EXTENDED SITUATION AWARENESS THEORY FOR

MOBILE AUGMENTED REALITY INTERFACES TO SUPPORT NAVIGATION

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ABSTRACT

Despite the increasingly sophisticated capabilities of mobile AR guidance applications in providing new ways of interacting with the surrounding environment, empirical research remains needed in four principal areas: 1) identifying user needs and use cases, 2) developing an appropriate theoretical framework, 3) understanding user's interactions with the surrounding environment, and 4) avoiding information overload. To address these needs, a mixed-methods approach, involving two studies, was used to extend current Situation Awareness (SA) theory and evaluate the application of an extended theory. These were achieved in the context of a reality-augmented environment for the task of exploring an unfamiliar urban context.

The first study examined SA in terms of the processes that an individual employs and the essential requirements needed to develop SA for the case of urban exploratory navigation using mobile augmented reality (MAR). From this study, SA-supported design implications for an MAR guidance application were developed, and used to evaluate the application of an extended SA theoretical cognitive model. The second study validated the earlier findings, and involved two specific applications of the translated SA-supported interface design and an evaluation of five conceptual design concepts.

Results of the AR interface application suggested a significant SA-supported interface design effect on user's SA, which is dependent on the number of Points of Interest (POIs) included in the interface. Results of the embedded Map interface application showed a significant SA-support interface design effect on a user's SA. The SA-supported interface designs helped participants complete task queries faster and led to higher perceived interface usability.

This work demonstrates that, by adopting a systematic approach, transformed requirements can be obtained and used to design and develop SA-supported strategies. In doing so, subsequent implementation of SA-supported strategies could enhance a user's SA in the context exploratory navigation in an urban environment using MAR. Indeed, a validation process was initiated for the extracted user requirements, by conducting evaluations on these SA-supported strategies. Finally, a set of

preliminary design recommendations is proposed, with the goal of their eventual incorporation into the design and development of more effective mobile AR guidance applications.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Recent years have witnessed significant advances in the field of mobile Augmented Reality (AR) (Feiner, 2002; King, 2009; Vaughan-Nichols, 2009). Although mobile AR has long been regarded as an important technology in targeted high-end settings (e.g., military visual systems and industrial automation training), it has been evolving away from those technological military/industrial uses and is moving into mainstream, consumer-driven applications in highly sophisticated ways. As described by Tokusho and Feiner (2009), the physical world and the virtual world are becoming seamlessly intermingled. Information spaces (e.g., cyberspace, hypermedia, Internet) and contexts (e.g., augmented reality, virtual reality, real world) that were previously disconnected are gradually converging towards a unified world (Grasset, Mulloni, Billinghurst, & Schmalstieg, 2011).

A mobile AR system is a general information system much like a computer, with potential for literally hundreds of applications (Nilsson, 2010) across a wide spectrum of purposes. These applications can provide fascinating views into annotated worlds (Narzt, 2006), by which users are able to see things that they were unable to see just a few years ago. For example, a repair person can now see instructions highlighting the parts to be replaced in a broken piece of equipment; firefighters can now see the layout of a burning building in order to avoid hazards that previously would have been invisible; soldiers can now see the positions of enemy snipers who have been spotted by unmanned reconnaissance planes. Similarly, using mass-marketed mobile AR applications, we can view the interiors of homes for sale near us[1], the name of the stars and constellations over our heads[23], the names and details of the mountains we see before us[45], what crimes have recently been committed in our neighborhoods[6], browse the quality and price of a restaurant before we go inside[7], and so much more.

Among various mobile AR applications, mobile AR guidance applications have significant potential in domains such as tourism, emergency evacuation and notification, disaster management, driving, etc. Such systems assist their users in navigating a space. In simple terms, a mobile AR guidance application is a location-based information system that combines location-based data (e.g., location and route

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[1]ZipReality Real Estate mobile AR application: http://www.ziprealty.com/
[2] Star Chart mobile AR application: https://play.google.com/store/apps/details?id=com.escapistgames.starchart&hl=en
[3] Start Walk mobile AR application: http://vitotechnology.com/star-walk.html
[4]Panoramascope mobile AR application: http://panoramascope.com/
[5] Peaks mobile AR application: http://peaks.augmented-outdoors.com/
[6]SpotCrime mobile AR application: http://itunes.apple.com/us/app/spotcrime/id347343610?mt=8
[7] Yelp application: http://www.yelp.com/christiansburg-va-us

information) with the user's real-time view to a user. It provides a richer, more nuanced perspective of the surrounding world. For instance, factory workers in emergency situations could use mobile AR guidance systems to navigate around potential hazards; drivers could use windshield mobile AR guidance systems to identify traffic conditions and landmarks of interests; mobile AR guidance systems can be used by front-end emergency personnel (e.g., firemen and policemen) in high-demand field situations to navigate in hazardous environments in order to identify trapped people and potential explosions; and military personnel could use mobile AR guidance systems to gain information such as the locations and capabilities of both friendly and enemy forces. The potential applications are limited only by the developer's imagination.

One increasingly important domain for mobile AR guidance applications is travel and leisure tourism, which contributed 6.3 trillion US dollars to worldwide GDP (approximately 9% of the worldwide GDP) in 2011, and which was forecasted to grow an additional 2.8% in 2012, according to the World Travel & Tourism Council[8]. As an information-based, information-rich business, tourism has turned out to be a highly attractive and rewarding application area for mobile information services. Mobile information systems support a variety of tourism sectors and includes a wide range of applications, such as mobile guides for touring in urban areas, museum and exhibition spaces, and cultural heritage sites (Emmanouilidis, 2012). As one novel type of mobile information systems, mobile AR location-based guidance applications have proven to have enormous potential for tourism (Ganapathy, 2012; Hollerer & Feiner, 2004; Seo, 2011; Yovcheva, Buhalis, & Gatzidis, 2012).

In particular, mass-marketed Smartphone-based mobile AR guidance applications—representing a synergy of handheld mobile devices, context-awareness and AR technology—are likely to have a substantial impact on the tourism industry (Kurkovsky, Koshy, Novak, & Szul, 2012). This sector of mobile AR guidance applications has rapidly grown because of its novelty, intuitiveness and "immersiveness" (Drummond, 2007; Narzt, 2006; Noh, Sunar, & Pan, 2009; Reitmayr & Schmalstieg, 2004a; Roberts et al., 2002; White & Feiner, 2009; J. Wither, DiVerdi, & Hollerer, 2009)—not to mention the *availability* of mobile AR-enabled Smartphones, and the *technological feasibility* of Smartphone devices with high resolution touch display, GPS sensors, magnetometers, faster networks, cloud computing and location-based information tailored to the user's real-world location (Linaza et al., 2012; Rehrl et al., 2012; Vaughan-Nichols, 2009).

Therefore, not surprisingly, a growing number of publically-available mobile platforms use mobile AR guidance applications that are designed to enhance the travel/tourism experience (Boyer & Marcus, 2011;

[8] http://www.wttc.org/research/economic-impact-research/

Ishiguro, 2011; Johnson & Witchey, 2011; Lee, 2009); these include Layar[9], Wikitude[10] and Google Goggles[11]. These types of mobile AR applications fall into the general category of mobile navigation systems known as "magic lens" (Olsson & Salo, 2011). This type of system provides overlapping layers of information about Points of Interest (POIs) that users see around them through their Smartphone cameras. People visiting places can learn about buildings, sightseeing places, historical locations, activities and noteworthy events, dining options, etc. In other words, people use these mobile AR guidance applications to explore their surroundings in urban settings (Yovcheva et al., 2012).

Therefore, there is no doubt that mobile AR technologies will continue to revolutionize the ways digital information is presented to and accessed by people who seek more powerful ways to interact with their environments in different situations (Vaittinen, Karkkainen, & Olsson, 2010).

1.2 Research Problem

Despite the increasingly sophisticated capabilities of mobile AR guidance applications in providing new ways of interacting with our surrounding environment, its benefits are seriously compromised by its problems. In fact, some mobile AR applications have been criticized as "useless" (Olsson & Salo, 2011). Researchers are examining organizational, technical, and perceptual issues of mobile AR guidance systems with some success (Boyer & Marcus, 2011; Kruijff, Swan, & Feiner, 2010; Neuhofer, Govaers, Mokni, & Alexander, 2012). Nonetheless, we believe that one of the fundamental problems in Human Factors evaluations of mobile AR systems is insufficient research on how a user interacts with his/her surroundings in the mobile AR-enabled context in four principal areas: 1) insufficient identification of user needs and use cases, 2) lack of theoretical framework, 3) conflicting evidence on user's interactions with surrounding environment, and 4) information overload.

1.2.1 Insufficient Identification on User Needs

First, user information needs and requirements for mobile AR guidance applications in the context of exploratory navigation have been studied very little; indeed, the lack of user-centered studies and underutilized user-centered design methods have been identified as Augmented Reality (AR) domain-wide problems (Dhir, Olsson, & Elnaffar, 2012; Olsson, Karkkainen, Lagerstam, & Venta-Olkkonen, 2012). In spite of acknowledging that understanding and specifying user requirements are vital in the development process, mobile AR designers and developers typically do not involve end users in the early

[9] Layar application: http://layar.com
[10] Wikitude application: http://www.wikitude.com/
[11] http://www.google.com/mobile/google-mobile-app/

phase of development, but rather wait until they have a prototype test before users are involved (Olsson et al., 2012).

However, failing to adequately study user system needs at the beginning of development, especially with respect to a novel technology, may result in inaccurate assumptions about end users—such as who they are, their needs, and their capabilities. These assumptions, although incomplete or false, may then be incorporated into design specifications (Martin, Clark, Morgan, Crowe, & Murphy, 2012). Researchers have already expressed concerns regarding the user experience and the unmet expectations of end users (Boyer & Marcus, 2011; Pogue, 2011). For example, according to a recent survey on user experiences with mobile AR guidance applications, positive evaluations (e.g., novelty) were overshadowed by the uselessness of applications, such as those caused by excessive and irrelevant content (Olsson & Salo, 2011). Only a few respondents reported that their reason for obtaining mobile AR applications was to meet an actual need for information, compared to the overwhelming factor of curiosity and an interest about mobile AR technology. In this regard, current mobile AR applications in meeting user requirements are quite unsatisfactory, thereby inhibiting mobile AR from becoming a ubiquitous technology in people's day-to-day lives (Rekimoto, 1997).

1.2.2 Lack of Theoretical Framework

Second, research has shown that using mobile AR applications to help users develop and maintain general awareness of their surrounding environment is one of the greatest desired information needs (Borgia, De Marsico, Panizzi, & Pietrangeli, 2012; Dhir et al., 2012; Olsson, Lagerstam, Karkkainen, & Vaananen-Vainio-Mattila, 2011). Despite the fact that mobile AR guidance applications can enhance such awareness through a 3D egocentric view—which might not be satisfied by traditional approaches such as maps, radios, and conventional handheld displays (Chou & ChanLin, 2012; Tokusho & Feiner, 2009)—the challenge is that there is no theoretical framework or even a clear terminology associated with this increasingly ubiquitous phenomenon. For example, researchers have used a variety of terms to describe situational information needs (e.g., personal context-awareness, environment awareness, awareness of the environment, spatial awareness or simply awareness) while still lacking a detailed theoretical foundation (Chou & ChanLin, 2012).

From a human factors perspective, such awareness can be considered as a general type of situation awareness, which refers to "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988). Here, *situation* means those pieces of information that are relevant to the individual's task at hand. We continuously process information to support situation awareness throughout any given day (Pielot, Krull, & Boll, 2010). We use our senses to perceive what is going on around us, to interpret the received information, and to make decisions (Pielot et al., 2010).

The need to maintain situation awareness is essential to navigation tasks (Darken & Peterson, 2002), since it requires a high degree of engagement with the physical environment (even including surface, obstacles, the sky, etc.) (Hutchins & Lintern, 1995). According to Wickens (1999), tasks involving understanding our environmental spaces are aspects of the more general concept of *situation awareness* (Wickens, 1999). Specifically, as we travel through an environment we typically have two types of goals: 1) *understanding* the structure of the space, and 2) *navigating* through the space in order to reach a destination without getting lost or colliding with hazards. In this process, our perception involves extracting information continuously about our self-motion or the motion of other objects in the environment (Gibson, 1979; Warren, Wertheim, & Wertheim, 1990; Wickens, 1999). People tend to have a mental representation of the environment, which facilitates them navigating through it. In order to plan effectively in a dynamic, changing environment, people must have a relatively accurate awareness of both current and evolving situations (Wickens, 1999).

Unfortunately, although researchers have investigated the concept of situation awareness, until now there is still a paucity of understanding of how users build up situation awareness in the context of mobile AR-enabled navigation – and more importantly, how such an understanding can guide the design of SA-supported mobile AR guidance applications.

1.2.3 Interacting with Surrounding Environment

Third, studies have also suggested that while the original intent of using mobile AR technology is to increase meaningful interactions with the surrounding environment, some actual usage scenarios have produced the opposite result. In other words, depending on the system, people might suffer a loss of such engagement with the environment, thereby resulting in a loss of situation awareness. Since Smartphone-based mobile AR guidance applications have only recently reached the mass-marketed mainstream, relevant research is extremely limited or hidden in proprietary documents. However, some effects can be inferred from relevant research domains, such as mobile AR-like GPS navigation systems in driving. This research shares some common traits with Smartphone-based mobile AR guidance applications, such as AR augmentation and navigation capabilities (Jagoe, 2002), even though GPS systems are used in a more professional and specialized manner. Evidence shows that GPS navigation systems actually disengage people from their surrounding environment, partially because users simply follow verbal and/or illustrated GPS-supplied instructions and arrive at their destination at the end without having really interacted with their surroundings (Leshed, Velden, Rieger, Kot, & Sengers, 2008). This finding is also substantiated by

Ma and Kaber (2007), who reported an interesting relationship between situation awareness and the use of an AR-like navigation aid. The researchers discovered that when a driver in a car is aided by a perfect navigation system, the driver will pay less attention to the environment and situation awareness will decrease, as opposed to when the user is aided by a navigation aid that is not perfect.

Additionally, using of mobile AR guidance application might also impact user's interaction with their surrounding environment. Physically, users who rely on mobile AR applications on their phones have to walk through their environment with their eyes on their phone, held at arm's length—a posture with unfortunate implications for potential safety problems (Pogue, 2011). In the similar fashion, Huang et al. (2012) conducted a study to investigate the influence of mobile map-based, AR-based, and voice-based technology on spatial knowledge acquisition (or spatial learning) in tasks (landmark recognition, route direction, and landmark placement). The results indicate that all three interfaces led to poor results in spatial knowledge acquisition, and suggested that people did not put active mental effort into deriving information (Huang, Schmidt, & Gartner, 2012).

Thus, evidence seems to indicate that because mobile AR technology alters a user's experiences with environmental interactions—for example, how people feel, think, and engage with the physical (and social) spaces they are in—this technology mediation may result in the *loss* of interaction with the environment (Aporta et al., 2005).

1.2.4 Information Overload

The fourth and final identified problem associated with mobile AR guidance applications is content management, which, in fact, represents an area where mobile AR has been greatly challenged (Kurkovsky et al., 2012). There is an inherent challenge in trying to fit and present potentially limitless information into a small display (Ganapathy, 2012). Real-world views invariably contain multiple objects or places, each of which can be considered a potential source of digital information, so it is easy to inundate a mobile AR with virtual information (Frohlich, Simon, Baillie, & Anegg, 2006; King, 2009). One could justifiably argue that the human mind possesses an astounding capacity for processing and integrating information, so a mobile AR interface should simply make all available information visible and let users decide for themselves what is necessary and relevant information to performing the task at hand. However, a large amount of information is associated with excessive visual clustering on mobile AR, and may limit a user's processing capabilities due to overload (Julier, Baillot, Lanzagorta, Brown, & Rosenblum, 2001; Julier et al., 2000; Stedmon, Kalawsky, Hill, & Cook, 1999). Evidence shows that excessive and irrelevant information content significantly affects the user's experience and can lead to mental overload (Ginige, Romano, Sebillo, Vitiello, & Di Giovanni, 2012; Seo, 2011; Stedmon et al., 1999).

In addition, for mobile AR guidance applications, the total volume of data increases as the spatial area increases (Reitmayr & Schmalstieg, 2004b). Thus, being deployed in an unfamiliar or crowded area in an urban environment generates additional mental workload, which, in combination with the information overload described before, may lead to disorientation and incertitude (Neuhofer et al., 2012).

In summary, these identified problems with respect to a user's interactions with surrounding environment in a mobile AR-enabled environment create great challenges for HCI researchers and designers who are tasked with developing useful mobile AR guidance applications. Because mobile AR guidance systems are evolving so rapidly (i.e., end-user applications are mushrooming) (Dhir et al., 2012), understanding essential user-oriented issues is critical to developing mobile AR applications that are truly useful (T. Olsson & M. Salo, 2011). Unless user interactions with the surrounding environment in the mobile AR-enabled environment can be thoroughly understood and captured, any resulting products could be seriously compromised and ultimately could be proven to be ineffectual (Spath, Hermann, Peissner, & Sproll, 2012). To address these problems, this research is focused on identifying a new theoretical perspective via the exploration of applicable theories, extending, refining and validating the application of the new theoretical perspective in the context of mobile AR-enabled navigation. The effort is intended to provide a set of preliminary design recommendations for mobile AR guidance applications.

1.2.5 Situation Awareness Theory - A New Perspective

1.2.5.1 Situation Awareness (SA) Introduction

As stated, situation awareness is a ubiquitous aspect of everyday experience. SA refers to a broad construct for explaining information processing of awareness development in different situations. In simple terms, SA is one's internal model of the external world at any given point in time (Endsley, 1988) and serves as the basis for understanding of the state of the environment (Endsley, 1995a). It provides a foundation for subsequent decision-making and performance (Endsley, 1995a; Endsley & Garland, 2000).

According to Gilson (1995), SA was first associated with German flying ace, Oswarld Boelke (1891-1916) during the First World War. Boelke stressed the importance of gaining an awareness of the enemy before they gained a similar awareness, and in response, devised methods for accomplishing goals. This idea was called *situation awareness* (Gilson, 1995). Until the late 1980s, however, this concept did not receive much attention in the academic literature; since that time, it has become a hot topic (Stanton, Chambers, & Piggott, 2001). The initial push for SA research and development emerged from the aviation industry, where there is considerable pressure for pilots and air traffic controllers to develop better situational awareness to keep track of what's happening around them (Jensen, 1997). Although there has been a considerable time lag between initial identification of the SA phenomena and the maturity of the concept, the degree to which real problems with SA are being perceived and addressed is bridging the gap (Stanton et al., 2001). In particular, the concept of SA has received a great deal of attention from the Human Factors community (Stanton, 2005), which is investigating its applicability to many areas and applications, including automation, operation control management, emergency response, training, error analysis, design selection, teamwork, weather forecasting, computer mediated discussion, homeland security and military operations (Alan, 2008; Dominguez, 1994; Durso & Sethumadhavan, 2008; Endsley, 1988; Endsley, 1995b; Endsley & Kiris, 1995; Endsley & Rodgers, 1994; Jones & Endsley, 1996; Klein, 1995; Li, Liu, Chen, & Zhang, 2012; Mogford, 1997; Scott, 2009; Stanton & Young, 2000; Wickens, 2008).

Endsley (2000) has defined "situation" as "a set of environmental conditions and system states with which the participant is interacting that can be characterized uniquely by a set of information knowledge, and response options (p. 34). Every situation has associated with specific knowledge required to accomplish a particular task. Therefore "awareness" referred to the information and knowledge associated with a "situation" (Endsley, 2000). Since SA refers to the level of awareness that a person has of his/her current, ongoing situation (Stanton, 2005), the concept of "situation" can take on broad meanings—in other words, SA is domain-dependent and can refer to a general awareness or a detailed understanding of existing circumstances (Endsley, Bolte, & Jones, 2003; Endsley & Garland, 2000; Endsley, BoltÈ, & Jones, 2003; Greitzer, 2008). For example, SA could refer to a doctor noticing a patient's symptoms to diagnosing an illness (Wickens, 1999), or a pilot observing other planes, the weather, and changes in the approaching terrain or understanding a system's state in system safety (Stanton et al., 2001). Further, Sarter and Woods (1991) described and highlighted that even in one particular domain (e.g., aviation), information components of SA will vary between contexts or conditions (Pew, 1994; Sarter & Woods, 1991).

