform an investigator that you cannot complete the task. One of the investigators will explain the tasks in more detail before you start the second part. At the end of each condition, you will be asked to fill out a short questionnaire about the test.

We do not foresee any particular risks or discomfort resulting from participation in the study. The study will be recorded on video, which will solely be used for the research outlined above.

All data we record during the experiment will be kept confidential; if it is published in an academic venue, we will make sure to present the data in such a way that it will not be possible to infer the identity of any participant from it.

In addition, we might want to show short excerpts from the video footage captured during the study to illustrate particular aspects of our research or to convey how the experiment was run. Please indicate below whether you agree to the video footage being used in such a way.

☐ Yes, I consent to excerpts from the video footage being shown to an academic audience.

☐ No, I do not want excerpts from the video footage to be shown to an academic audience.

If you have any questions about this experiment, either now or later, please call or write to:

Fathi Hamhoum, PhD student

Culture Lab, School of Computing Science

Newcastle University

Newcastle upon Tyne, NE1 7RU

Mobile phone 07799828153

f.a.a.hamhoum1@ncl.ac.uk

Your signature below indicates that the investigators have answered all of your questions to your satisfaction and that you consent to volunteer for this study.

Participant’s signature: ________________________________ Date_______

Investigator’s signature: ______________________________ Date: _______

C.2 Questionnaires

C.2.1 Initial Questionnaire

Thank you for taking the time to fill in this questionnaire; it should only take about ten minutes. Please return your completed questionnaire to one of the investigators. If you have any questions about this questionnaire, please ask one of the investigators.

Q1. Please tell us your age [Please tick only one]

- ☐ 18-25
- ☐ 26-33
- ☐ 34-41
- ☐ 42-49
- ☐ 50-57
- ☐ 58-65
- ☐ Over 65

Q2. Is your vision affected by colour-blindness? [Please tick only one]

☐ Yes ☐ No

Q3. How would you describe your eyesight? (If you are wearing glasses or contact lenses, please describe your vision when wearing glasses or contact lenses.) [Please tick only one]

- ☐ Short-sighted
- ☐ Farsighted
- ☐ Neither short-sighted nor farsighted

Q4. Are you familiar with the pilgrimage, Hajj, which Muslims perform in Mecca every year? [Please tick only one]

☐ Yes ☐ No (please continue with Q5)

If yes, please tell us how you learned about it. [Please tick all that apply]

☐ Books

☐ School

☐ Mosque

☐ Television

☐ Internet

☐ Family / Friends

☐ Other (please specify) …………………………………………..

Q5. Have you already gone on a pilgrimage to Mecca? [Please tick only one]

☐ Yes ☐ No (Please continue with Q6)

If yes, how would you describe your experience while performing the Hajj Pillars, which involves walking in the Haram? Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with each statement:

	Statements about your experience while performing Pilgrimage at Mecca
1	It was easy to find someone who is lost at Mecca while doing Hajj rituals.
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍
2	Many means were available to help pilgrims finding each other at Mecca's Haram (e.g. signs).
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍
4	Identifying where to meet in case of losing was very difficult.
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍

5	The place was very crowded and it is more likely to lose your relative at any time inside the Mecca's Haram.
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍
6	The majority of pilgrims find it easy to go back to accommodation alone.
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍
7	Pilgrims who lose each other do not receive much help (e.g. through signage).
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍
7	It was difficult to find someone who is lost at Mecca while doing Hajj rituals.
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍
8	Only a few people are performing the Hajj Pillars at the same time.
	Strongly Disagree Strongly Agree ❍ ❍ ❍ ❍ ❍ ❍ ❍

Please list three **problems** you were facing when performing the Hajj Pillars:

Please list three **aspects that helped you** perform the Hajj Pillars:

Q6.Did someone, who had been on a pilgrimage to Mecca, ever discuss his or her experience with you? [Please tick one]

☐ Yes ☐ No (please continue with Q7)

If yes, do you recall any of the positive or negative aspects they mentioned?

Please list three **problems** mentioned about Hajj Pillars:

Please list three **helpful aspects** mentioned about the Hajj Pillars:

Q7. Do you have any further comments about the pilgrimage to Mecca? If you do, please use the space provided below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators now.

C.2.2 Questionnaires after experiment

Dots condition questionnaire: Signs show Dots and different colour background.

Q1. Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with these statements about the displays-based system that were placed inside the study area.

Your responses will help us understand what aspects of the system you are particularly concerned about and the aspects that satisfy you. To as great a degree as possible, think about all the tasks that you have done with the system while you answer these questionnaire.