1.2.6 The Role of SA Theory in Addressing Mobile AR-Based Challenges

In this research, we introduce SA theory into the context of mobile AR-enabled navigation, and use it as a theoretical framework to empirically analyze the complexities of user interactions with their surrounding environment in such a context.

Although the specific SA elements and the "situation" will vary between domains, the underlying principle and SA theory can be applied across domains. SA is a three-level process comprised of perception, comprehension, and projection of elements in the environment. In aviation, for example, a pilot's SA has been described by Endsley (1998) as his/her on-going knowledge of the environment at the present moment. The pilot perceives with his/her sense that some elements (e.g., an aircraft, a mountain, a warning light) are present in the environment, along with their relevant characteristics (e.g., color, size, speed, location). The pilot then puts together his/her knowledge about these elements to form patterns with the other elements (gestalt). A holistic picture of the environment is formed and used to comprehend the significance of objects and events. Once the pilot comprehends these elements (e.g., enemy planes) within a certain proximity of each other and in a certain geographical location, the pilot is able to project a near future scenario of the environment (Endsley, 1988).

Mobile AR-enabled navigation leverages the natural behavior of users to do exploratory navigation and goal-determined navigation. In such a context, users' task is to explore and navigate to a destination depending upon their goals by interacting with their surroundings. SA theory provides a general framework for understanding the way people interact with their environment from the perspective of human situation awareness development. Building on such understanding, we can design mobile AR technology to assist a user's interactions with the surrounding environment by supporting that individual's situation awareness, specifically by supporting three levels (perception, comprehension, and projection of environment). By adopting a situation awareness perspective, the author believes that mobile AR guidance systems will achieve two important goals: 1) lead users to more effective interactions with their surrounding environment; and 2) facilitate the user's situation awareness development and subsequent on-site decision-making process.

1.2.6.1 Interacting with Surrounding Environment

Issues of navigating with mobile AR guidance systems are complex and subtle, where virtual and material spaces have been inextricably linked. Mobile AR users not only engage with the physical environment that surrounds them, but they also engage with the virtual-technological environment offered by digital augmentations. In a mobile AR-enabled environment, these digital augmentations are primarily visual, interactive, and occur in real-time—thereby tightly weaving the material and social fabric of an environment to bring out different ways of interacting with it (Gordon & e Silva, 2011; Graham, Zook, & Boulton, 2012). An object in such an environment possesses both physical attributes and a multifaceted, digital augmented (e.g., visual and textual) representation. A mobile AR guidance system might have digital content such as user-generated and geo-tagged content (e.g., Wikipedia articles, live Twitter feeds, photographs, a GPS track of a bus, or social recommendations). These data are constantly made available and are increasingly reflective of real-time events rather than time-delayed information (Graham et al., 2012; Reitmayr & Schmalstieg, 2004a). Adopting a situation awareness perspective can help us build an understanding of the process users employ to develop situation awareness in interacting with a mobile AR-enabled surrounding environment.

1.2.6.2 Information Needs

As stated previously, users do not process all of the information that is available to them. The human mind is naturally limited by characteristics such as perception, attention, and working memory. In a mobile AR-enabled environment, excessive information could contribute to the individual's mental overload, thereby resulting in impaired awareness of surroundings in navigation. To address the problem, information should be displayed only for the elements that are relevant to the user for a particular task at a particular time (Wither, 2009). Essentially, the mobile AR designer and developer need to build an understanding of what information is needed by users and how it will be used (Salmon et al., 2008). SA theory can help us with an understanding of how people choose information, weave it together, and interpret it in an ongoing and ever-changing fashion since both situations and operator goal states invariably change (Endsley, 2000).

Thus, we believe that in order to develop a mental model of interacting with the "augmented" surrounding environment, a spatial layout of the environment is insufficient. The content enacted in augmented reality is spatially, temporally, personally and socially context-dependent (Graham et al., 2012). These multifaceted data are more and more important to constructing a seamless representation of place (Graham et al., 2012). Therefore, this emerging phenomenon requires a paradigm shift in space navigation—from answering a small collection of conventional navigation questions such as "where am I?" (Hutchins & Lintern, 1995), to a series of more multifaceted and complicated questions such as "what is going on around me?" That is, there is a shift from spatial awareness to situation awareness. This calls upon researchers to examine the ways in which virtual representations of environment are implicated in the products and experiences of environment as augmented realities (Graham et al., 2012; Westlund, Gomez-Barroso, Compano, & Feijoo, 2011). Through our analysis, we believe SA theory can be appropriately applied to respond to this need, with the goal of creating a more complete picture of a user's relationship with the surrounding environment in space navigation.

1.3 Research Objectives

This work seeks to fill the knowledge void by providing a theoretical standpoint that will integrate SA into mobile AR-enabled exploratory navigation research. Specifically, our interest is confined to exploratory navigation that occurs in urban environments. Urban navigation is used as a test bed because it supports navigation tasks in the rapidly-changing context of a typical urban environment (Tamminen, Oulasvirta, Toiskallio, & Kankainen, 2004). The selection of urban context reflects a demographical trend towards becoming “an urban world”, according to the United Nations Population Fund (2007), and it can also be generalizable to other, perhaps less challenging applications.

The main purposes of this research work are to extend and refine situation awareness theory in the context of mobile AR-enabled urban exploratory navigation, and validate the extended application of the theory in such context. The initial step is to explore the process users employ to develop situation awareness and corresponding information requirements in the context of mobile AR-enabled urban exploratory navigation. Once this understanding is acquired, improvements in users’ situation awareness in urban exploratory navigation can be initiated in a design prototype.

Based on Endsley’s three-level theory, we need to extend and refine SA theory in the context of mobile AR-enabled urban exploratory navigation. This understanding is “interface- free (or technology-free).” According to Endsley (2003), this knowledge is called “perfect SA” knowledge. The logic behind this concept is that if the logic of an interface-free theory holds, then in 100 years designers would still be able to use it to guide their design choices in designing a variety of mobile AR products. Such understanding would help designers generate design ideas for mobile AR guidance applications to support SA. Because interface only provides a means of instantiating some variables that represent a construct (Briggs, 2006), the design should be focusing on mobile AR-supported cognitive process, rather than on the mobile AR interface itself. In other words, the outcome we seek to improve with mobile AR technology is a user’s situation awareness of his/her surroundings, not the interface itself. Mobile AR interface is only a means to effect such changes. Therefore, we should first understand the phenomenon of interest, after which we can think about ways to design interfaces to improve it. Specific research objectives are listed as follows:

1. To extend or modify the application of situation awareness theory to Mobile Augmented Reality (AR)-enabled urban exploratory navigation as the exploratory context (RQ1, RQ2)
    a) To understand the process of users’ situation awareness development in the context of mobile AR-enabled urban exploratory navigation.
    b) To understand users’ situation awareness information needs and requirements in terms of interacting with their surrounding environment in mobile AR-enabled urban exploratory navigation;
    c) To derive interface design implications of SA-supported solutions for mobile AR guidance applications.
2. To validate the extended preliminary cognitive model through evaluating the derived SA-supported design implications in mobile AR guidance applications in the context of urban exploratory navigation. (RQ3)

A side product of this research, namely, a mobile AR guidance application for urban navigation, will be conceptually designed and vision-prototyped.

1.4 Research Questions

The major research questions of this study are listed as follows:

1. RQ1: What process do users employ to develop situation awareness in the context of mobile AR-enabled urban exploratory navigation?

2. RQ2: What users' situation awareness requirements are in the context of mobile AR-enabled urban exploratory navigation?

3. RQ3: What are the differences between the proposed situation awareness-supported mobile AR guidance interface and a currently available interface in terms of a) the user's situation awareness b) the user's perceived usability in urban exploratory navigation?

1.5 Approach

To answer these research questions, this research had two studies:

Study 1: Situation Awareness Theory Refinement (SA Requirements Analysis)

Study 2: Theory Validation (Interface Evaluation)

Overall, a mixed-methods approach was used to extend, refine and validate situation awareness theory in the context of mobile AR-enabled urban exploratory navigation.

Study 1: In the first study, a qualitative approach was used to elicit the process that users employed to develop situation awareness in the context of mobile AR-enabled urban exploratory navigation, as well as to collect users' situation awareness requirements in such a context. The purpose of the first study was two-fold: 1) to explore and identify the process that users employ to develop situation awareness; and 2) to explore and generate themes about mobile AR users' situation awareness requirements in the outdoor urban environment, using contextual inquiry methods of fieldwork observation, concurrent think-aloud and face-to-face semi-structured interviews. Meanwhile, user tasks in the context of mobile AR-enabled navigation were identified. During this process, a goal-directed hierarchical task analysis was conducted and workflow of user tasks was generated. Content analysis was used to identify the process of situation awareness development in such a context, and analyze and classify situation awareness requirements. Meanwhile, situation awareness probes were generated for use in measuring SA during Study 2.

Based on these results, SA theory was extended and refined to explain the observed phenomenon—and in particular how it can be applied to the domain of mobile AR-enabled exploratory navigation. A prototypical theoretical model of situation awareness in the context of mobile AR-enabled urban exploratory navigation was generated.

Interface design and development: In order to validate the application of the prototypical theoretical model, SA-supported design implications for a mobile AR guidance application were derived from the findings obtained from Study 1. This process transformed a user's SA requirements into a set of more concrete SA-supported design requirements, and subsequently into detailed design solutions. Conceptual prototypical interfaces were generated to demonstrate part of the conceptual design of the SA-supported mobile AR guidance application by integrating the user's extracted SA requirements for the follow-up in lab interface evaluation.

Study 2: The design of conceptual prototypical interfaces was empirically evaluated to examine if a user's situation awareness was supported by the SA-supported mobile AR design. For this purpose, corresponding interfaces of a mobile AR guidance application employed during the previous requirements elicitation phase were used again as baseline interfaces with the same level of interaction as the developed conceptual design interface. A goal-based formative empirical evaluation was conducted. In this process, application of extended situation awareness theory was validated, which involved comparing SA-supported interface (which the prototypical theory was applicable to) against the baseline interface for the mobile AR exploratory navigation domain to determine if there was a difference.

The overall research framework proposed herein is depicted in Figure 1, while the correspondence between the research questions and research approaches is shown in Figure 2. With a focus on understanding users' situation awareness development, we are careful to note the assumption of *technological determinism.* This assumption would suggest that mobile AR technologies should have a *concrete* and *deterministic* effect (Leshed et al., 2008) on a user's information processing of the world. However, by adopting a user-centered perspective, we are held to the greater ethical responsibility of recognizing the capability and limitations of individuals (situation awareness as a cognitive ability) in a technological context (mobile AR-enabled urban navigation) and the ability of a user to reject or demand a re-design of the technology.

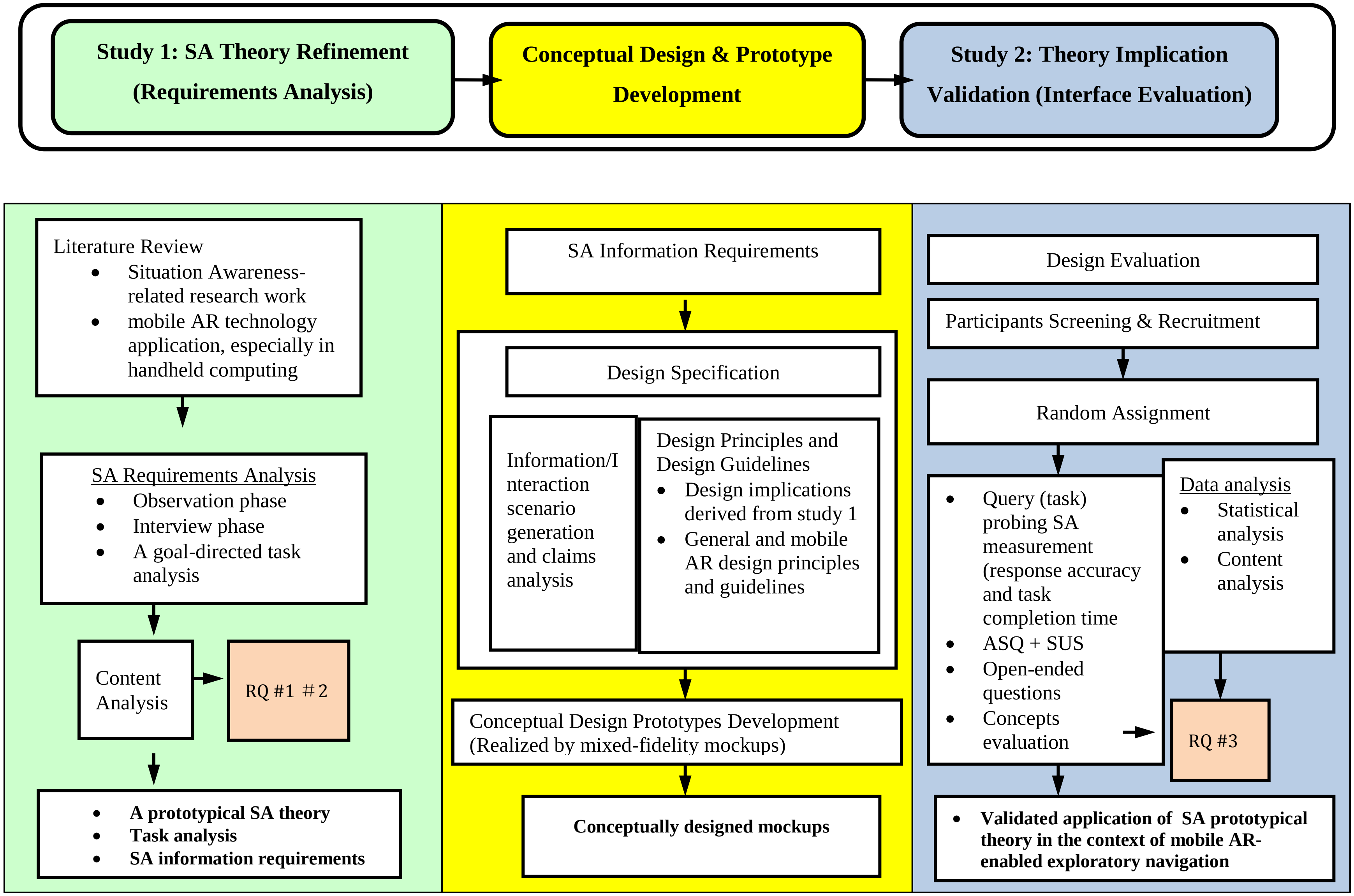

Figure 1. Overall conceptual framework

CHAPTER 2 LITERATURE REVIEW

2.1 Awareness Research in HCI

2.1.1 Human Computer Interaction (HCI)

The main objective of HCI is to improve the usability and usefulness of technical systems and devices (Nickerson & Landauer, 1997). The view of the human as an information processing unit—and thus intelligence as processing—has a foundational framework within HCI. This view originated from Broadbent's view of cognition as a sequential series of processes (Broadbent, 1958). The core of HCI, therefore, lies at the interface between a technological system and the human utilizing that system (Card, Moran, & Newell, 1983). HCI views the human as an input-output computer. Simply put, in the human cognition model, information enters the mind in various forms, the information is processed on several levels, and then the mind or body produces a response. This perspective represents a fundamental view of how basic research in human psychology and human cognition has expanded into interface design theories. There are three major theories associated with HCI: 1) explanatory theories, 2) predictive theories, and 3) theories consisting of taxonomies and models. Explanatory theories explain the interaction between the human and computer. Predictive theories quantify the human-computer interaction in order to predict it, such as Fitts law used to describe speed in relation to object size (Fitts, 1954). Theories involving taxonomies and models are more results-oriented, such as GOMS used to model a user's interaction with a computer to its elementary actions (Card et al., 1983).

2.1.2 Overview of Awareness Research (AR) in HCI

In general, the literature surrounding awareness is primarily concerned with the use of information technology to assist individuals in becoming aware, understanding relevant information, and maintaining awareness (Talaei-Khoei, Ray, Parameshwaran, & Lewis, 2012). Awareness is defined as a consciousness of internal or external events or experiences (APA, 2007). It is having knowledge or being well informed. Awareness concepts or constructs stemming from applied sociology and psychology (such as group awareness, social awareness, task-specific awareness, objective self-awareness, situation awareness, visual awareness, motion awareness, spatial awareness, referential awareness, and object awareness) provide a foundation for development and are put into practice by computer interaction developers (Gross, 2005).

Awareness research in HCI has a long history and concerns a variety of issues that are relevant in the context of human computer interaction—from an awareness of simple facts or events all the way to a rich and nuanced understanding of another person's daily activities (Markopoulos, 2009). These various research studies use different tactics, depending on the nature of the awareness information. For example, in CSCW (computer-supported cooperative work), information relating to knowledge of group and individual activity, information sharing, and coordination contribute to what is referred to as *awareness* (Dourish & Bellotti, 1992). As described by the researchers, *awareness* is an understanding of the activities of others, which provides a context for your own activity. In Situation Awareness (SA), awareness information refers to a generic understanding of what is going on around an individual, consisting of any needed information and capabilities that one needs to achieve a goal or reach a decision (Endsley & Garland, 2000). SA has also been discussed in a wide range of usages, such as hazard awareness, systems awareness, and task awareness (Wickens, 2000).

From psychological/theoretical and neurobiological perspectives, Lamme's awareness model has been adopted as a theoretical and logical foundation of all awareness research: we are "conscious" of many inputs, and with attention, this conscious experience can be reported (Lamme, 2003). Human needs served by awareness are fundamental and timeless (Markopoulos, 2009). For centuries people have used all available means to construct and maintain awareness, and humans possess highly-evolved mechanisms for awareness (Kandel & Schwartz, 1981). Technologies are entering into this evolutionarily developed pattern. These technologies can mediate interactions between individuals and dramatically extend the range of what an individual can be aware of (Biocca et al., 2003). Meanwhile, human needs in part develop from people's usage of existing technologies (Carroll, 1992), so it cannot be assumed that an ultimate state has already been achieved where people's needs have been met conclusively (Markopoulos, 2009). In other words, technologies are employed to help meet human needs, which are described at a fundamental and generic level (Markopoulos, 2009). In awareness systems, most of the focus is on the substance and the real-time resource allocation of attention and short-term memory to the people, information objects, and the environments nearby (Biocca et al., 2003).

2.1.3 Awareness Information

As stated above, although there are definitely some overlapping areas, based on the type of awareness information provided, awareness systems can be generally categorized as 1) systems providing information of presence and activities of social practices; 2) systems presenting ambient information; 3) systems providing context-awareness; 4) systems supporting people's situation awareness.

The first body of work principally involves information of presence and activities of social practices. Most of the work, which was done in the 1990s, focused on designing computer-supported cooperative work (CSCW) software systems to provide users with awareness information about the presence, activities, and availability of members in collaborative communities (Gross, 2005). Awareness of individual and group activities is critical to successful collaboration (Dourish & Bellotti, 1992).

Maintaining awareness of co-located and distant work and social groups has been a long-term research thread in awareness design. This work encompasses *group awareness* (Begole, 1999) or *workspace awareness* (Gutwin & Greenberg, 1998), which provides a context for your own activity based on an understanding of the activities of others; *informal awareness*, the pervasive experience of who is around, what these persons are doing, and what they are going to do (Gutwin, 1996a); *social awareness,* an understanding of the availability of different kinds of information (e.g., interests and attention) or the emotional state of a conversational partner through eye contact, facial expression, and body language; and *group-structural awareness,* information about the group itself and its members, such as their roles, stats and responsibilities within a group (Dourish & Bellotti, 1992). In short, this thread of awareness research addresses the up-to-minute knowledge of other people's activities that is required for others to coordinate and complete a group task (Gross, 2005; Gutwin & Greenberg, 1995).

By way of example, *group awareness* is maintained by keeping track of information such as other people's locations (where are they working?), their actions (what are they doing?), their interaction history (what have they already done?), and their intentions (what are they likely to do next?) (Gutwin & Greenberg, 1995). *Social awareness* is maintained by the working context of co-workers (Bardram & Hansen, 2004). In one study, doctors and nurses were not co-located, making it impossible to monitor or display each other's activities. Thus, a Context-Mediated Social Awareness (CMSA) device, the "AwarePhone," has been introduced as a mechanism for establishing social awareness amongst physically-separated colleagues through access to their working context. It emphasizes how the context can be used to provide social awareness between co-workers who are not co-located (Bardram & Hansen, 2004). In summary, this type of knowledge in awareness research involves two groups of information: *what* is happening with another person (e.g., amount of activity, nature of actions, changes, and expectations), and *where* it is happening (e.g., location of focus, view extents, area of influence, or objects in use) (Gutwin, 1996b).

In addition to these traditional awareness constructs, AR technology introduces more awareness concepts into CWCW research. AR plays an important role in both co-located physical spaces and geographically-separated places, because non-verbal communication, such as eye gaze, pointing and body movement, must be synthesized using computer-mediated techniques (Chastine, 2007). To achieve meaningful information exchange and collaborative work in a shared physical space, *referential awareness* and *spatial awareness* have been actively researched. *Referential awareness* is the ability for one participant to refer to a set of objects (e.g. via a gesture) and for that reference to be understood by another (Chastine, 2007). It is described as a process comprised of the phases of selection, representation, and acknowledgement (Worksharing, 2006).Techniques that support these processes have been proposed, such as show-through techniques (e.g., *cutway* and *transparency* techniques) (Argelaguet, 2011), as well as contextual and environmental factors that influence referential awareness, such as occlusion, visualization, and proximity (Chastine & Zhu, 2008). Using AR for spatial displays, graphics can be overlaid onto real surroundings, thereby providing a shared reference frame—together with speech—to communicate effectively (Green, Richardson, Slavin, & Stiles, 2007).

The second body of awareness research in HCI addresses *ambient information system* design issues, also known as *peripheral display* and *notification systems,* with some differentiation between them (Pousman, 2006). Broadly speaking, researchers develop *ambient display systems* of this type that use a multitude of everyday objects or things (e.g., lights, sounds, shadows, artificial flowers, mobiles, etc.) to display various types of information—e.g., stock prices, weather forecasts, or the presence or absence of colleagues. Ambient information systems are created to convey information to users, which typically is important to a user's sense of wellbeing and general awareness, but not critical to their work or personal life (Pousman, 2006). While some research in this category overlaps with CSCW research (e.g., sociotechnical systems), a significant number of research studies has emphasized the representation of information about a user's world to make people aware of activity- or object-related information, such as network traffic (Pousman, 2006). For example, a system platform may be based on the integration of ambient information displays (lamps, a table fountain, and a humidifier) to make people aware of web-based activity (Schmidt, 2001).

The third category of awareness research has focused on context-aware systems. Context awareness is a new field of research in HCI that did not closely relate to user interface issues until the past decade or so (Hakkila, 2006). The term "context-aware computing" was first introduced by Schilit (1994) as computing that "*adapts according to its location of use, the collection of nearby people and objects, as well as changes to those objects over time*" (p. 23) . Since then, context-aware computing has often been linked to research on ubiquitous computing, pervasive computing, and situated computing (Dourish, 2004). From a human factors perspective, the motivation for developing a context-aware system is to compensate for a human's limitations—such as deficits in attention, memory, learning, comprehension, and decision-making—by the system's acquisition of information about its context-of-use through the use of sensor-based computational tools (Rogers, 2006). Related definitions of context-aware systems also exist. For this study, the following definition of a context-aware system has been adopted: "The system that uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" (Abowd et al., 1999).

Context-aware applications have been used to support three kinds of features: 1) presenting context information and services to users, 2) automating an action for users, and 3) tagging of context information for later retrieval (Dourish, 2004). It must be noted that context-awareness is not limited to mobile devices, but has been applied to a various other applications as well—for example, automated video and audio capture in a lecture room, house front doors, smart furniture, hospital beds, and mobile handheld devices. These applications, which have been widely adopted by a diverse group of users (especially in the form of mobile phones), constitute an interesting platform for context-awareness (Hakkila, 2006).

The fourth category involves situation awareness research, which is also the focus of the current study. The next section will provide a thorough review of the body of situation awareness research.

2.2 Situation Awareness and Situation Awareness Theory

As previously described in the Introduction to this study, SA research has been a human factors research topic for decades. Despite some common interpretations of SA, researchers have yet to agree on a single definition for situation awareness, although the following three schools of thought seem to predominate: 1) SA as a psychological phenomenon, 2) SA as an engineering concept that resides in the world, and 3) SA as an emergent property arising from people's interaction with their environment (Sorensen, Stanton, & Banks, 2011). Among those different perspectives, Endsley's definition has received the most attention (Durso & Sethumadhavan, 2008; C.D. Wickens, 2008). Situation awareness, according to Endsley, is informally defined as "knowing what's going on around you and understanding what that information means to you now and in the future" (Endsley, 2000, p.5) and, more formally, as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 2000, p.27).

Despite claims by some researchers that SA is derived from instinct or even "extra-sensory perception" (Klein, 1995), SA has been recognized as a critical, yet often elusive, foundation for successful decision-making across a broad range of complex and dynamic systems (Endsley, 1995b; Salmon et al., 2008). It is operationalized in terms of information-processing states in the mind of operator—between the perception and decision-making stages (Endsley, 1988; Endsley et al., 2003; Endsley, 1995b; Sorensen et al., 2011; Wickens, 2008). Endsley's (1988) SA theory grounds the construct within the general context of the human information processing model (Wickens, 1992). It encompasses perceptual and comprehension processes, but not decision-making and response-execution processes. This theory resulted in a three-level SA framework: perception, comprehension, and projection (Endsley, 1995b; Endsley & Kiris, 1995). Also, despite numerous cognitive processes involved with SA, there are some critical cognitive mechanisms related to the development of SA, as illustrated in Figure 3 (Endsley, 1995b; Wickens, 2008).

2.2.1 Endsley's Information Processing Framework

Endsley's three-level theoretical framework considers SA as emerging from complex cognitive processes (Durso & Gronlund, 1999; Wickens, 2008). It describes SA as a state of knowledge that results from the processes used to achieve it. That process is known as situation assessment (Endsley, 2000).

Level 1 SA: Level 1 comprises one's perception of existing environmental elements. To achieve Level 1 SA, one has to perceive the status, attributes and dynamics of the relevant elements in the environment. In this process, attention is directed to the most relevant environmental cues, which are based on task goals and past experience in the form of mental models or schemata. For example, in Level 1 SA, a military commander would need to perceive data on the location, capabilities, types of weapons used, numbers of vehicles, morale and condition of his own forces, and of enemy forces in the surrounding environment.
Level 2 SA: Level 2 comprises the comprehension of the current status, which is achieved through the integration and synthesis of the information achieved in Level 1 SA. To reach comprehension, the individual must possess an understanding of what each element means in relation to his or her situation and goals—mostly in the working memory system, which goes beyond perceiving simple information that is presented in a given situation. Level 2 involves integrating pieces of information, as well as prioritizing the perceived information and meaning as it relates to goals and objectives. To achieve Level 2 SA, that military commander would need to comprehend the current status of his own troops, the enemy troops, and civilians in relation to the current tasks and mission goals.

Level 3 SA: Level 3 SA entails projecting the likely future status of a given situation, which involves predicting the anticipated status of individual elements within the current environment. If an individual can anticipate and envision the future status or actions of elements in the environment, he/she will be more likely to predict what might happen next. To achieve Level 3 SA, that same commander would be able to predict how and where the enemy is about to attack as a result of a comprehension of the elements of the situation.

In terms of elements of awareness, Endsley (2000) described the elements of awareness that need to be included: current state of the system (including all the relevant variables); predicted state in the "near" future; information and knowledge required in support of the crew's current activities; activity phase; prioritized list of current goal(s); and information and knowledge needed to support anticipated "near" future contexts. To achieve SA, the crew member may draw on various information resources, including: sensory information from the environment, visual and auditory displays, decision aids and support systems, extra- and intracrew communication, and crew member background knowledge and expertise (Endsley, 2000). Therefore, in complex and highly automated systems, besides spatial awareness, other elements of awareness, such as mission-goal awareness, system awareness, and resource awareness should be included as well (Endsley, 2000).

It should be noted that sources of SA vary between domains. In many domains, in addition to the SA provided by the system interface, people may be able to directly view and hear information from the environment itself (e.g., pilots, drivers, machine operators), while in some cases they may not (e.g., individuals who have to rely on remotely transmitted information). For any given area and task under analysis, it is necessary to determine exactly what the sources and elements in this definition are (Endsley, 1993).

Furthermore, because situation awareness is domain specific, it is not appropriate to say that a person has "good situation awareness." One has to indicate a specific *awareness of what*, such as awareness of surrounding traffic, of the approaching weather, of the state of automation in a vehicle, of the momentary responsibility for tasks, of a stress-related decrease in one's physical or cognitive capabilities, etc. (Wickens, 1999, 2000). For the remainder of this work, the focus will be on situation awareness in exploratory navigation—specifically, to an awareness of the surrounding environment in urban exploratory navigation tasks. To simplify the discussion, the term "situation awareness" or SA was used to indicate situation awareness in terms of environmental surroundings.

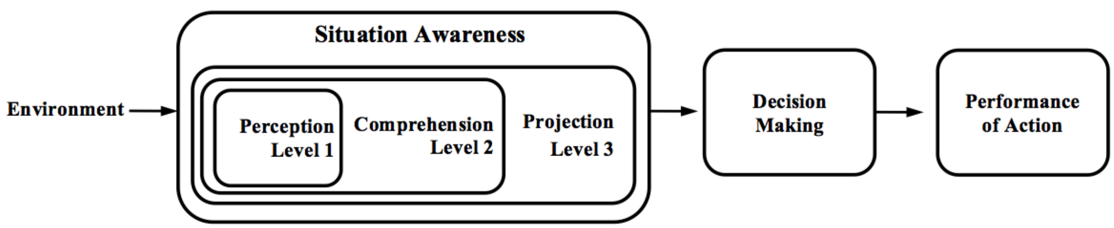

Figure 2. Model of Situation Awareness adapted from Endsley (1995b)

2.2.2 Important Cognitive Mechanisms of Developing SA

Human rarely perform like perfectly rational observers of a situation. It is not "human nature" to be completely rational and impartial in considering what is important to look at, or be perfectly aware of what is going on around them (Dekker & Lutzhoft, 2004). All theories of SA rely on the idea of matching, correlating or creating correspondence between an external world of stimuli (i.e., objective cues) and the internal world of mental representations, which is subjective in nature. A close correspondence (or a good match) between the mental and the material will produce "good SA;"

otherwise, a person will have a "deficient SA" or "loss of SA". Thus, SA is about accuracy—that is, achieving an accurate mapping between the objective world and the subjective representation of the world. The awareness of an objective world is called an ideal SA, while that of subjective representation is actual SA (Dekker & Lutzhoft, 2004). Thus, the design goal is to support users to achieve their best SA.

Despite the fact that the environment in a mobile context may be less complex than it is in more multifaceted environments, such as battle, aviation, or emergencies (i.e., where situations can change very quickly), the fundamental principles are the same. Two main sources contribute to SA development: 1) explicit focus or active knowledge in working memory, and 2) implicit focus or less active knowledge that is relevant to the current situation in long-term memory. The first related notion is attention. The use of attention in the human information acquisition or perception process presents certain inherent constraints on human capability to accurately perceive multiple items in parallel. This represents a major hurdle in SA (Endsley, 1995b). Direct attention is needed not only for perceiving and processing cues, but also for the later stages of making decision and response execution (Endsley, 1995b). Attention demands a focus on information needs, decision-making, and multiple tasks, which can exceed one's limited attention capacity (Endsley, 1995b). Attention to information is prioritized based on how important that information is perceived to be (Endsley, 2000). To form good SA, a system should help people direct their limited attention in efficient ways to the most task-relevant and important information to gain sufficient awareness of what is going on (Endsley, 2000).

Once perceived, information needs to be combined, interpreted and projected in working memory. A constraint of SA is limited working memory, or working memory losses. People may not be able to remember where information was initially perceived (Jones & Endsley, 1996). The implication for design is that the system should provide a means of integrating information without overloading working memory (Endsley, 2000). Several strategies to reduce the effect of working memory on SA have been suggested in the literature, including information prioritizing, chunking, "gistification" of information (e.g., encoding only relative values of information), and providing external memory cues (Endsley et al., 2003; Endsley, 2000; Jones & Endsley, 1996).

Attention (selective attention) directs the acquisition of information essential for Level 1 SA. In this process, long-term memory knowledge, which is stored in the form of a mental model or schemata, directs attention to support Level 1 SA (Wickens, 2008). For example, if someone already has some knowledge of a particular landmark or a historic scene, when revisiting that location he/she will pull from their long-term memory to recognize or recall the relevant information about that place. Knowledge of structures (e.g., expectancies) aids understanding and comprehension of them via top-down processes.

It must be noted that the relationship between the SA model and Mogford's (1997) Mental Model has long been discussed. Although they are both conceptual models that represent abstract notions (Craik, 1943), the distinctions and connections between these two continue to intrigue human factors researchers. Mental models represent an older concept that dates back at least to Craik's 1943 programmatic work in *The Nature of Explanation*. Some have asserted that there is certainly some overlap between SA and mental representations (Stanton & Young, 2000). Endsley stated that SA "can be conceived of as the pilot's internal model of the world around him at any point in time" (Endsley, 1988). In essence, SA represents the current state of the mental model (Endsley & Garland, 2000). For example, one can have a general mental model of what a car engine is, but the SA model is the state it is believed to be in now (e.g., fuel, temperature)—what Mogford termed a "a gestalt comprehension of the state" (Mogford, 1997). So in addition to having the current value of engine temperature, the situational model also contains an understanding of the impact of that state on projected events (e.g., whether the engine might overheat) (Endsley, 2000). Overall, the mental model and schemata are believed to be central mechanisms for overcoming limited working memory constraints to forming SA. More discussion about this topic can be found in (Endsley et al., 2003; Endsley, 1995b, 2000; Endsley & Garland, 2000).

Some researchers have emphasized the role of *interaction* between the person and his/her environment (Smith & Hancock, 1995). In this sense, SA is best understood as the interaction between people, their environment, and the artifacts within it. SA is conceptualized as the *competence* that has an invariant structure but can be adapted by up-to-minute knowledge from interactions with the environment (Smith & Hancock, 1995). *Performance* is dependent on information available in the environment, while *competence* is independent of the particulars of a situation (Smith & Hancock, 1995). This view guides the process of constructing knowledge (the big picture) of both current and likely events. This reinforces and emphasizes that there are *some things* in a situation that are critical and relevant to the goals at hand—but there are also other things that are not relevant at all (Endsley, 1988). Thus, SA may be good or poor depending on the factors that constrain that *interaction* (Endsley, 1988).

Additionally, the literature suggests that some individuals are better at SA than others because of individual differences in attributes. The main body of this type of research has focused on cognitive factors that affect SA in complex situations and systems. Endsley and Bolstad (1994) described a relationship between spatial and perceptual skills and SA. In a study of Air Force F-15 pilots, flying experience has been found to be an effective predictor of SA (Carretta, Perry Jr, & Ree, 1996). When controlling for flying hours, cognitive factors such as working memory, spatial reasoning and attention were positively correlated to SA. Researchers have also reported that working memory and psychomotor abilities are correlated with individual differences in SA (Gugerty & Tirre, 1996). Moreover, personality was reported to correlate with SA as well (Saus, Johnsen, Eid, & Thayer, 2012).

2.2.3 Situation Awareness vs. Computer assistance

As stated previously, mobile augmented reality (mobile AR) is a fast-growing, mass-marketed domain in both academic and industrial research. Current mobile AR research at universities and corporations is primarily funded by the military and targets advances in satellite navigation, heads-up displays for pilots, navigational support, communication enhancements, as well as civilian uses for some of these developments (Van Krevelen & Poelman, 2010). Interestingly, SA is also a concept stemming from military research that is being extended more generally and broadly to driving, healthcare, and other application domains. SA theory has great potential for providing a rich and multifaceted mobile AR user experience (UX), given its explanatory nature and theoretical guidance in various mobile application areas for regular mobile AR end users.

Specifically, SA theory has had a significant influence on cognitive engineering; SA is also important in cognitive ergonomic issues related to training, teamwork, automation, and the design of new human-technical systems (Durso & Sethumadhavan, 2008). Cognitive processes for developing SA from perception to comprehension to projection can be aided by computing systems (Durso & Sethumadhavan, 2008; Holsopple et al., 2010), with most SA errors arising from a failure to obtain essential information (Stanton & Young, 2000). Overcoming human information processing limitations (limited attention, perception, working memory) is an essential part of systems design (e.g., medical systems, aircraft and air traffic control systems, information networks, offices, automobiles, power plants) or internet design (Durso & Sethumadhavan, 2008; Endsley et al., 2003). These design implications have been important in a variety of contexts, including commercial and military aircraft, air traffic control, large-systems operations, tactical and strategic systems, driving, and medical decision-making (Endsley, 1995b). Endsley (2003) described that the way in which information is presented to the operator through an interface influences SA. For example, establishing and maintaining fireground situation awareness is critical for effective rescue, fire control and property conservation involving teams of firefighters performing a full range of assigned tasks at the same time (Alan, 2008). As one design application developed to achieve this goal, coloring the involved area as red, the vulnerable area as yellow, and uninvolved regions as green within a fire area represents some basic tactical components that show the geometry and the geography of the current fire location, the size of the fire and its paths (Alan, 2008). Some additional questions of interests relating to SA are (1) how long the fire has been burning, and (2) what type of structural material is burning (“National Fire Fighter Near-Miss Annual Report,” 2008).

Despite impressive advances, system design has also been challenged and complicated by many factors. Studies have shown that there is an interesting relationship between SA and human performance under different circumstances. For example, when a driver in a car was aided by a perfect navigation system, the driver would pay less attention to the environment; as a result, his/her SA would actually decrease in comparison to the driver using the imperfect driving aid (Ma & Kaber, 2007). However, in most real-world domains the need for SA remains—particularly in cases when reactive stimulus-responses are not enough and more proactive, goal-driven cognitive processes are needed for successful performance (Endsley, Bolté, & Jones, 2003).

2.2.4 Evaluation Methods of Systems for SA

2.2.4.1 Evaluation of Information Systems

Scriven distinguished between two types of evaluation in information systems evaluation: *formative* and *summative* (Scriven, 1991, 1996). Although distinctions between the two are not entirely dichotomous (Patton, 2002), they do represent different processes. Formative evaluation usually takes place during the design process, when prototypes or system versions are produced and evaluated (Scriven, 1991). For example, lower fidelity prototypes (e.g., wireframes and paper prototypes) are typically representative of formative evaluation outcomes (Dumas & Fox, 2009). In contrast, as the adjective suggests a summative evaluation is meant to evaluate a program at its conclusion.

In general, information systems can be evaluated either using *analytical* methods (involving modeling and analysis of a system's features and implications) or *empirical* methods (involving observations or other data collection requiring user involvement) (Rosson & Carroll, 2002; Scriven, 1996). Both methods involve three different strategies of evaluation: *goal-based evaluation*, *goal-free evaluation* and *criteria-based evaluation* (Cronholm & Goldkuhl, 2003). The first is *goal-based evaluation*, which is driven by specific goals to measure the extent to which an information system has attained clear and specific objectives. The fulfillment of goals can be evaluated using either quantitative or qualitative strategies (or both). A quantitative strategy is designed to determine if a particular goal (or goals) has been fulfilled, which is expressed as a numerical outcome. Conversely, a qualitative strategy seeks to describe in words how certain goals are fulfilled. The second is *goal-free evaluation*, which is a more interpretive strategy; it does involve formulating any specific goals, but instead aims at a deeper understanding of what is to be evaluated. Typically, this type of evaluation involves a wide range of stakeholders, and the evaluator makes a deliberate attempt to avoid all rhetoric related to goals. The third is *criteria-based evaluation*, which typically utilizes a predefined set of criteria such as checklists, heuristics, and principles. The criteria used are grounded in and derived from one or more perspectives or theories, such as Nielsen's checklist, which emerges from cognitive science (Nielsen, 1993; Jakob Nielsen & Molich, 1990). The criteria are general and not as specific as goals.

2.2.4.2 Evaluation of Systems for SA

Because SA is an internalized mental construct, creating measures to adequately evaluate and describe it is not an easy task. Several ways of classifying SA measures have been identified. Researchers have categorized them into six measures: retrospective, concurrent, subjective, process, performance, and signal detection theoretic measures (Gravell & Schopper, 1994); or into three categories: on-line indices, indirect probes, and model-based approaches (Adams, Tenney, & Pew, 1995). SA measures have also been described as two orthogonal dimensions—on-line or off-line—crossed with direct and indirect measurement, or more general categorization of subjective measures, query methods, and implicit performance measures.