	Statements about Signage system
1	Overall, I am satisfied with how easy it is to use this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
2	It was simple to use this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
3	I can effectively complete the tasks using this system

	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
4	The information provided with the system is easy to understand.
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
5	I feel comfortable using this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
6	It was easy to learn to use this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
7	Whenever I make a mistake using the system, I recover easily and quickly
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
8	The organization of information on the system screens is clear
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
9	The interface of this system is pleasant
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
10	I like using the interface of this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
11	It saves me time when I use it
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
12	I can use it without written instructions
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍

Please list the three most negative aspects of the system:

Please list the three most positive aspects of the system:

Q2.Please click on the scale to represent how low/high you felt for each of the factors during the task.

	Statement about the System workload
1	*Mental Demand:* the mental and perceptual activities (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.). To what extent was the task mentally demanding?
	very Low very High ❍❍❍❍❍❍❍❍
2	*Physical Demand:* the physical activities (e.g. turning, controlling, activating, etc.)The task being easy or demanding, slow or brisk, slack or strenuous, restful or laborious. To what extend was the task physically demanding?
	very Low very High ❍❍❍❍❍❍❍❍

3	*Temporal Demand:* How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?
	very Low very High ❍❍❍❍❍❍❍❍
4	*Performance:* How successful do you think you were in accomplishing the goals of the task?
	very Low very High ❍❍❍❍❍❍❍❍
5	*Effort:* To what extent did you have to work hard (mentally and physically) to accomplish your level of performance?
	very Low very High ❍❍❍❍❍❍❍❍
6	*Frustration:* To what extent did you feel insecure, discouraged, irritated, stressed and annoyed during the task?
	very Low very High ❍❍❍❍❍❍❍❍

Q3. Do you think it would be acceptable to install displays (such as the ones used in the study) in Mecca, e.g. dynamic displays on the outer gates of the Haram and static signs that distributed in corridors? [Please select only one option.]

☐ Yes ☐ No

If no, please briefly describe why you think it is unacceptable:

Q4. Installing displays (such as the ones used in the study) in Mecca would help pilgrims find each other? [Please tick one of the circles]

Strongly Disagree Strongly Agree

❍❍❍❍❍❍❍

Q5. Is it possible to understand and use the system (displays) without being given instructions? [Please tick one of the circles]

Strongly Disagree Strongly Agree

❍❍❍❍❍❍❍

Q6. Do you have any further comments about the system or the situation of pilgrims losing each other? If you do, please use the space provided below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators now.

Symbol condition questionnaire: in this condition, symbols with different colour background: each sign contains one symbol.

Q1. Please read the following statements carefully and then tick one of the circles to indicate whether and how strongly you agree/disagree with these statements about the displays-based system that were placed inside the study area.

Your responses will help us understand what aspects of the system you are particularly concerned about and the aspects that satisfy you.

To as great a degree as possible, think about all the tasks that you have done with the system while you answer these questionnaire.

	Statements about Signage system
1	Overall, I am satisfied with how easy it is to use this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
2	It was simple to use this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
3	I can effectively complete the tasks using this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
4	The information provided with the system is easy to understand.
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
5	I feel comfortable using this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
6	It was easy to learn to use this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍

7	Whenever I make a mistake using the system, I recover easily and quickly
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
8	The organization of information on the system screens is clear
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
9	The interface of this system is pleasant
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
10	I like using the interface of this system
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
11	It saves me time when I use it
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍
12	I can use it without written instructions
	Strongly disagree Strongly agree ❍❍❍❍❍❍❍

Please list the three most negative aspects of the system:

Please list the three most positive aspects of the system:

Q2.Please click on the scale to represent how low/high you felt for each of the factors during the task.

	Statement about the Tasks load
1	*Mental Demand:* the mental and perceptual activities (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.). To what extent was the task mentally demanding?
	very Low very High ❍❍❍❍❍❍❍❍
2	*Physical Demand:* the physical activities (e.g. turning, controlling, activating, etc.)The task being easy or demanding, slow or brisk, slack or strenuous, restful or laborious. To what extend was the task physically demanding?
	very Low very High ❍❍❍❍❍❍❍❍
3	Temporal Demand: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?
	very Low very High ❍❍❍❍❍❍❍❍
4	Performance: How successful do you think you were in accomplishing the goals of the task?
	very Low very High ❍❍❍❍❍❍❍❍
5	Effort: To what extent did you have to work hard (mentally and physically) to accomplish your level of performance?
	very Low very High ❍❍❍❍❍❍❍❍

6	Frustration: To what extent did you feel insecure, discouraged, irritated, stressed and annoyed during the task?
	very Low very High ❍❍❍❍❍❍❍❍

Q3. Do you think it would be acceptable to install displays (such as the ones used in the study) in Mecca, e.g. dynamic displays on the outer gates of the Haram and static signs that distributed in corridors? [Please select only one option.]

☐ Yes ☐ No

If no, please briefly describe why you think it is unacceptable:

Q4. Installing displays (such as the ones used in the study) in Mecca would help pilgrims find each other? [Please tick one of the circles]

Strongly Disagree Strongly Agree

❍❍❍❍❍❍❍

Q5. Is it possible to understand and use the system (displays) without being given instructions? [Please tick one of the circles]

Strongly Disagree Strongly Agree

❍❍❍❍❍❍❍

Q6. Do you have any further comments about the system or the situation of pilgrims losing each other? If you do, please use the space provided below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators now.