For this proposed study, Endsley's categories were used, which group SA measures as *direct* measures and *indirect* measures; these are further divided into process measures, and behavioral and performance measures (see Figure 3) (Endsley & Garland, 2000). *Indirect* measures involve inferring SA from observable processes (including verbal protocols, communication analysis, and psychophysiological metrics), behaviors, or performance outcomes. *Direct* measures are considered a better way to measure SA than indirect measures because the latter are not exact and are harder to confirm (Endsley & Garland, 2000). Direct measures can be categorized as both *subjective* measures and *objective* measures (see Figure 4).

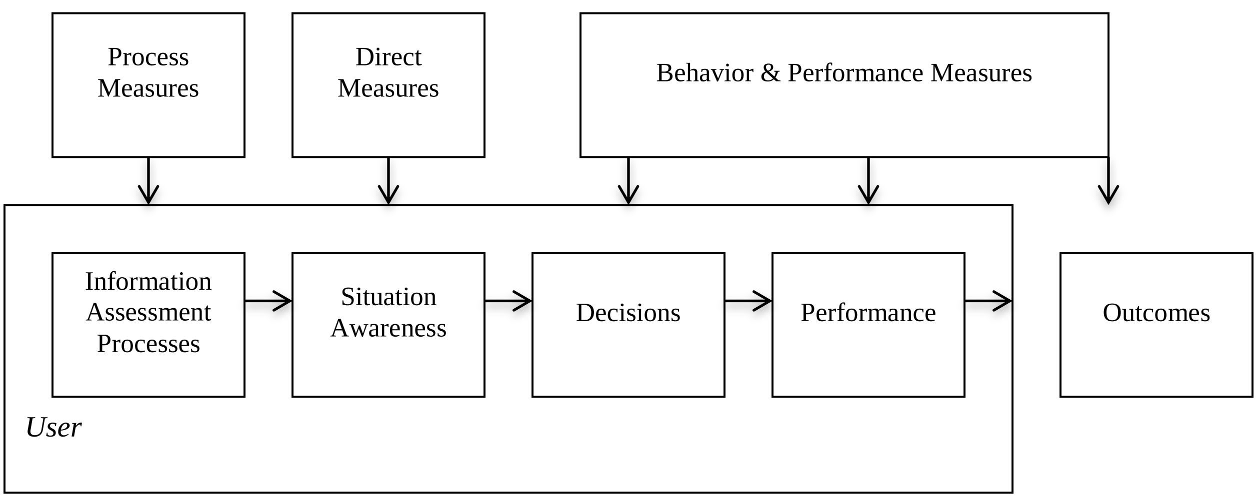

Figure 3. Approaches to SA measurement from Endsley and Garland (2000)

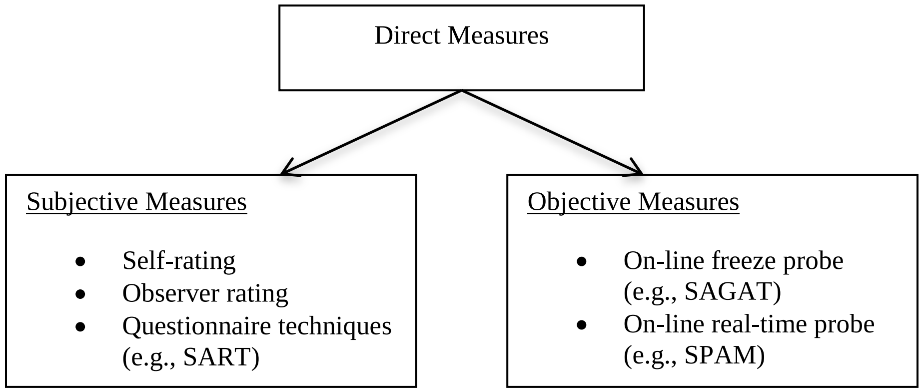

Figure 4. Direct measures of SA

2.3 Navigation and Spatial Knowledge

2.3.1 Navigation

Navigation refers to the process of solving one class of spatial problems, the movement of a person from one location on the earth's surface to another (Downs & Stea, 1977). It has been defined as the behavior of moving towards a destination with all the motor, sensory, and cognitive processes that it involves. In a virtual environment, navigation refers to the overall interaction of moving within and around an environment, involving both *motion* (also called *travel*) and *wayfinding* activities (Bowman, 1999; D.A. Bowman, Koller, & Hodges, 1997; Darken & Peterson, 2002; Grasset et al., 2011). *Motion* refers to a user's low-level motor activities to control position and orientation within the environment. It depends on skillfully coordinating actions to avoid obstacles in the immediate path (Ross & Blasch, 2002). *Wayfinding*, defined in terms of spatial problem solving, refers to a person's abilities to reach destinations in the everyday environment (Passini & Proulx, 1988). It is the means by which a person employs his or her *spatial orientation* to maintain a heading toward a destination, regardless of the need to avoid or move around obstacles in his or her path (Ross & Blasch, 2002). *Spatial orientation* refers to the ability to establish and maintain an awareness of one's position in space relative to landmarks in the surrounding environment and relative to a particular destination (Grantham, 1995).

From an information processing perspective, the process of wayfinding has been defined as a composite of three interrelated processes: *decision making*, which results in a plan of action or decision plan to reach a given destination; *decision executing*, which transforms the plan into overt spatial behavior and movement at the right place in space; and *information processing*, which involves devising environmental perception and cognitive activities that permit the former two decision-related processes to occur (Passini & Proulx, 1988). In this process, wayfinding involves high-level cognitive activities. Specifically, wayfinding (navigation) has been divided into four activities: 1) orienting oneself in the environment; 2) choosing the route (or making a plan for the next action); 3) keeping on track; and 4) recognizing that the destination has been reached (Downs & Stea, 1977). These activities require acquiring and structuring spatial knowledge (Doug A. Bowman, 2005; Darken & Peterson, 2002; Grasset et al., 2011).

2.3.2 Spatial Knowledge

Spatial knowledge is essential for navigation activities. Associated with spatial knowledge is the "cognitive map," which is a mental representation of an environment (Tolman, 1948). According to Hutchins (1995), one must possess some representation of space—a map—whether internally inscribed in the mind or as an external tool. Within the map, every object or feature in one's environment is assigned a determinate location.

There are several types of spatial knowledge of an environment. One longstanding, well-established model of spatial knowledge representation is the Landmark, Route, Survey (LRS) model described by Seigel and White (Siegel & White, 1975), and subsequently refined by Goldin and Thorndyke (Goldin & Thorndyke, 1981). The LRS model describes the classification of and the development process of spatial knowledge. *Landmark knowledge* refers to the visual appearance of salient, static, and orientation-dependent cues and objects in the environment. This knowledge is developed by people directly viewing the environment or through indirect exposure to it (e.g., viewing a series of photographs). *Route knowledge* refers to a point-by-point sequence of actions needed to travel a specific route. This knowledge is developed as landmarks are connected by paths. It provides information on the distance along the route, the turns and actions to be taken, and the ordering of landmarks. It can be thought of as a graph of nodes and edges that is constantly growing as more nodes and edges are added. As the graph becomes more complete, *survey knowledge* is developed. Survey knowledge refers to the relationship between landmarks and routes in the environment in a global coordinate system. This knowledge can be acquired by repeated navigation trips in the environment or by using a navigational aid (e.g., viewing a map).

In terms of an urban context, a city is similarly classified into five types by Lynch (1960): *landmarks, paths (routes), nodes, districts* and *edges.* A l*andmark* is a particular place that can be used as a reference point, which is similar to the definition in the LRS model. *Paths* are channels through which people travel, such as pathways, hallways. *Nodes* are strategic points in the environment, typically the convergence of paths, where wayfinding decisions are often made. *Districts* are individual areas of the environment with recognizable characteristics. *Edges* are breaks in the continuity of the environment (e.g., a river) (Lynch, 1960).

Due to the longstanding importance of landmarks for navigation, the notion of landmarks continues to attract research attention in both geographical and information contexts. Sorrows and Hirtle (1999) developed a formal landmark theory for real and electronic spaces. The researchers categorized landmarks as follows:

Visual landmarks are objects that are visually distinctive. Features that contrast with surroundings, prominence of spatial location, and visual characteristics make them particularly memorable.

Cognitive landmarks have unique meanings that stand out. They may be personally, culturally or historically important, but can be missed by those who are not familiar with the environment since they have no markings or signage.

Structural landmarks are important nodes of intersecting paths whose importance comes from their role or location in the structure of the space, regardless of whether they are visually distinctive or not.

2.3.3 Navigation vs. Situation Awareness

In the navigation domain, situation awareness is important when navigating an environment (Smets, te Brake, Buurman, Neerincx, & van Oostendorp, 2011a); the generation of complete, accurate, and up-to-the-minute situation awareness is essential for navigational tasks. For instance, the literature shows that SA is important for navigational fieldworkers and emergency responders in varying scenarios (Scott, 2009). Mobile systems used by fieldworkers in dynamic environments need to be better designed—not only to enable users to process high volumes of data quickly and accurately, but more importantly, to enhance outdoor use in various dynamic environments. Similarly, when an emergency occurs such as a nuclear accident, the information regarding nuclear accidents is dynamic and the status on accident sites changes frequently; people need to be promptly informed of the site location, escape directions, and other critical information (Tsai et al., 2012).

In situations when SA is compromised, the potential for human error increases (Scott, 2009). As such, there is an ongoing research effort dedicated to improving SA to minimize emergency responder injuries and fatalities (Scott, 2009). According to the National Fire Fighter Near-Miss Report (2008), the loss of SA involved with misinterpreting surroundings, not recognizing factors or cues, gathering incomplete information, or being narrowly-focused or impaired, are all considered to be contributing factors in near-miss firefighting events and involuntary unsafe occurrences that result in injuries, fatalities, or property damage. Therefore, building up and maintaining SA is critical in navigation tasks and represents a significant challenge for mobile navigation systems.

Navigation activities can be categorized as either *exploratory navigation* or *goal-orientated navigation* (Kelly et al., 2009; Yang et al., 2011). People in these activities are involved in *a series of relationships* with the surroundings in which they are travelling (Aporta et al., 2005). With respect to exploration and navigation behaviors, users usually walk while intermittently looking at their surroundings, to acquire and keep their situation awareness—i.e., attempting to determine "what is around them" and "what's going on around them."

With regard to operational behaviors of navigation, researchers have investigated the behavior of a pedestrian as he/she walks from origin to destination. Accordingly, observed pedestrian behavior includes changes in speed, changes in direction, passing strategies, and distance between objects (Usher & Strawderman, 2010). At this level, the decision to change speeds (e.g., slows down or stops) is dependent upon the pedestrian's goals and his/her corresponding situation awareness. The speed of the pedestrian will remain constant unless conditions for change are presented (Usher & Strawderman, 2010).

In terms of interacting with the environment, people have to be situation-aware and take in a high volume of information to navigate the space (Usher & Strawderman, 2010). Navigation is a complex behavior, requiring the subject to perceive the environment, deduce the significance of the environment, and subsequently select where to go based on the learned criteria (Penner & Mizumori, 2011). Ingold (2000) provided an example of hunter's trade to illustrate human involvement with the environment:

> The hunter learns by accompanying more experienced hands in the woods. As he goes about, he is instructed in what to look out for, and his attention is drawn to subtle clues that he might otherwise fail to notice: in other words, he is led to develop a sophisticated perceptual *awareness of the properties of his surroundings* and of the *possibilities* they afford for action. For example, he learns to register those qualities of surface texture that enable one to tell, merely from touch, how long ago an animal left its imprint in the snow, and how fast it was travelling. (p. 34)

With respect to Ingold's (2000) example, in exploratory navigation the hunter appears to benefit from perceiving relevant salient and/or subtle environmental cues in his navigation task. In other words, people perceive environmental cues in their navigation activities and these environmental cues, in turn, help with subsequent activities. Furthermore, evidence in navigation research of the visually impaired, reveals that people with visual impairments make use of navigational aids to "perceive" environmental cues (Yang et al., 2011). These navigational aids are either low-tech (e.g., white canes or guide dogs) or high-tech (e.g., GPS devices or electronic obstacle avoidance systems). It is well established that with the help of navigational aids, the visually impaired compensate for missed information through other non-visual environmental cues to increase their awareness of surroundings (Passini & Proulx, 1988).

In summary, navigation activities involve sensory perception, learning and decision-making, memory consolidation and updating, and planned movement (Penner & Mizumori, 2011). In navigation, without a predetermined destination people must have a relatively accurate awareness of their immediate and evolving situation to plan effectively in dynamic and varying environments (Wickens, 1999); in essence, one observes their surroundings and makes corresponding decisions (Usher & Strawderman, 2010). Processing information such as visual landmarks, structural landmarks and subtle environmental cues is not only important in guiding a user's navigation to a destination, it also provides the user with additional information to browse, observe, and select between alternatives based on their goals or interests. With computer-aided guidance systems, the user is able to effectively decide which Points of Interest (POI) in the encompassing environment to focus on (Jacob, Mooney, & Winstanley, 2012). Tasks involving these activities correspond to the more general concepts of situation awareness, requiring perception, comprehension, and projection of the state of the surrounding environment.

2.3.4 Model of Navigation

In line with Darken and Peterson (2002)—and based on the model proposed by Jul and Furnas (1997) (Figure 4)—most other navigation models (Chen & Stanney, 1999; Downs & Stea, 1977) are either too specific to one type of environment, or they do not capture the intricacies of the task. Likewise, considering that navigation is a situated action (Suchman, 1987), effective planning and task execution are intertwined in the context of the situation (Spence, 1999). The following quote by Darken describes how the model works:

> I'm at the shopping mall and decide I need a pair of shoes. I have just formulated a goal. Now, how should I go about finding shoes? I decide to try the department stores. Department stores are typically on the far points of the mall. I have just formulated a strategy. The next step is to gather information so I don't walk off in a random direction. I decide to seek out a map of the mall. I am acquiring information and scanning (perceiving) my environment. This is the tight wayfinding/motion loop referred to earlier. I view my surroundings, assess my progress towards my goal, and make judgments as to how to guide my movement. At any time in this loop, I may decide to stop looking for shoes and look for books instead. This is a change in goal. I could also decide to look for a small shoe store instead of a department store. This is a change of strategy. In any case, the task continues, shifting focus and process as necessary. (p.5)

As can be seen in Figure 4, there is an apparent gap between *goal forming* and *strategy selection*. Generally, people have limited decision plans before embarking in the environment; they need a great deal of information about their immediate environment that can be obtained from awareness of environmental cues. Thus, a recurrent influx of information is required to ensure they are aware of what is happening around them, determine where they want to go, and enable them to make a decision and execute the appropriate action at the appropriate juncture.

In exploring their immediate environment, people need to be able to access and browse essential information about their surroundings. Accessing and browsing this information not only links to a particular navigational performance, but it also helps foster a greater sense of awareness during navigation. A mobile computer could assist this process. Particularly, a mobile AR information browser, as one of visualization solutions, can be used to bridge this gap, and mobile AR technology enabled with location-based service is the required tool to achieve it. It mediates the experience of the user who is constantly interacting with the real world with overlaid virtual information and provides users with such information about “what’s going on” in their surroundings instead of letting users wander and wonder. The next section will provide the latest research on mobile AR research in the domain of navigation.

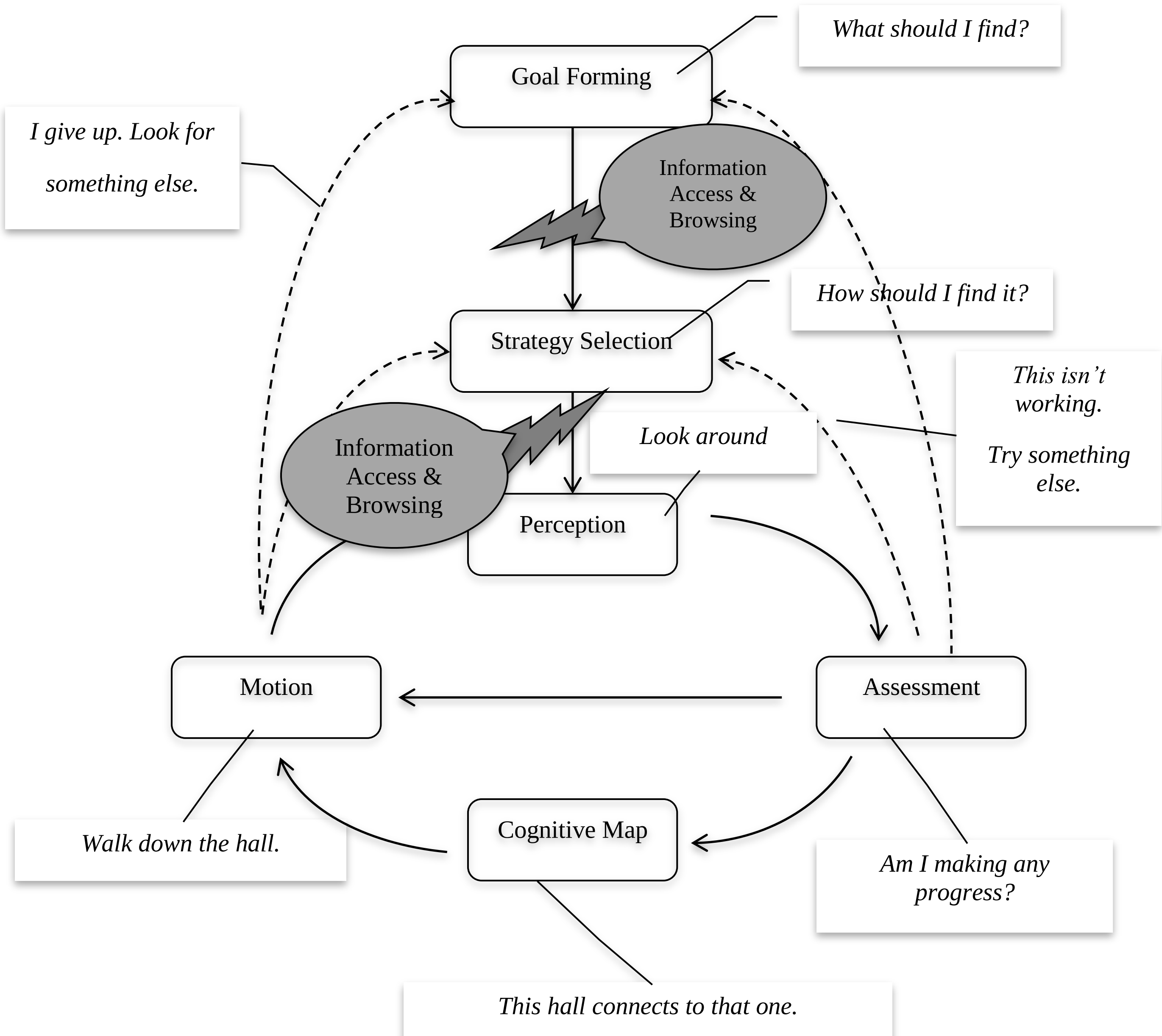

Figure 5. Model of navigation from Darken (2002)

2.4 Model of Situation Awareness in Navigation Systems

As stated, situation awareness is used to describe how well a person understands a situation (Endsley, 1995b). For instance, in a war situation, leaders need to make prompt decisions and synchronize forces based on all available information—and in particular by answering questions such as “Where am I?” “Where are my friends?” “Where is the enemy?” “What activities are they doing?” Similarly, in an urban area (e.g., on a busy street), an individual (perhaps a visitor) needs to be aware of what is around them with respect to objects, places, events, and more to make informed decisions of what they will do next—with or without a predefined goal in mind. Answering questions such as “Where am I?” “What is the building standing in front of me” “Is anywhere nearby going to have any special event?” “Where can I find a nearby restaurant with some entertainment (e.g., live music) at the time of dinner?” “Will I be able to get to that place in 20 minutes?” “ How long is the wait if I go to this restaurant now?” will help them make decisions. Consider visiting a busy, bustling city where you will later meet a friend. You come directly out of the hotel and make your way to the center of the city. You stroll around on the street without knowing where you want to go or what you can do in the nearby region for the next three hours before your local friend comes to meet you. This is a simple example of a situation where knowing what is around you and what is going on is important to users in the context of urban exploratory navigation.

In a sense, a user’s environment is laden with numerous sources of information beyond one’s normal senses (Pyssysalo, Repo, Turunen, & Lankila, 2000). The individual not only engages with the immediate physical environment, he/she also engages with the virtual-technological environment offered by digital augmentations. These digital augmentations are tightly woven into the material and social fabric of cities to engender different ways of experiencing them (Gordon & e Silva, 2011; Graham et al., 2012). Therefore, an object in such an environment possesses both physical attributes and a digital augmented representation. Information comes in all sorts: the location; direction and distance of places and possibly moving objects and persons; virtual information, such as friends’ footprint, virtual tags of persons, places and objects, recommendations and reviews, local alerts, local news, air quality of region and weather information (Gaonkar, Li, Choudhury, Cox, & Schmidt, 2008). This data is constantly available and is increasingly reflective of real-time events rather than time-laggard information (Graham et al., 2012; Reitmayr & Schmalstieg, 2004a).

2.4.1 Situation Awareness in the Digitally Augmented Space

In the case of the aforementioned scenario (visiting an urban area), this definition could refer to where the interesting places are, understanding what has happened and is happening there, and projecting where one will be at or what will happen in near future (e.g., a few minutes, half an hour). SA theory provides a theoretical perspective by which to examine user needs in the digitally augmented space. It stresses a holistic way to view an individual's information needs that will enable him or her to interact with the surrounding environment. Indeed, spatial understanding cannot be disconnected with its identity and temporal components.

Moreover, in an increasingly digitally-connected world, the social component, as exemplified by social participation and social collaboration, is gaining importance as an information interaction ground (Counts & Fisher, 2008; Gaonkar et al., 2008). Interactions between acquaintanceship-based social networks and unacquainted individuals commonly occur in the context of urban exploratory navigation. Serendipitous social networks are situation-centric, where the traveler interacts with unacquainted individuals; thus, such relationships are typically instantaneously constructed, continuously changing, and easily dissolved. Alternatively, acquaintanceship-based social networks are mostly peer-based, where one generally interacts with friends and acquaintances based on existing social ties (Jang, Choe, & Song, 2011). For example, a tourist travelling alone in a foreign country may come across another traveler, initiate a conversation, share experiences, and exchange travel tips. According to Jang (2011), these two individuals are sharing the same immediate situation in such a context. A recent survey reveals that users may be willing to help each other and answer questions—even if they are strangers—based on a concept called altruism (Morris, Teevan, & Panovich, 2010). Such "kindness of strangers" is typically built on the belief that the helped one is similar to the helper in such situations (Constant, Sproull, & Kiesler, 1996). This type of social participation forms a broadly-defined category of "social collaboration" that connects those who need information to those who can provide it (Constant et al., 1996).

To sum up, situation awareness information in the context of urban exploratory navigation is associated with the following components:

1) *Spatial component* where a person develops awareness about a place and can detect or monitor what is happening there. Spatial awareness helps mobile users to be aware of and understand places in the surrounding environment. For example, knowing the location, direction, and distance of places and possibly moving objects and persons (including oneself) in surroundings.
2) *Temporal component* provides awareness about past, present, and future activities that are important to a mobile user's goals and tasks. Temporal awareness is important in temporal coordination because it helps users align their own actions to a log of past activities, to current activities, and to the anticipated future flow of activities. For example, a mobile user who has several hours to spend in the center of the city can plan his activities, adjust the allocation of time on those activities, determine activity schedules (e.g. shows and movies schedule, open hours) and identify upcoming events of interest in the nearby region. In addition, one can project

themselves into a future state or a specified place where they could find themselves in, say, three minutes time.

3) *Attributes (identity) component* helps mobile users to be aware of what is happening in a place, any activities taking place in the surrounding environment (e.g., a museum status of a series of exhibition), the people who are there, or relevant information about the identity of the place (e.g., activities recommended by other visitors).
4) *Social component* plays an important role in exploratory navigation. According to a recent survey about the types of questions that people ask members of their social networks, those that fit the scope of this research include the following: recommendations, opinions, factual knowledge, invitations, and question topics—which would include places, restaurants, current events, and shopping (Morris et al., 2010).

2.4.2 Proposed Model and Framework

SA involves the perception of the elements in the environment, the comprehension of their meaning, and the projection of their status in the near future. It is important to support each level of cognitive process (SA L1 perception, SA L2 comprehension, and SA L3 projection) to achieve situation awareness. Based on SA theory, three-levels of SA using mobile AR support in the context of urban navigation is developed, comprising levels of perception, comprehension and projection. A schematic model that illustrates the process is shown in Figure 5. Level 1 encompasses the perception of characteristics and attributes of individual elements of interests, such as people, objects, places, and events in the real world. Level 2 consists of recognizing properties of elements, patterns, and relationship among elements in or across a particular group. Level 3 involves making a projection of the surrounding environment in the near future. Note that one’s situation awareness for a particular task is a continuous and dynamic changing process that is “updating” itself constantly.

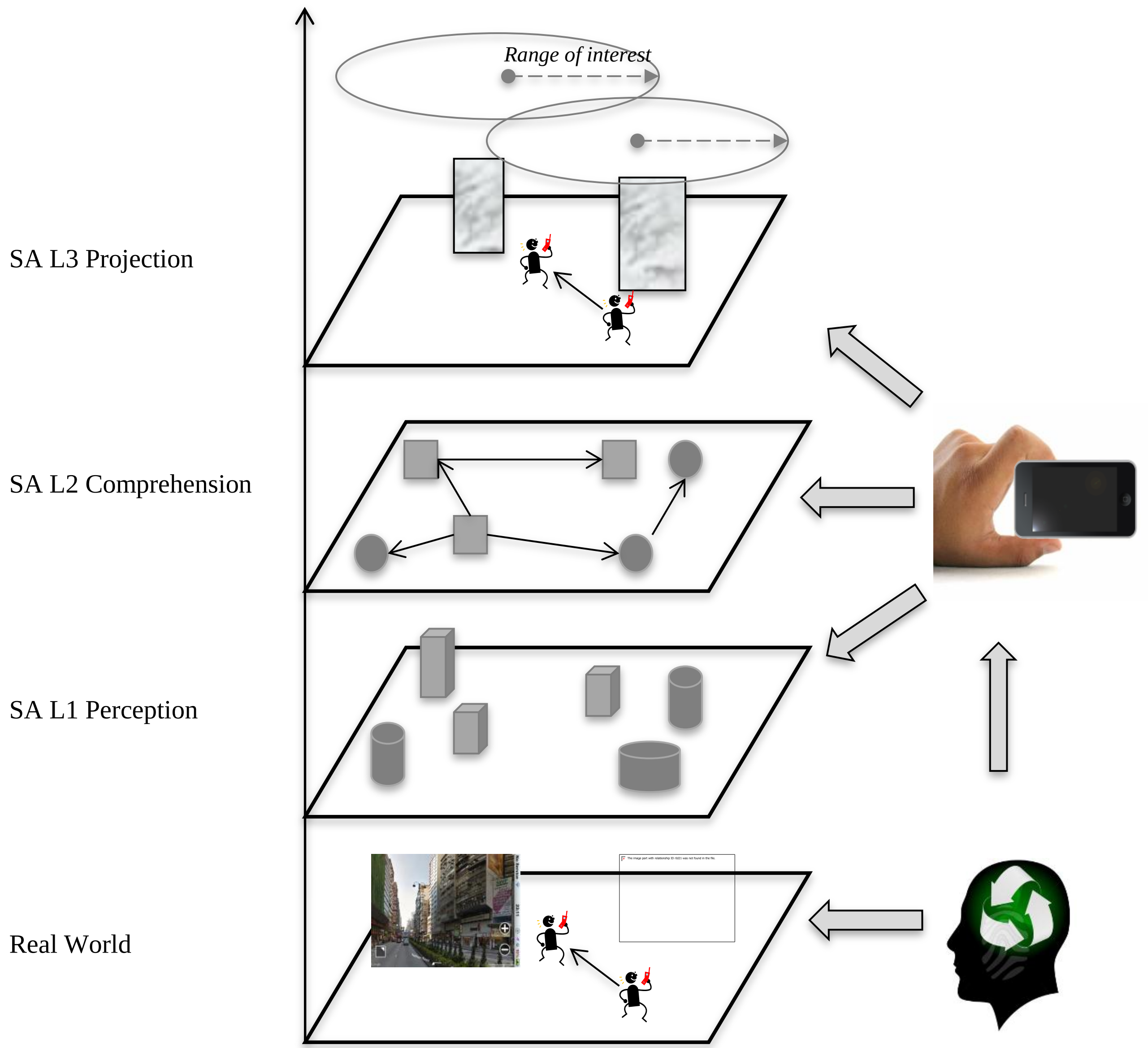

Figure 6. Three levels of Situation Awareness and mobile AR guidance systems' support

Additionally, from a more holistic standpoint, decision-making (e.g., where to go, what to do next) and action execution (e.g., navigating to the place of interest) are downstream from SA (See Figure 6). Decision-making is regarded as a downstream human information process of situation-awareness formation originally proposed in the Endsley's SA framework (Endsley et al., 2003; Endsley, 1995b; Endsley & Garland, 2000). One's situation awareness should be supported to facilitate subsequent decision-making, such as navigating to the target place. One can decide which place or activity to go to in the nearby area if he/she is aware of places around the area, their identities or status, and temporal and social components associated with them.

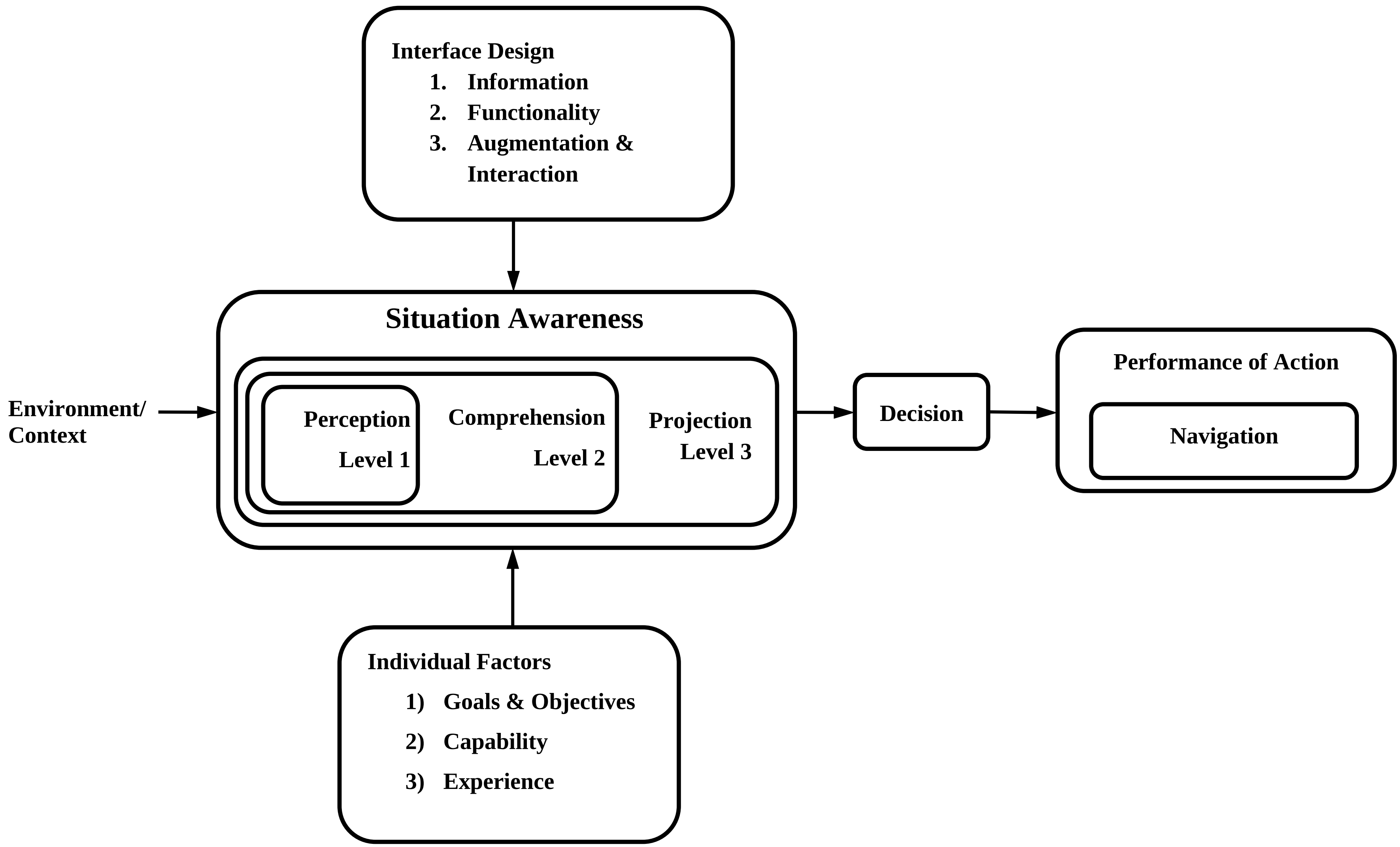

Figure 7. The role of Situation Awareness in information processing in the context of navigation adapted from Endsley (2003)

2.5 Mobile Augmented Reality (Mobile AR) Navigation Systems

2.5.1 Overview of Mobile Augmented Reality (Mobile AR)

2.5.1.1 Augmented Reality (AR)

Augmented Reality (AR) technology allows the real-time fusion of computer-generated digital content with the real world. AR has been widely used in sales and advertising, training and maintenance, design, medical applications, robotics, education, gaming, geo-visualization, architecture, construction, navigation, and tourism (Azuma, 1997; Haller, Billinghurst, & Thomas, 2007; Normand, Servières, & Moreau, 2012; Kolbe, 2004; Liu, Tan, & Chu, 2007; Normand, & Moreau, 2012; Sielhorst, Feuerstein, & Navab, 2008; Van Krevelen & Poelman, 2010; Yim, 2010). In general, AR is regarded as a variation of virtual environments (VE), or more commonly virtual reality (VR). AR differs from VE since the former is achieved with virtual objects superimposed upon or composited with the real world; in contrast, VE completely replaces the real world with a syntactic environment where a user is inside and immersed. Specifically, AR on the virtual/real continuum is considered as a "middle ground" between VE (completely virtual) and tele-presence (completely real), appearing to the user that virtual and real world coexist in the same place (Kishino & Milgram, 1994). Types of virtual information that AR augments include graphics, audio, tactile, touch, smell, and taste (Van Krevelen & Poelman, 2010)—among which, visual augmentation is the major realization type. The overlaid augmentation onto a user's field-of-view provides users with "extra" information about their surroundings, or provides visual guidance for the completion of a task (Walther-Franks & Malaka, 2008; Yu, Jin, Luo, Lai, & Huang, 2010). AR offers superior intuitiveness and user interactivity over other traditional multimedia (Yim, 2010), enabling people to interact with the surrounding real world in entirely different ways (Billinghurst & Thomas, 2011; Feiner, Macintyre, & Seligmann, 1993; Hollerer, Feiner, & Pavlik, 1999; Kurkovsky et al., 2012; Van Krevelen & Poelman, 2010).

A variety of AR applications exist. As one of the pioneering AR researchers, Azuma (1997) published a survey of six categories of potential AR applications, including medical, maintenance and repair, robot, path planning, entertainment, and military aircraft navigation targeting. Recent research has categorized AR applications based on different classification rules. Normand (2012) provided a review detailing four taxonomy categories: technique-centered, user-centered, information-centered, and interaction-centered AR applications. Other researchers have proposed a classification system based on two main factors that affect the visualization of location-based data: the environment model used, and the viewpoint used (Suomela & Lehikoinen, 2004). In this categorization, the environment model was used to describe the different dimensions that users employ to visualize the environment, ranging from 3D (applications have an accurate 3D model of the environment and the location-based data is placed on its actual location in an augmented view) to 0D (applications present the data to the user, but nothing about its location or relation to the user). The user's perspective view was used to denote the viewpoint; the user sees the environment as if looking at it from a first-person view or a third-person view.

2.5.1.2 Mobile Augmented Reality (mobile AR)

Since the initial prototype of the Head-Mounted Display (HMD) was first introduced over 40 years ago, mobile AR has been a vigorous research field. The first concept, called an optical see-through Head Mounted Device, combined real and virtual images via a semi-transparent mirror (Sutherland, 1968). According to Vaughan-Nichols (2009), the first real mobile AR system in use dates back to the first aircraft heads-up display, the British military's airborne Mark VIII Interception Radar Gunsighting's Windscreen project. This system is overlaid on a pilot's windshield radar screen and delivers information about whether or not nearby aircraft are friend or foe (Vaughan-Nichols, 2009). Subsequently, the term "augmented reality" was coined by Caudell (1992), who designed a head-mounted digital display for Boeing to help workers assemble aircraft parts by displaying virtual schematics. Simple wire frames and template outlines were projected on the factory floor (Caudell, 1992; Vaughan-Nichols, 2009).

The earliest mobile AR navigation system was a combination system of backpack and HMD by which a user can view information around him or her by simply turning head left, right, up, down (Billinghurst, Bowskill, Jessop, & Morphett, 1998). Based on Feiner's innovative Touring Machine, which used Field-of-View (FOV) and head movement control (S. Feiner, MacIntyre, Hallerer, & Webster, 1997), other researchers continued to explore combining the use of backpack and HMD-based mobile AR systems for other application domains, such as outdoor gaming (Thomas et al., 2000), navigation (Thomas, Demczuk, Piekarski, Hepworth, & Gunther, 1998b), and historical reconstructions (Vlahakis et al., 2002).

Enabling technologies for mobile AR systems have had to focus on technological advancements in processing power to fuel increasingly sophisticated devices—from the first mobile phones that did not have enough processing power, to mobile workstations and wearable PCs, Tablet PCs, UMPCs (ultra mobile PCs), PDAs, and most recently the Smartphone. Smartphones are fully featured high-end mobile phones featuring PDA (personal digital assistant) capabilities (e.g., data processing applications) requiring large amounts of processing power (Papagiannakis, 2008; Van Krevelen & Poelman, 2010). Likewise, software architectures such as wireless networking, tracking, and registration components have rapidly changed and diversified. Wireless networking for mobile AR now includes wireless WANs (wireless wide area networks) and 3G (the third generation) networking, WLANs (wireless local area networks), and WPANs (wireless personal area networks). Tracking and registration for mobile AR can be described as optical marker-based, optical markerless, GPS, etc. Most notably, since 2004 marker-based tracking technologies used by simple image processing phones have been transformed to techniques using markerless tracking algorithms, creating the basis of Smartphone-based tracking techniques for public use (Mohring, Lessig, & Bimber, 2004; Reitmayr & Drummond, 2006; Wagner, Reitmayr, Mulloni, Drummond, & Schmalstieg, 2008)

2.5.2 Smartphone-based Mobile AR Navigation and Location-based Services (LBSs)

2.5.2.1 Smartphone-based mobile AR Navigation Applications

Many publically available mobile AR city guidance applications have flooded the market, gaining popularity for use across different mobile platforms. Two main drivers are behind this trend. First is the *availability* of AR-enabled Smartphones as PDAs, and the *technological feasibility* of Smartphone devices with high resolution touch display, GPS sensors, magnetometers (Rehrl et al., 2012) and faster networks and cloud computing (Linaza et al., 2012). Evidence of this proliferation is apparent. The installed platform of AR-capable *Smartphones* has increased dramatically, from 8 million to more than 100 million in 2010, moreover, Smartphone manufacturers have started to preload AR browsers into handsets (Kaufman, 2011). Adding to this is an increasing number of AR *applications* for Smartphones that are available to users. In March 2012, there were nearly 1440 applications with descriptions listing AR as a feature in Apple's iTunes store[12], including tourist guides and sightseeing applications. AR-software *development kits*, such as the metaio Mobile SDK[13], either from leading platforms or mobile AR companies for use by mobile AR developers, have also proliferated. A research report on the mobile AR market indicates that the increasing number of brands, retailers and mobile vendors investing in mobile AR applications and services and global revenues are expected to reach 1.5 billion dollars by 2015 (Kaufman, 2011).