C.2.3 Comparison Questionnaire

Based upon what you have done and experienced in the study, please rank the following ***conditions (Dots and Symbol) according to the following dimensions by filling in '1' for the best, and '2' for the worst condition.*** *Remember, no both conditions can have the same ranking*.

	Statements about Usability and Satisfaction	Dots Condition	Symbol Condition
1	Overall, I am satisfied with how easy it is to use this system		
2	It was simple to use this system		
3	I can effectively complete the tasks using this system.		
4	The information provided with the system is easy to understand.		
5	I feel comfortable using this system		
6	It was easy to learn to use this system		
7	Whenever I make a mistake using the system, I recover easily and quickly		
8	The organization of information on the system screens is clear		
9	The interface of this system is pleasant		
10	I like using the interface of this system		
11	It saves me time when I use it		
12	I can use it without written instructions		

Please write any further comments below:

Thank you for filling in this questionnaire. Please hand it back to one of the investigators now.

C.3 Study procedure

The form has been prepared to follow the study run steps as the following:

Investigator fills the form based on the participant tasks while the experiment running.

Participant No __

Dot condition ☐

Symbols condition ☐

Task 1	**Done**	**Not done**	**Notes**
Fill in initial questionnaire			
Dynamic signage - trial 1			
Walking on the same place (on specific spot)			
Get information from the dynamic display (memorize the last sign information)			
Distractions task - trial 1			
Read screen content (sentence and image)			
Match them and,			
Say Yes if refer to the same thing or No if not			
Static sings - trial 1			
Stand on the circle available (three directional arrow)			
Read a sign to find your information			
Move foot to suitable direction or raise hand			
would you please tell us what colour and how many dots / symbol did you get from the dynamic display	**Colour**	**Image** **Dots no.**	
Task 2	**Done**	**Not done**	**Notes**
Dynamic signage - trial 2			
Walking on the same place (on specific spot)			
Get information from the dynamic display (memorize the last sign information)			
Distractions task - trial 2			
Read screen content (sentence and image)			
Match them and			
Say Yes if refer to the same thing or No if not			
Static sings - trial 2			
Stand on the circle available (three directional arrow)			
Read a sign to find your information			
Move foot to suitable direction or raise hand			
would you please tell us what colour and how many dots did you get from the dynamic display	**Colour**	**Image** **Dots no.**	
Task 3	**Done**	**Not done**	**Notes**
Dynamic signage - trial 3			
Walking on the same place (on specific spot)			
Get information from the dynamic display (memorize the last sign information)			
Distractions task - trial 3			
Read screen content (sentence and image)			
Match them and			
Say Yes if refer to the same thing or No if not			

Static sings - trial 3			
Stand on the circle available (three directional arrow)			
Read a sign to find your information			
Move foot to suitable direction or raise hand			
would you please tell us what colour and how many dots did you get from the dynamic display	**colour**	**image** / **Dots no.**	

Task 4	**Done**	**Not done**	**Notes**
Dynamic signage - trial 4			
Walking on the same place (on specific spot)			
Get information from the dynamic display (memorize the last sign information)			
Distractions task - trial 4			
Read screen content (sentence and image)			
Match them and			
Say Yes if refer to the same thing or No if not			
Static sings - trial 4			
Stand on the circle available (three directional arrow)			
Read a sign to find your information			
Move foot to suitable direction or raise hand			
would you please tell us what colour and how many dots did you get from the dynamic display	**Colour**	**Image** / **Dots no.**	
Task 5	**Done**	**Not done**	**Notes**
Dynamic signage - trial 5			
Walking on the same place (on specific spot)			
Get information from the dynamic display (memorize the last sign information)			
Distractions task - trial 5			
Read screen content (sentence and image)			
Match them and			
Say Yes if refer to the same thing or No if not			
Static sings - trial 5			
Stand on the circle available (three directional arrow)			
Read a sign to find your information			
Move foot to suitable direction or raise hand			
would you please tell us what colour and how many dots did you get from the dynamic display	**Colour**	**Image** / **Dots no.**	
Task 6	**Done**	**Not done**	**Notes**
Dynamic signage - trial 6			
Walking on the same place (on specific spot)			
Get information from the dynamic display (memorize the last sign information)			
Distractions task - trial 6			
Read screen content (sentence and image)			
Match them and			
Say Yes if refer to the same thing or No if not			
Static sings - trial 6			
Stand on the circle available (three directional arrow)			
Read a sign to find your information			
Move foot to suitable direction or raise hand			
would you please tell us what colour and how many dots did you get from the dynamic display	**Colour**	**Image** / **Dots no.**	
Fill out final question			