Second, Location-based Services (LBSs)—used with Smartphones and other types of mobile technology—are another major driving force behind MARs entering the mainstream (Vaughan-Nichols, 2009). LBSs (also known as location-aware service, location-related service, and location service) are defined by the GSMassociation[14] (Global System for Mobile Communication) as services that use the location of the target for adding value to the service, where the target is the "entity" to be located (and the target is not necessarily the user of the service). Location-based technology leverages context information

[12] Application store for iPhone http://itunes.apple.com
[13] http://www.metaio.com/software/mobile-sdk/
[14] http://www.gsma.com/

about a physical location to provide information that is tailored to our real-world location, providing service such as filtering of information (e.g., for selecting nearby places of interests) or showing the location of a target on the map (Kupper, 2005).

In another words, mobile phones enabled by LBSs can detect our context information in physical space (A. de Souza E Silva & Sutko, 2011). After the release of GPS-enabled phones in the United States in 2008 (iPhone 3G[15] and Google's Android operating system[16]), the popularization and commercialization of location-aware applications have dramatically increased. For example, supported by location-based information, mobile AR can be used for exploring locations[17], social networking[18], acquiring information (e.g., quality and price) about a new restaurant[19], the name of the stars and constellations over your head[20][21], the names of the mountains in front of you[22][23], what crimes have recently been committed in your neighbohood[24], and many more.

2.5.2.2 Location-based Services (LBSs)

Since the mid-1990s, location-based services have increased due to the proliferation and wide-spread adoption of location-aware technologies such as IrDA, RFID, WiFi and Global Positioning Systems (GPS). Meanwhile, the mobile phone industry is spearheading rapid advances in mobile technology delivered through Smartphone terminals (West & Mace, 2010). Together with the use of mobile data services and evolving Smartphone technology, the delivery of LBS creates value through live entertainment, news, sports, and other information, as well as applications that add functionality to the device (West & Mace, 2010). From the user's perspective, this enables a person to navigate a city, to see which nearby restaurants are the most popular, to check on traffic, to find particular information about a location, to access place-specific information about a place, etc. (de Souza E Silva & Sutko, 2011). From the service provider's perspective, LBS is a value-added service that provides a new source of revenue for multiple stakeholders in the mobile value chain, which can be generated from their investments in fixed infrastructure (Berger, 2003; Rao, 2003). Although there is no consensus on the scope or definition of LBSs, in essence they are computer applications that deliver information specific to the location of the

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[15]http://www.apple.com/iphone/
[16]http://www.android.com/
[17]ZipReality Real Estate application: http://www.ziprealty.com/
[18] Tweet360 application: http://www.twitter-360.com/
[19] Yelp application: http://www.yelp.com/christiansburg-va-us
[20] Star Chart application: https://play.google.com/store/apps/details?id=com.escapistgames.starchart&hl=en
[21] Start Walk application: http://vitotechnology.com/star-walk.html
[22]Panoramascope application: http://panoramascope.com/
[23] Peaks application: http://peaks.augmented-outdoors.com/
[24]SpotCrime application: http://itunes.apple.com/us/app/spotcrime/id347343610?mt=8

device and user. LBSs are associated with mobile cartography, information science, GIScience, geopositioning, and ubiquitous computing.

LBS applications can be organized into four broad functions for the traveler (Koeppel, 2000): 1) localization of persons, objects, and places; 2) identifying routes between them; 3) searching within a set proximity for objects (e.g., restaurants, shops, or hotels), looking for place-dependent information (e.g., sights or advertising), or finding services such as English-speaking medical doctors in Germany; and 4) finding information about traveling conditions, such as traffic-related data or local weather news.

Recent LBSs applications on mobile phones integrate established models of geotagging, mapping and social networking into their functionality. Much of the existing research focuses on using location awareness to provide information about a user's spatial surroundings (Schmandt & Marmasse, 2004). This certainly can be very helpful if one gets lost, needs to find the nearest ATM machine, or wishes to locate a specific place.

2.5.2.3 Context-awareness systems

Location-based services are considered part of the greater ecology of context-aware computing (Kupper, 2005). More recently, context and context-aware research with its supporting service has been developing and expanding at a tremendous rate with the generation of additional data such as spatial and temporal data (how much and how rapidly things are changing). Since the first definition of context awareness was proposed by Schilit and Theimer (1994)—namely, the ability of a computing system to adapt to its surrounding environment—it has been widely used as a mechanism for sensing a user's surroundings to provide that person with certain intelligent awareness (Mowafi, 2010). The motivation behind context-aware computing is to use sensor-based and computational tools to compensate for the limitations of human decision-making processes and cognitive deficits in attention, memory, and comprehension.

Using the term "context" from conversation analysts, which refers to a setting where action unfolds (Laurier, 2001), Schilit's definition of context in HCI is probably one of the broadest definitions. Schilit claimed that context encompasses a user's location, lighting, noise level, network connectivity, communication costs, communication bandwidth, and the social situation—e.g., whether you are with your manager or with a co-worker" (Schilit et al., 1994). Context information is "information about its context, such as location, time, temperature or user identity" (Ryan, Pascoe, & Morse, 1998). According to Schilit, the important aspects of context are where you are, who you are with and what resources are nearby (Schilit et al., 1994). Later, context information would include the location, identity and state of people, groups and computational and physical objects, such as vital signs, air quality, and network availability (Dey, Abowd, & Salber, 2001).

There are a number of ways to categorize context information. By synthesizing these different perspectives, Kupper's (2005) categorization is appropriate for this study because it context information into primary context and secondary context. Context information in mobile computing can partly be derived from different sensor information. Primary context encompasses any kind of raw data that can be selected and received from sensors (e.g., light sensors, biosensors, microphones, accelerometers, location sensors (Schmidt, 2001)). This raw data can be refined, integrated, deducted, or filtered to derive secondary context, which is a higher level of context information (Kupper, 2005).

Context-aware services are defined as services that automatically adapt their behavior, for example, filtering or presenting information to one or several parameters reflecting the context of a target (Kupper, 2005). As can be seen from Figure 8, LBSs are considered part of the greater ecology of context-aware computing (Kupper, 2005). It must also be noted that in many cases there is no clear-cut boundary between types of context (Kupper, 2005). For example, spatial context and social context are usually tied together to present information about social presence. Some context information can also be accessed from other sources and not necessarily sensed *in situ*. Mobile Internet services, which constitute a distributed computing environment, allow for the extracting of context information by georeferencing methods. For example, one can retrieve weather information for a given location from a meteorological web service (Reichenbacher, 2004).

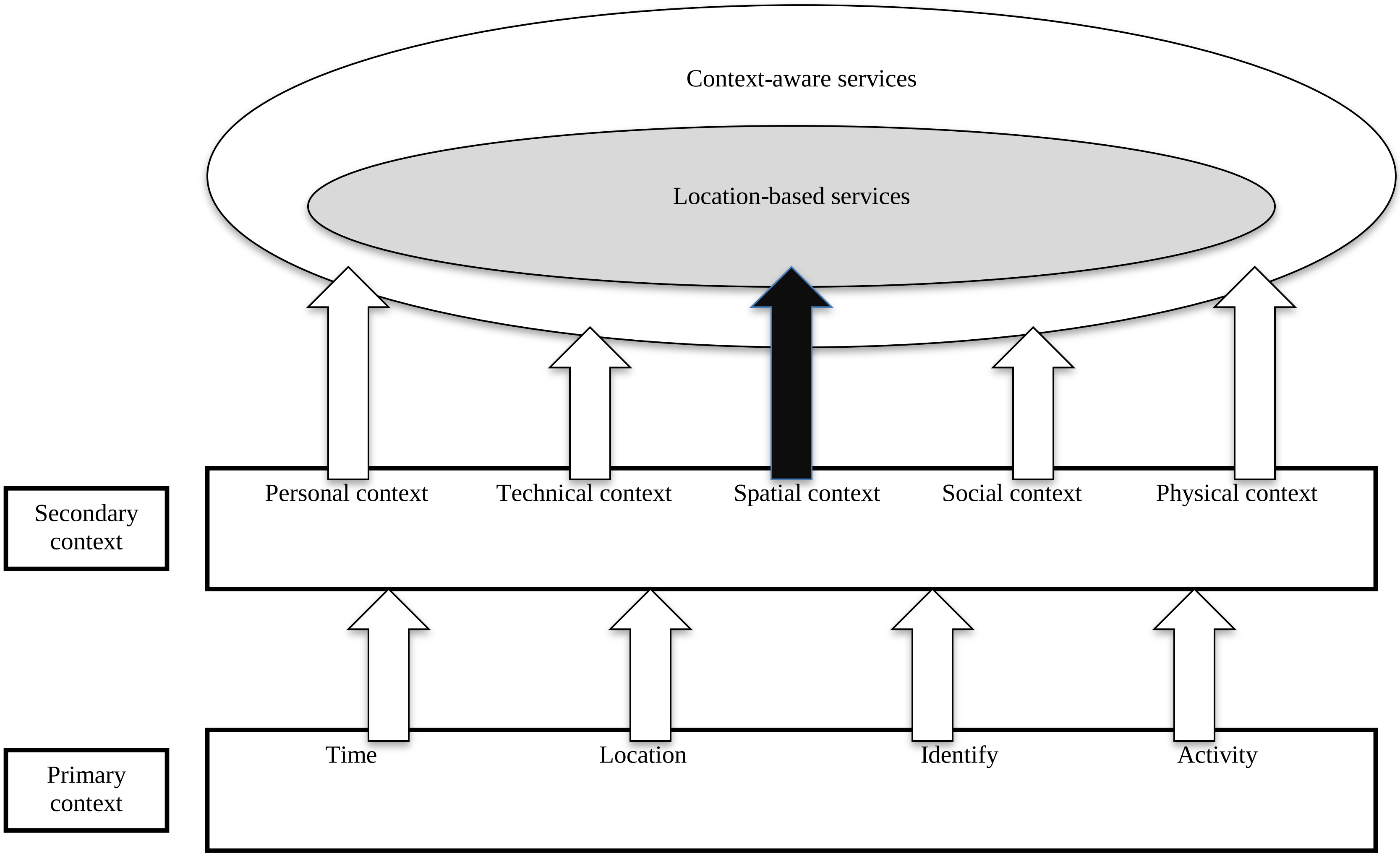

Figure 8. Context-aware services from Kupper (2005)

2.5.2.4 Core Smartphone-based mobile AR Technology

In general, AR is based on a few core technologies—principally tracking, registration and display (Henrysson, 2007). Tracking refers to the system knowing where (position) and how (orientation) to present virtual information to the user and his or her viewpoint. Registration is the result of tracking, which aligns the virtual information on display devices. Display technology provides a “view” for the user combining virtual and real information

A particular unified mobile AR system was described as a layer-based integration model for encompassing diverse types of media and functionality (Lee, 2009). A similar model is now used by commercially-available Smartphone-based mobile AR guidance applications to provide virtual information superimposed on the real world, such as Layar[25] and Wikitude[26] applications for mobile phones.

One available Smartphone-based mobile AR city guide, known as Layar, provides layers of information about Points of Interest (POIs) that users see around them via their Smartphone cameras. It can overlay various types of information about POIs including real estate listings, ATM locations, places with Wikipedia entries, public works of art, and so on. The system first utilizes the phone’s location-based services to determine the user’s location, after which it identifies local POIs and obtains information about them from various resources (e.g., websites). The system provisioning website then transmits the data to the phone and AR browser (Vaughan-Nichols, 2009). Important to note is that current Smartphone-based mobile AR applications only combine retrieved information using the camera’s video streams of the real world and present it to the user. Thus, the camera on most current Smartphones is just used as an interface, meaning that the system could work without it (Alzahrani, Loke, & Lu, 2011).

In reviewing the various mobile technologies for handheld phone-based mobile AR systems, several core technologies are essential (Billinghurst & Thomas, 2011; Papagiannakis, 2008), including:

- Mobile processor: Central Processing Unit (CPU) for processing user input, video images and running any application simulations.
- Graphics hardware: Graphical Processing Unit (GPU) system for generating virtual images.
- Camera: Camera hardware for capturing live video images to be used for AR tracking and/or for overlaying virtual image[27] or other information onto the video views.

[25]Layar application: http://layar.com
[26]Wikitude application: http://www.wikitude.com/
[27] Most public used mobile phone-based mobile AR is using the latter method to deliver mobile AR content on mobile user’s device.

- Display hardware: A handheld, head-worn, or projected display used to create the AR view by combining virtual images with images from the real world.
- Networking: Wireless or cellular networking support that allows the mobile device to connect to remote databases
- Sensor hardware: Location sensors (e.g., GPS, compass), gyroscopic, light sensors, biosensors, accelerometers or other sensors that can be used to specify the user's status (e.g., position or orientation) in the real world.

For further information about the technical aspects of mobile AR, one can refer to these surveys of mobile and wireless technologies for mobile augmented reality systems (Azuma, 1997; Dunser, Grasset, & Billinghurst, 2008; Papagiannakis, 2008; Van Krevelen & Poelman, 2010).

2.5.3 Mobile AR in Navigation

2.5.3.1 Characteristics of mobile AR Navigation Systems

Among pedestrian navigation interfaces, such as digital mapping or photograph-, text-, voice-, or tactile-based interfaces, most of the previous work has focused on map-based navigation support (Baus, Cheverst, & Kray, 2005). However, in terms of interacting with surroundings, map-based interfaces are proving to be somewhat unsatisfactory. Evidence shows that even when a user is close by a POI, a long time is requierd to relate the map to the environment to locate the POI (Brown & Laurier, 2005). That is, users have to be able to identify how map depictions correspond to landmarks in their particular spatial location (Hutchins & Lintern, 1995). Establishing this correspondence (the process of matching map presentation to real world view) is the essential cognitive activity in using map navigation (Davies, Li, & Albrecht, 2010; Davies & Uttal, 2007). Unfortunately, separating the map data and physical site can impose additional cognitive load on the user in generating a cognitive map of the real scene. In addition, small screen display, individual differences in map-reading skills (Hirtle, 2011), and perhaps even gender differences (Lawton, 1994) have been reported to restrict map use in certain contexts.

What differentiates mobile AR navigation systems from map-based navigation systems is the different visualization approaches used to present information about the current location and its surrounding to the mobile user (Kolbe, 2004). Evidence shows that photorealistic street-level views (e.g., views in mobile AR viewer) is more effective at providing route presentation and direction support (e.g., supporting user's awareness of the current walking direction), and identifying real-world buildings and nearby landmarks than a traditional graphical map and photorealistic satellite map (Jacob et al., 2012; Walther-Franks & Malaka, 2008). This is probably because mobile AR navigation systems provide more specific visual feedback, thereby lessening the attentional demand required to merge information between the physical world and the mobile device (Hollerer, 2004). In principle, it is possible to focus simultaneously on the physical world and computer-generated information.

To summarize, three main characteristics of mobile AR navigation guides have been identified in the literature. First, mobile AR systems are *direct and intuitive*. mobile AR information is presented in the same context as the object it relates to, so it provides the ability to contextualize and localize virtual information directly (Wither, 2009). In terms of interacting with surroundings, mobile AR-enabled views more directly correspond to a user's real world views by providing geographical position and orientation (Drummond, 2007; Roberts et al., 2002; White & Feiner, 2009). The importance of this strong mobile AR correspondence is perhaps best illustrated in a study by Tsai et al (2012), who showed that a geographical information (GI)-based mobile AR application, called Mobile Escape Guidelines (MEG), was able to provide visual support and aid in the evacuation of people from a nuclear accident site (Tsai et al., 2012).

Similarly, mobile AR systems offer intuitive data browsing of location-referenced information (Reitmayr & Schmalstieg, 2004a). At a particular spatial location, the user's perception of the real world can be greatly enhanced by additional virtual information such as video clips and 3D objects (Reitmayr & Schmalstieg, 2004a). For example, AR browsers can present useful information such as temperature, air quality, and air pressure in the user's immediate surroundings (Pyssysalo et al., 2000).

The second important trait of mobile AR systems is *immersiveness*. mobile AR mobile guides not only provide contextual mobility (Rasinger, Fuchs, & Hopken, 2007), which conventional mobile information guides can offer, but also provide a more immersive experience for visitors on-site. mobile AR systems can deliver rich and lively information that is not directly visible while physically visiting the site (Frohlich et al., 2006). For instance, mobile AR guides for cultural tourism are often used to reconstruct historical buildings and monuments from a previous era (Noh et al., 2009). This enables users to experience a virtual reconstruction of past life, ancient scenes, or virtual characters combined with audio and video narratives that tell more about the history of the featured objects (Epstein, 2006; Noh et al., 2009; Seo, 2011). These mobile AR guides have become an important platform for people to learn more about given events and historical elements by facilitating an immersive experience that increases their interest and their understanding of the context (Park, Nam, & Shi, 2006).

The third critical trait of mobile AR systems is *integrability* with diverse modalities and multiple enabling technologies (e.g., context-aware technology) (Pyssysalo et al., 2000). The user's perception of the real world is enhanced by computer-generated multimodal entities, such as images, 3D objects, and spatialized audio (Reitmayr & Schmalstieg, 2004a). For instance, ARCHEOGUIDE, a personalized on-site tour assistant, was developed to help tourists navigate sites and visualize a reconstruction of ancient life. This system used multimodal user interfaces (consisting of image, video and audio) to personalize the flow of information to its pre-established user's profile to cater to various types of users (Vlahakis et al., 2002). Likewise, a program known as iTacitus (Intelligent Tourism and Cultural Information through Ubiquitous Services) provides tourism and cultural information through multimedia content such as 3D virtual models and video/audio recordings. It also employs contextual filters by selectively displaying information based on an individual user's location, interests and history (iTacitus, 2008). A similar concept was adopted by Cultural Heritage Layers using multi-media content (e.g., drawings, paintings, and photographs of buildings) and context-aware capability to show and explain the development and history of landmarks (Zoellner, Keil, Drevensek, & Wuest, 2009). This platform was also among the first to use visual effects such as fading and smooth transition between pictures (as seen in Adobe Flash or JavaScript) to increase immersion and familiarization with AR technology.

2.5.3.2 Constraints of Smartphone-based mobile AR Navigational Guidance Systems

The published HCI literature on handheld augmented reality has concentrated largely on building perceptually-correct connections between real-world objects and digital content (Kruijff et al., 2010). The literature describes three significant challenges with respect to outdoor mobile AR guidance systems (Neuhofer et al., 2012): 1) *organizational* aspects regarding their integration into an existing IT-infrastructure and consistently providing up-to-date information on the environment; 2) *technical* issues, including tracking accuracy and reliability (e.g., jittering problems, inaccurate alignment), display type, size, resolution and brightness, battery capacity, limitations of sensors on the phone and so forth (Boyer & Marcus, 2011); and 3) *cognitive* properties of the information system, relating to presented and structured information and graphical user interface design in the user's field of view. These technical issues are further divided into four areas that impact the way augmentation is perceived: a) environment (e.g., structure, colors and natural conditions of the environment), b) capturing (the process of converting an optical image to a digital signal by a camera), c) augmentation (registration of digital content over video imagery), and d) display device of mobile AR applications (e.g., field of view (FOV), viewing angle offset, color fidelity, reflection, and latency) (Kruijff et al., 2010). Similarly, cognitive challenges can include information content and density, cognitive workload, attention effects, symbology characteristics, and the overlaying of text and graphics combinations (Stedmon et al., 1999).

In addition to the three problem areas briefly described above, there are other constraints in the Smartphone platform and context-of-use of mobile devices. Some of them are inherent constraints embedded in handheld mobile computing devices (e.g., context issues) (Kjeldskov & Stage, 2004;

Pascoe, Ryan, & Morse, 2000), while others are specific to Smartphone-based mobile AR systems(e.g., ergonomic constraints). These constraints are summarized as follows.

Restrictions by Smartphone platform:

1) The attributes of Smartphone's screen: A mobile device interface has its own unique characteristics and challenges due to its inherent limitations, including the size of the screen, resolution of the display, non-traditional input methods, and navigational difficulties (Nah, Siau, & Sheng, 2005). For example, one ubiquitous restriction is the miniaturization of mobile screens due to the demand that they are easily portable (Pascoe et al., 2000). Because of the limited screen size of the Smartphone, it is often not possible to show all relevant information simultaneously. This results in hierarchical information structure that causes higher demands on the user's short-term memory (Pospischil, Umlauft, & Michlmayr, 2002).
2) The camera's optical characteristics: The optics used in Smartphone cameras produce an image with a wider field of view than would be seen looking directly through a rectangular frame the size of the display. Thus, it is a much smaller field of view compared to the view seen from a single human eye (Kurkovsky et al., 2012; Tokusho & Feiner, 2009).
3) Other factors: Responsiveness, battery life, connectivity and other operating factors affect the performance capabilities of mobile AR systems (Pascoe et al., 2000).

Restrictions by context-of-use:

1) Situational impairment factors: Mobile interaction is heavily contingent on the context, which varies greatly in a mobile environment. The increasing mobility and ubiquity of mobile computer systems make the context-of-use continuously changing. When factors or aspects of a user's environment adversely affect his or her ability to perform certain activities (e.g., distraction, ambient noise), situational impairment occurs (Sears, Lin, Jacko, & Xiao, 2003; Sears & Young, 2003).

2) Ergonomic constraints: The design of a camera on the opposite side of the display requires mobile AR users to hold the phone in an outstretched hand when trying to view more distant real-world objects, or angle it uncomfortably upwards when capturing the image of a tall building (Kurkovsky et al., 2012; Tokusho & Feiner, 2009). This ergonomic constrain was inevitably introduced by the combination of the smartphone platform and the context-of-use.

2.6 Mobile AR Guidance Systems

The process of navigation could be categorized into two primary types—exploratory navigation (exploration) and goal-directed navigation—and mobile AR navigation guides are developed to support both (Grasset et al., 2011). These two types of activities are most often intertwined together. On the one hand, *goal-directed navigation* can be supported by visualizing the path from one location to another directly in the frame of reference of the physical environment (Grasset et al., 2011). Most often, wayfinding instructions, such as an arrow or a path, are superimposed on the street to give information to the user about the turns to take (Grasset et al., 2011). On the other hand, *exploratory navigation* is supported through digital augmentations that provide information regarding the nearby environment, such as buildings or nearby streets (Grasset et al., 2011). In this way, the environment becomes an anchor for geo-referenced hypermedia databases. Users can physically navigate this environment and look at the various annotated objects.

Because little research has been done in the field of exploration in the mobile AR-enabled context, in line with Sutcliffe (2000), in virtual environments exploratory navigation is further divided into *goal-directed exploration* and *serendipitous browsing (simplified as browsing).* What distinguishes the two is the presence or absence of a clearly-defined goal (Sutcliffe & Kaur, 2000) —such as finding a specific place. In exploratory navigation, these augmented annotations do not directly provide wayfinding instructions; instead, they help people understand the environment and build a user-directed concept of the surroundings.

2.6.1 Goal-directed Navigation

Previous work in the field of goal-directed navigation has included both indoor and outdoor navigation systems (Frohlich et al., 2006; Kolbe, 2004; Reitmayr & Schmalstieg, 2004a). Most systems directly point out locations by overlaying navigational (e.g., directional) instructions onto the image of the user's environment to assist user's wayfinding activity. Directional instructions include directional arrows, trails to follow (e.g., "painted lines on the floor" (Hile & Borriello, 2008)), or geo-tagged landmarks or their images (Hile et al., 2009). One of early works in this field is a wearable computer system with a see-through head-mounted display providing the position of waypoints (Piekarski & Thomas, 2001; Thomas, Demczuk, Piekarski, Hepworth, & Gunther, 1998a). This system allows a user to explicitly define a desired path as a finite sequence of waypoints. Similarly, for indoor navigation systems one of the pioneering works was Signpost, which used an indoor tracking system that covered specific areas of the studied building. The tracking system was based on visual tracking of fiducial markers enhanced by inertial sensors to show the user the direction of the next waypoint (Reitmayr & Schmalstieg, 2003). In the indoor context, displayed information often relates to what events are taking place, which resources are reserved and by whom, and when someone is in his or her office (Hile & Borriello, 2008).

In addition to requiring users to manually define the next waypoint(s), subsequent mobile AR systems for outdoor navigation were developed to show the computer-determined path. For example, Reitmayr (2004) developed a mobile AR system that computed the shortest path from the current location to a specific target location (e.g., a supermarket) in a known network with possible routes. These waypoints were presented as cylinders in the environment connected by arrows. This system also supported collaboration among users allowing a user to follow, guide, or meet other users at intermediate positions (Reitmayr & Schmalstieg, 2004a).

2.6.2 Exploratory Navigation

The other type of navigation is exploratory navigation. It has traditionally been supported by tourist guides (e.g., paper or digital) or Internet information, both of which provide a great deal of information to users prior to reaching a destination. In exploratory navigation, people tend to have two sub-goals, including 1) *goal-directed exploration* or *search for* local objects, such as searching for restaurants, movies, stores; or 2) *serendipitous browsing* or *exploratory browsing* surroundings, such as serendipitous discovery of activities and venues (Bellotti et al., 2008; Ludford, Frankowski, Reily, Wilms, & Terveen, 2006). Exploratory navigation encourages users to explore new areas and discover new locations around them to gain serendipitous information about their surroundings (Rayoung Yang, 2011).

To support such activity, location-based mobile AR navigation systems enable the user to visualize (browse) geo-referenced hypermedia information while physically navigating through the space (Grasset et al., 2011; Reitmayr & Schmalstieg, 2003, 2004a). Specifically, mobile AR navigation systems help users accomplish their tasks by providing them with relevant information about their environment (Hollerer, Feiner, Terauchi, Rashid, & Hallaway, 1999). The information includes position, direction and distance of objects (or places), names and other properties of buildings and infrastructure, notices of new services and upcoming events, open hours, etc. All of the presented information may or may not be visible from a user's current location (Rayoung Yang, 2011). In this context, mobile AR navigation systems are applications that not only are used to find a certain destination, but also process and retrieve information from online databases and present it to mobile users, helping them to make decisions and be informed about their environment (Hollerer, 2004).

Mobile AR information browsing in this category was first demonstrated by Rekimoto, who develoed a prototype palmtop AR system called NaviCam (Rekimoto, 1997). To overcome the cumbersome usage of headgear HMDs, NaviCam recognized real-world objects using the video images by palmtop reading identification (ID) tags. Based on the recognized ID tag, the system retrieved and displayed information about the real-world object to the user. Another early system is known as Touring Machine (Feiner et al., 1997). The Touring Machine allowed users to browse geo-referenced data about Columbia University in New York. The program added virtual tags to real university buildings to show which departments were in which buildings via a tracked see-through head-worn display and a hand-held display. It presented contextual information visually and was connected to a relatively large area in the physical world through the combined use of multiple displays and interactive technologies (Feiner et al., 1997).

Hollerer and Feiner (1999) also used the same wearable setup with a head-worn display for a navigation system called MARS (Mobile Augmented Reality Systems). This system offered users the possibility of interacting with linked spatial multimedia information such as text, audio, static image, video and 3D graphics (Hollerer, Feiner, Terauchi, et al., 1999). Since then, many touring systems have appeared and the development of campus navigation systems, in particular, has become one of the fast-growing areas for mobile AR outdoor navigation systems. Most of the current campus-navigation systems are Smartphone-based and allow visitors to use their mobile devices to access and experience visualized information about a university's buildings and history. A number of universities have either developed or are developing this type of program, including Purdue University, the University of Wisconsin-Madison, West Virginia University, Arizona State University, Georgia Tech, etc. (Chou & ChanLin, 2012).

Context Compass, another early application, showed how pedestrian navigation can benefit from heads-up AR interfaces in which the system orients the mobile user towards the POI (Suomela & Lehikoinen, 2000). This system adopted a compass metaphor to present information in the real world at the top of the user's view. Any object could be selected and viewed by the user by simply looking at it. Suomela and Lehikoinen also discussed the provision of contextual information as an entity that characterizes the situation. Following Abowd (1997), an entity is a person, place, or object that is considered relevant to the interaction between a user and an application (Abowd et al., 1997). In Context Compass, for example, objects around the user were shown at the top of the viewer along with compass points, which the user then highlighted and activated. This work represents an early effort to present contextual information to users with respect to their current situation—with context defined as a collection of certain virtual objects in a limited environment (Suomela & Lehikoinen, 2000). Although the authors noted that the number of objects belonging to the current context was restricted by certain conditions (e.g., the user's profile and interactions), it failed to provide any information on the specifications of these virtual objects and how to identify them.

Reitmayr and Schmalstieg (2004b) developed a head-worn outdoor navigation system with goal-directed navigation functions (e.g., follow, guide and meet modes). This system also featured an information-browsing mode for exploratory navigation (Reitmayr & Schmalstieg, 2004b), which presented the user location-based information that could be selected by gaze. Specifically, the authors designed the system to deliver historical and cultural information about the sights in Vienna, Austria, which was obtained from printed guidebooks. The user was able to interact with the system by selecting from a subset of icons and keywords to which the icon related. This information-browsing mode also supported multiple users, which could be selected and shared on another user's display.

Another head-worn system, a mobile AR restaurant guide developed at Columbia University, provided an interface to a database of restaurants in the Morningside Heights area of Manhattan (Hollerer, 2004). Information about restaurants was supported by two modes: an overview 3D map and direct annotations at the actual restaurant locations. Having selected a restaurant, the user could then bring up a popup window with further information about the site including a brief description, address and phone number, an image of the interior, the menu, reviews of the restaurant, and its external web page.

One of the earliest handheld mobile phone-based AR systems based on the NaviCam system is MARA (Mobile Augmented Reality Applications), developed by Nokia (Kahari & Murphy, 2006). MARA is an interface that supports user interactions with their surrounding environment through the use of a standard mobile phone. MARA identfied POIs around the mobile user, using squares to indicate the locations of the POI with their distance written as a text label shown in the viewfinder. It allowed users to "click" hyperlinks associated with the real-world objects to obtain further information. The system also featured the adaptability to provide different UI metaphors based on the manner in which the device being held (flat or upwards).

In addition to navigation-relevant augmented information, mobile AR also provides indirectly related information for navigation in an outdoor context. For example, in one study researchers developed a mobile AR application that provides real-time data about nearby transportation including information about nearby bus stops and arrival times, as well as more detailed bus routes and distances, in order provide mobile users with more info-mobility data (Borgia et al., 2012).

2.7 User-Centered Design vs. Interface of Mobile AR navigation systems

2.7.1 User-centered Design and User Requirements

Human Computer Interaction (HCI) as a research domain dates back to the 1970s and Hansen's "Know thy user" approach to systems development (Hansen, 1971). According to Dix et al. (2004), HCI "involves the design, implementation and evaluation of interactive systems in the context of the user's task and work"(Dix, 2004). This definition should include all types of computers—including traditional desktop computers and more ubiquitous computers, such as mobile AR systems (Nilsson, 2010).

The essence of User-centered Design (UCD) is the active involvement of all types of stakeholders, especially end users. End users are actively involved throughout all phases—product design, development, and evaluation. As the first developmental step of UCD, a thorough analysis of user requirements is conducted to offer insights into user needs, which are a valuable source of inspiration for designers to come up with new design solutions. User requirements include summary descriptions of the tasks that the system will support and the functions that will be provided to support them (Maguire, 2001). It also provides example task scenarios and possible interactions for the system, in addition to describing any features of the system necessary to meet the context-of-use characteristics (Maguire, 2001). In order to solicit user requirements, developers must first consider user types/profiles and task scenarios.

2.7.2 User Types

User types are people who need navigation support and might want to use the mobile AR guidance applications on-site in an urban historical, residential or commercial site (Dhir et al., 2012; Olsson & Salo, 2011). They can be tourists or urbanites interested in any and all kinds of leisure activities (aka leisure tourism) or tourists who are in emergency situations (e.g., gun violence). For leisure purposes, mobile AR guidance systems can be used by city visitors who want to explore the location by visiting landmarks and historical places, dining at local venues, or finding noteworthy events and activities. For public safety purposes, mobile AR guidance systems can be used by people in emergency situations who need to examine their surroundings and evacuate to a safe place.

2.7.3 Context

2.7.3.1 Context vs. Situation

This study requires clear definitions of the notions of *context* and *situation*. In situation awareness, *situation* refers to those pieces of information that are relevant to the task at hand (Endsley et al., 2003). Thus, the notions of *situational information* and *context information* are different. The term "context" seems to comprise “everything,” whereas “situation” only consists of specific aspects that are related to user’s goals and tasks at hand. Although “context” in HCI is more or less linked to a user’s goals and tasks, there is more emphasis on the interaction between humans and computers at the operation level.

Therefore, given the above rationale, we can claim that from a user’s perspective, *context information* does not become *situational information* unless 1) it will be processed through a series of perceptual and cognitive processes; and 2) it is relevant to the user’s goals and tasks at hand. That is, *context information* can be analyzed, interpreted, and inferred through a subjective measure that is relevant to the user’s goals and tasks. Therefore, this gives a terminology base for extending SA theory in context-aware mobile AR navigation systems.

2.7.4 User Needs Analysis and User Requirements of Mobile AR Navigation Systems

2.7.4.1 User Needs Analysis and User Requirements

To support user tasks and produce products that people want to use, user needs and requirements analysis are critical. Specifically, information is needed about user goals and tasks, preferences, expectations, and specific information about functions or desirable user interface solutions. All these elements become system *requirements* (Spath et al., 2012). *User needs* refer to the least formal data that include factors or conditions necessary for a user to achieve desired goals (Spath et al., 2012). *User requirements* are formal descriptions that “provide the basis for design and evaluation of interactive systems to meet some or all of the identified user needs” (ISO, 2010). Specifically, user requirements state any function, constraint, or other property needed to satisfy user needs (Kujala, Kauppinen, & Rekola, 2001). Further, user requirements can be categorized into diverse subtypes with different emphases, such as user capability, usability requirements, organizational requirements, compatibility with standards, information requirements, etc. (Spath et al., 2012). In terms of task-related information requirements, user requirements usually contain *functional requirements* and *nonfunctional requirements*. Functional requirements describe system functionalities and services, while nonfunctional requirements specify quality aspects of the product (e.g., usability, privacy, reliability, performance, pleasure) (ISO, 2009).

During the initial design phase, it is challenging for designers to capture requirements accurately because users typically don’t know what they want and cannot clearly articulate their needs. According to Robertson (2011), user requirements are subdivided into conscious requirements and unconscious requirements. The former refers to design features that users knowingly want to incorporate, while the latter indicates design features and technology possibilities that must be teased from the client (Robertson, 2001). This challenge has shown particularly difficult in eliciting and validating requirements in mobile AR applications (S á& Churchill, 2013).

2.7.4.2 User Requirements and Users Expectations in mobile AR Navigational Systems

As stated in the Introduction section, previous research has shown that user information needs for mobile AR in the context of urban exploratory navigation have been minimally studied; moreover, the lack of user studies and underutilized User-Centered Design (UCD) approaches have been identified as AR domain-wide problems (Dhir et al., 2012; Olsson et al., 2012). Compared to user research on websites or conventional mobile sites, little research in mass-marketed applications of mobile AR has been conducted. Consequently, this scarcity of knowledge has somewhat hindered the mass adoption of mobile AR computing applications.

At present, the lack of mobile AR user requirement research and failure to adopt a full-fledged UCD perspective most likely stem from four separate issues: 1) mobile AR applications are technology-driven and current research efforts are focusing on technology development rather than on optimizing usability (Martin, Norris, Murphy, & Crowe, 2008); 2) functioning real-time mobile AR systems are typically too cumbersome for potential users (Walther-Franks & Malaka, 2008); 3) the development of mobile AR applications is still an expensive and non-intuitive task (Di Capua, Costagliola, De Rosa, & Fuccella, 2011); and 4) time and financial constraints result from severe market competitions (Martin et al., 2012).

In general, current user-requirements research on mobile AR guidance applications is deficient in its overall understanding of information needs—for example, what can be presented to a user and what a user needs from a mobile AR in the context of urban exploratory navigation. Nonetheless, some studies of user information requirements of mobile AR systems do exist. However, this body of research is more focused on nonfunctional requirements stressing the overall quality and attributes of systems, rather than requirements that are specifically concerned with the functionality of a system.

2.7.4.3 Nonfunctional User Requirements of mobile AR Navigation Systems

In a recent study by Olsson et al. (2011), interviews were conducted in shopping centers to elicit the central characteristics of expected user experiences and user requirements related to general mobile AR services. Results indicated that users expected mobile AR services to have an intuitive interface to provide them a sense of efficiency, empower them with context-aware services and proactive functionalities, and raise their awareness of the information related to their surrounding environments. Additionally, users expressed that they would use mobile AR services to gain increased insight into objects, places, and immediately noteworthy events in their surroundings. Thus, the potential of browsing one’s surroundings in increasingly sophisticated ways seems to be highly valued by users.

Despite existing research that helps to enhance our understanding of mobile AR services in general, these studies tend to describe abstract and high-level user experience-oriented requirements, such as inspiration, creativity, intuitiveness, playfulness, etc. These abstract requirements are too general to really help researchers in understanding the information needs and requirements that can be applied to the information design of mobile AR guidance applications. In addition, the proposed requirements focus more on holistic, expected user experiences and hedonic information that provide users with self-fulfilling values, such as a sense of being inspired and naturalness, rather than proposing any specificity regarding user's interactions with their surroundings.

Olsson (2011) and his colleagues conducted an online user survey to study the overall user experiences of the mobile AR consumer applications available at the time (Olsson & Salo, 2011). Examined applications include MARs used for information browsing and image recognition. Their findings disclosed a contradictory mix of user experiences regarding mobile AR application usage. For example, fairly positive user experiences (e.g., novelty and useful information content) were overshadowed by highly negative experiences—such as user concerns about the application's pragmatic uselessness, technical unreliability, and especially, excessive irrelevant content. However, survey results also pointed to definite agreement that using mobile AR navigation guides enabled users to "develop a good conception of their surroundings" (Olsson & Salo, 2011). In terms of statistics of usage, results showed that mobile AR guidance applications were principally used in metropolitan areas, city centers, campuses, industrial locations, or other popular daytime areas. More than half of the users reported that they had used the applications at least on a weekly basis. In addition, results suggested that after a user's "curiosity" period had passed, the growing amount of content and functionality likely became the main motivation for long-term use of mobile AR guidance applications (Olsson & Salo, 2011).

In another study focusing on user expectations and needs for mobile AR technology, Dhir and his colleagues reported that users expect mobile AR information to be *useful*; *personalized* as to what, how and when information is received; *reliable* in terms of accuracy and authenticity of the presented information; and *relevant* with respect to providing contemporary, useful, and valuable information (Dhir et al., 2012). This study reinforced that one of the greatest motivations for using mobile AR technology is the demand for useful information in comparison to other needs (e.g., hedonic) in various mobile contexts. Specifically, users expressed the need to enhance their existing knowledge about the current environment and surroundings, such as real-time traffic, weather, newspaper headlines, offers and discounts, ratings and recommendations, and information on current and future events for decision-making (Dhir et al., 2012). Furthermore, information provided by mobile AR guidance applications are expected to increase user confidence in decision-making, reduce cognitive load, solve the problem of the language barrier, and be accessible without physically visiting places. mobile AR applications should also have social features allowing users to interface with online social media (e.g., Facebook and Twitter) to improve the social experience (Dhir et al., 2012).Although their study focused on user needs and expectations of mobile AR information, and identified four characteristics of information (usefulness, personalization, relevance, reliability), it tends toward generalities and lacks a specific focus on navigation systems.

2.7.4.4 Functional Requirements of mobile AR Navigation Systems

The functional requirements of mobile AR navigation systems are those associated with necessary tasks, actions, or activities that must be accomplished by the system (Lightsey, 2001). It encompasses the types of information that should be presented, the types of functions that should be performed, and the capabilities the system should bestow on the user.

Many types of information are desired from a mobile AR navigation system for urban exploration to make it truly useful across a wide range of parameters. For example, a mobile AR navigation system should include up-to-date tourism information (e.g., weather forecasts) (Proll, 2000); guidance information (e.g., mobile route advisory systems or information pertaining to visitor recommendations) (Chiu, 2005; C.-C. Yu, 2005); performance information to know how to achieve the highest return from a chosen alternative (e.g., information about road conditions and event changes) (Berger, 2003); and exploration information (Joerg Rasinger, 2009).

Table 1 lists a set of functionalities that describes current or expected mobile AR navigation systems. This table represents a synthesis of the body of work in mobile AR navigation systems with a particular emphasis on mobile navigation assistance and context-aware systems. The intention of compiling this table is to gain insights into the functionalities of current mobile AR navigation systems. To some extent, these amalgamated functionalities reflect the functional requirements of mobile AR navigation systems in terms of users interacting with their surroundings. They are summarized to shed some light on situation-awareness requirements of navigation since it a focus of the current study. For example, functional requirements of search and browse (Rasinger, 2009) and context-aware push functionalities (Cheverst, Mitchell, & Davies, 2001) can be considered relevant to developing situation awareness in the context of mobile AR-enabled navigation.

Table 1. Synthesized functionalities of mobile AR navigation systems

Category	No.	Sub-category	Description
General Information	1	Mobile search	Search mechanism that provides access to relevant information (Frohlich et al., 2006; Rasinger, 2009). Mobile search has been categorized into four main areas both for on-the-go uses or for stationary uses (Church & Smyth, 2008). Navigational search refers to a class of queries where the immediate intent is to reach a particular site, such as a company. Transactional search occurs whenever the user seeks further interactions such as shopping, gaming, or downloading files (e.g., images, videos, music, adult-related queries). Information search involves situations in which users attempt to find information online, while leisure search has an orientation towards entertainment and discovery options to organize a user's private time (Westlund et al., 2011).
	2	Browse (visible information)/Image recognition	Information browsing provides users with location-referenced information about objects in their surroundings, where information takes many different formats—e.g., other images, others' comments, internet-created information, etc.—and can be selected for more detailed information (Frohlich et al., 2006; Joerg Rasinger, 2009; Reitmayr & Schmalstieg, 2004a; Schmalstieg et al., 2007).
	3	Browse ("remote viewing" invisible information)	The concept of virtually "looking through buildings" (e.g., the "next blocks" in a certain direction) via an augmented reality view poses great potential for enhanced utilization as a way of imparting additional knowledge that is not directly visible in the physical surroundings; one must note that a user study showed that challenges associated with viewing nonvisible information included viewing range and orientation issues, comparing to map, radar, and Google Earth views (Frohlich et al., 2006).
	4	Information retrieval ("pull" information)	POI retrieval mechanisms allow users to "pull" information (or more detailed information) at will (Cheverst et al., 2001; Yang et al., 2011).
Spatial Information	5	Overview of a larger territory	This is enabled by integration with other types of augmentations, such as map services and a world-in-miniature approach, etc.
	6	Provide information content of nearby surroundings	Users should be able to see locations within a certain range of the current position (immediate surroundings), such as accessing the name of the POI and the distance to it (Yang, 2011). Users might need to access other information in their surroundings, such as transportation information (e.g., for mass transit riders).
	7	Support serendipity and free exploration of nearby surroundings	In addition to looking up information about a particular item, place, object and category, a system should enable people to discover new places because tourists may wish to explore available information about their surroundings with or without pre-defined task (goal/criteria) (Ajanki, 2011; Yang, 2011).

	8	Directional finder	When a POI along the street is not directly visible to them, but is along the path he/she intends to take, the user can point and query the availability. Users can point the phone in a specific direction to pull up POIs some distance away. For example, if a user points the phone southwest, the system should be able to give POIs in more distant surroundings (Yang, 2011). GeoWand (Jacob, 2012) proved that haptic technology, or haptics, is a powerful notification technique that can be used to convey distance to POI information and density of features along a particular street (Jacob et al., 2012).
	9	Adjustment of perceived spatial information	Location-based applications will identify and adjust to crowded areas and traffic patterns because traffic patterns and distractions in dense urban areas can distort a person's perception of distance (Ludford et al., 2006). For example, these applications will deliver messages that take into account the locale, where dense urban areas feel smaller.
Dynamic Information	10	Support for dynamic information	The system needs to stay informed about the current physical environment (e.g. via dynamic information retrieval from application servers) (Hollerer, 2004). The system should also support information that user requires on-the-fly (e.g., randomly picked opening hours, local weather, traffic news), which cannot be supplied in advance and thereby needs to be capable of dynamic change(Cheverst, Davies, Mitchell, Friday, & Efstratiou, 2000; Davies, Cheverst, Mitchell, & Friday, 1999). For example, in visiting Lancaster Castle, the castle was closed initially to the public because the courtroom (situated within the castle) was in session. If the court session were to finish early, the visitor would then be notified that the castle was open to the public (Davies et al., 1999). Dynamic mobile AR content can be accessed using the system and delivered at appropriate times (e.g., before the place, not after) and published and updated frequently (e.g., newspapers, brochures, public displays).
	11	"Push" notification	The tourist may miss out on important or interesting information, especially in information-rich urban settings (Cheverst et al., 2001; Rasinger, 2009). "Push" notification has a role to play in location-based systems, where immediately relevant information is "pushed" to users. These virtual reminders are associated with physical locations for spatially- or temporally-relevant information, such as social messaging (e.g., E-Graffiti), community announcements (e.g., GeoNotes),venue information (e.g., PlaceMail) or life-critical information in the battlefield (Gabbard et al., 2002). This is also called opportunistic reminders, which provides a early "just-in-time" or "just-in-place" prompt and task details later, telling the user to take spatially or temporally relevant action (Ludford et al., 2006).
Context-sensitive information	12	Personal context	Profiling should be allowed. The system needs to create a personal context for every user (Suomela & Lehikoinen, 2000). Personal context needs to be considered: visitor's interest, e.g., history or architecture, and visitor's current location, the user's profile, the age, the technical background of the visitor, and their preferred reading language (Cheverst et al., 2000).
	13	Environmental context	Environmental context includes the time of day, the opening times of attractions (Cheverst et al., 2000), road locations and types using Geographic Information System (GIS) datasets. The GIS community has a great deal of experience with storing, manipulating, and presenting large-scale geometric data to

			predict a user's travel time to a target place based on that person's current speed (Ludford et al., 2006).
	14	(Patterns of) human motion	The system should provide personalized recommendations to adapt the presentation of information depending upon the patterns of human motion, such as usage history (e.g., information that visitor has already seen), people's movement patterns through an area and geographic layout of the space (Ludford et al., 2006), the time of day, duration of stay, amount of pre-planning (Ludford et al., 2006), on inferences of a user's likely current interests and preferred activities from user profiles and patterns of past user behavior (Bellotti et al., 2008), to deliver messages in ways that fit patterns of human motion (Cheverst et al., 2000). For example, the system should narrow the information delivery radius for stationary users; if the visitor makes a return visit, the information should reflect that and adapt its presentation, such as providing a welcome back message (Cheverst et al., 2000).
	15	Implicit input	Unobtrusive implicit input from the user—specifically, eye movement patterns (e.g., selecting icons by looking at them) (Schmalstieg et al., 2007) and speech and other implicit feedback data—can be used for information filtering (A. Ajanki et al., 2011). The system infers the interests of the user based on the user's behavior and presents relevant augmented information based on such behavioral information. If the user shows further interest in the AR content, the system detects it and provides progressively more information (Ajanki et al., 2011). This functional requirement is one of the solutions to the information overload problem when the user may not have an explicit query in mind or may not even be searching. Therefore, the mobile AR system will display information based on the system's inferences on the user's behavior (Ajanki et al., 2011). However, the disadvantage associated with implicit input is that it needs a complete and thorough user profile and an accurate model of user behaviors.
Interactive mobile AR view	16	Interaction and direct manipulation of mobile AR content	Urban environments are rich in potential targets for annotation (Tokusho & Feiner, 2009). An interactive mobile AR view could serve as an interface to additional, more detailed information about a POI via online databases (Davies et al., 1999; Kahari & Murphy, 2006; J. Wither et al., 2009; Wither, 2009). In addition, users can interact with the information presented to them by creating, adding, editing, deleting annotations to specific physical locations and objects (Frohlich et al., 2006), in formats of visual textual annotations (S. Feiner et al., 1997; Thomas et al., 1998b) or multimedia information (Hollerer, Feiner, & Pavlik, 1999), or multi-modal interaction (e.g., accessing by voice activation) (Gabbard et al., 2002). Four types of interactivity with respect to mobile AR annotation exist (Wither et al., 2009): 1) static and offline (e.g., hyperlinks); 2) interactive (e.g., "clickable") but not editable; 3) editable; and 4) user-created annotation. For example, for textual annotation only keywords are provided. Selecting one provides more detailed information in a popup window (Schmalstieg et al., 2007).
	17	Multi-modal user interface	In addition to a visual interface, in an outdoor environment other interaction models (e.g., speech and voice recognition) will occur (Schmeil & Broll, 2006). Users will be more cognizant of the surrounding environment as a result of delivered information that users can perceive and comprehend, such as audio and haptic notifications (Frohlich et al., 2006; Jacob et al., 2012).

	18	Social interaction	mobile AR can also support collaboration among mobile users, which can be achieved by sharing information such as mobile users manipulating (e.g., exchanging or co-editing) mobile AR content.
	19	Filtering of mobile AR content	The option to filter information or layers based on several factors, such as user interests (e.g., weather and terrain, distance) to present information in an uncluttered way so that it is easy to interact with (Ajanki, 2011; Gabbard et al., 2002; Julier et al., 2000; Tsai et al., 2012). A set of rules of prioritization should be generated. Specifically, task-related data must prevail over neutral data, nearby information must prevail over distant information, and more important information must take precedence over minor information (Neuhofer et al., 2012).
	20	User control and pace of interaction	The system should enable visitors to control their pace of interaction with the system, for example, stopping or interrupting the tour when needed (Cheverst et al., 2000). Freezing the camera image (mobile AR view) when desired, while keeping the overlaid graphics live, support manipulating the interface and visualization without having to keep the device pointed at the scene. It's been found that on-screen user interface controls are best positioned in the lower left and lower right of the screen and along the edges where the user's thumbs could easily access them (White & Feiner, 2009). In addition, once the display is frozen, direct manipulation (e.g., touching the screen to show information) is useful.
Customizability	21	Customizability	Tour guide systems should provide information that can be tailored to different visitors with different needs (e.g., interests, sophistication of language used in descriptions, duration of the tour, budget of the visitor, etc.) (Davies et al., 1999). For example, the city guide system should enable visitors to tour the city on their own way. Some visitors prefer to follow a guided tour while others may choose to explore independently, following one or more guidebooks or street maps (Cheverst et al., 2000).
Support collaboration	22	Support collaboration	Mobile AR interaction does not limit itself to interactions between mobile AR content and one individual user. Such interactions can also support collaboration among mobile users, which can be achieved by sharing information. A mobile collaborative augmented reality application is one that allows multiple users to share an AR experience using their mobile devices (Reitmayr & Schmalstieg, 2001). The AR content can be shared among face-to-face or remote users, at the same time (synchronous collaboration) or at different times (asynchronous collaboration) (Billinghurst & Thomas, 2011). Examples are BARS (Julier et al., 2001), Shared Space project (Billinghurst, Weghorst, & Furness, 1998), Human Pacman (a collaborative mobile AR game) (Cheok et al., 2003), the Augmented Stroll (a mobile collaborative mobile AR services to archeologists in field works).

2.7.5 Interface of Mobile AR Navigation Systems –Augmentation & Interaction

2.7.5.1 Mobile AR Annotation

According to Wither et al. (2009), an augmented annotation is virtual information that describes in some way, and is registered to, an existing object. This is a general definition of mobile AR annotation, encompassing a broad range of uses. Virtual information is presented in a variety of formats: text, pictures, models, sounds, or haptic feedback (Wither et al., 2009). According to Hollerer (2004), real objects in the physical world are called *environmental objects*, in contrast to virtual annotated environment objects, which are referred to as *realized objects* (Hollerer, 2004). On the one hand, *realized objects* form the virtual layer of the mobile AR interface. Specifically, three properties of a general set of mobile AR physical objects have been defined. They are *type* attributes, *state* attributes, and *semantic* attributes. *Type* attributes refer to the intrinsic and unchangeable characteristics of the object, including *category* attributes based on varying categories of information, and *composition* attributes, being single or a collection of objects. *State* attributes describe the current state of the object—the value can change over time, such as the object's status, position, orientation, etc. *Semantic* attributes list the class properties and relationships that inform the mobile AR about the object's meaning and importance (Wither et al., 2009).

In terms of relationships between environmental objects and realized objects, Wither et al. (2009) further defined two types of relationships: semantic relationship (e.g., a realized object containing the name of the physical object), and spatial relationship, (e.g., a realized objects having spatial relevance to their surroundings (Wither et al., 2009). Semantic relationship is further categorized into five types in outdoor navigation: names, describes, adds to, modifies, and directs to (Wither et al., 2009). These categories with representative examples are summarized in Table 2. More precisely, a *semantic relationship* conveys information of *semantic relevance*, one of the dimensions of mobile AR annotations, which refers to a measurement of how closely an annotation resembles the physical object that it is annotating. In addition to *semantic relevance*, Wither et al. also described other five dimensions of mobile AR annotations: 1) *location complexity*, which refers to the complexity of the annotation's real world location, ranging from a single point to a 2D or 3D annotation region; 2) *location movement*, which refers to the location of the annotation on the screen; 3) *content complexity*, which can range from point-marking to animated 3D polygonal models with audio; 4) *interactivity* of the virtual content, ranging from static off-line annotation to user-generated on-line annotation; and 5) *annotation permanence.* Annotation permanence is further divided into four basic strategies: temporally controlled, user controlled, spatially controlled permanence, and information filtered permanence (Wither et al., 2009).

On the one hand, *environmental objects* represent the real part of the mobile AR interface. Following Wither et al. (2009), Alzahrani et al. (2011) described two types of *environmental objects* based on a criterion that the location of the object is static: 1) *physical objects* and 2) *geographical spots*. Further, *physical objects* are "moving" objects subdivided into: *single objects*, *collection of objects*, and *people*. On the other hand, *geographical spots* are "static" objects comprising two types: 1) *single point* in geographical space (e.g., roads intersection or a building location), and 2) *collection of geo-points*, which has more than one set of coordinates with two subgroups of a geographical line (e.g., a bicycle trail) or an area (e.g., a block in the city) (Alzahrani et al., 2011).

As mobile AR systems become more advanced, annotation authoring has become a popular but challenging research area. For example, Schall et al. (2008) introduced an annotation authoring tool that creates 2D information labels in 3D coordinates (Schall, Mendez, & Schmalstieg, 2008). The user can create an annotation at one's current location or at a distance. When the annotated object is at a distance, annotation authoring is much more challenging. To address this challenge, the following authoring techniques have been developed: 1) model-based annotation (a model of contextual information of the user) (Ajanki et al., 2011); 2) estimation-based annotation (e.g., the distance estimated by the user); 3) triangulation-based annotation (the accuracy of distance estimation increased by triangulation); and 4) measurement-based annotation (the distance known to the user) (Wither et al., 2009).

Table 2. Types of semantic relationships between environmental objects and realized objects

Types of semantic relationships	Description	Example(s)
Names	The annotation provides a name for the physical object that it is annotating.	Keywords used as names in Touring Machine (Feiner et al., 1997)
Describes	The annotation provides more descriptions about the physical object.	A textual description (Reitmayr & Schmalstieg, 2004a)
Adds-to	The annotation not only provides virtual content but also changes the physical object in the user's field of view by this add-on.	New objects are added to a park, such as trees, statues, or a picnic table (Piekarski & Thomas, 2003); ARQuake (Vlahakis et al., 2002); A completed version of a building under construction (Thomas et al., 2002)
Modifies	The annotation visually changes existing physical objects (e.g., overwriting the physical objects with virtual content).	Internal objects are visible through X-ray vision techniques (Bane & Hollerer, 2004); Historical guides, where a building can be replaced or modified to appear as it did in the past (Giiven & Feiner, 2006)
Directs-to	The annotation directs a user to a certain destination.	Showing the path to the destination (Reitmayr & Schmalstieg, 2004a); many examples are provided in the navigation section 2.3.

2.7.5.2 Visualization Principles for mobile AR System

Few formal guidelines have been formulated for designing mobile AR interface. As stated previously, Kruijff (2010) summarized a series of perceptual issues in mobile AR systems from a more technical perspective. In terms of image understanding and perception, Furmanski et al. (2002) argued that several issues also need to be considered: managing and controlling the quantity of extra-sensory information displayed, integrating multimodal cues (haptic and auditory sensations) from obscured locations, and interacting with information across multiple depth planes (Furmanski, Azuma, & Daily, 2002). The researchers further put forward a set of principles for visualizing occluded objects in AR applications (see Table 3) based on knowledge from perceptual psychology and cognitive science (Furmanski et al., 2002).

Table 3. Augmented Reality visualization guided by cognition from (Furmanski et al., 2002)

Category	Sub-category	Objective	Techniques
Image Processing	Image Enhancement	To manipulate image qualities (e.g. contrast, brightness, transparency to improve object's visibility.	Histogram equalization Homomorphic Filtering Three-dimensional sensors (e.g., CT and MRI(Megnetic resonance imaging)) Physics-based quantitative models (e.g., mammography) High pass filtering (e.g., highlighting portions of images)
	Image Understanding	To recognize structures and features with the aim of automatically describing the contents of an image.	Visual saliency Segmentation, ground, and perceptual grouping
Visual Perception	Depth-dependent Perceptual Cues		Transparency Occlusion Size-scaling gradients & texture Shading gradients Cross-referenced depth
	Perceptual Motion Binocular Cues		Motion parallax Structure-from-motion (SEM) Stereopsis

2.7.5.3 Mobile AR Augmentation - Perceptual Issues in mobile AR Interface

From a technical perspective, perceptual issues can be subdivided into five groups: environment, capturing, augmentation, display device, and users (Kruijff et al., 2010). Specifically, *environment* issues relate to the structure, colors and natural conditions (e.g., lighting) of the environment that impacts the way the augmentation is perceived (Gabbard et al., 2002; Gabbard, Swan, Zedlitz, & Winchester, 2010; Sandor et al., 2010). *Capturing* issues are associated with the process of converting an optical image to a digital signal by a camera, taking into account issues like image resolution, filtering, lens, exposure, color correctness and contrast, and capture frame-rate (Klein & Murray, 2008; Thropp & Chen, 2006). *Augmentation* refers to the registration of digital content over video imagery. Problems include registration accuracy, occlusion, overlapping and layout, rendering and resolution mismatch (Elmqvist, Assarsson, & Tsigas, 2007; Kalkofen, Mendez, & Schmalstieg, 2007; Tsuda, Yamamoto, & Kameda, 2006). Finally, technical issues associated with mobile *display devices* are field of view (FOV), viewing angle offset, display properties (e.g., display brightness, contrast, and resolution), color fidelity, reflection, and latency (Kruijff et al., 2010; Livingston, Barrow, & Sibley, 2009; Thropp & Chen, 2006). Studies on the perceptual capabilities of *users* involve individual differences (e.g., on visual acuity, color vision capabilities and spatial abilities), depth cues (e.g., pictorial, kinetic, physiological, binocular depth cues), and disparity planes (i.e., the depth disparity at which the augmentation exist and the real world is in) (Drascic & Milgram, 1996; Kruijff et al., 2010; Linn & Petersen, 1985).

2.7.5.4 Combining mobile AR with Other Embedded Interfaces in mobile AR Navigation Research

The interface of a mobile AR navigation system does not only contain mobile AR annotations as discussed in the previous section; it also typically utilizes and combines annotated instructions (e.g., textual instructions), a portion of a map, and illustrating guiding symbols (Pyssysalo et al., 2000). Textual illustrations can be a list of street names to follow and indications of which way to turn at an intersection. A part of the map in which the user currently find him/herself can also be used to show the path. The map is usually rotated so that current heading is up and the path is marked or painted on the map. In addition to map instructions, guiding symbols (e.g., arrows or footprints) are placed in each corner of the path to show users which way to walk (Pyssysalo et al., 2000).

Not uncommonly, multimedia (e.g., images, 3D objects, video) are also used as means to present augmented information in mobile AR navigation systems (Reitmayr & Schmalstieg, 2004a). More recently, panorama imaging, which shows the topology of surroundings previously taken at decision point location, is also used as a navigation aid (Walther-Franks & Malaka, 2008).

Table 4 summarizes a variety of annotation means to supplement mobile AR views found in both indoor and outdoor navigation systems. These different types of annotations can be viewed as parts of mobile AR systems because they are part of mobile AR views presented to the user through a Smartphone’s camera view.

Table 4. Types of mobile AR augmentations to support navigation activities

Other Means	Representative mobile AR Research in Navigation
Maps	mobile AR browsers usually have a menu option for accessing a map view. Maps represent a very efficient means for communication, analysis, synthesis and geographic data exploration of larger geographic information; this contrasts with mobile AR views that present data and information in a limited range. They are good ways to provide both insight and overview of spatial patterns, relationships and trends (van Elzakker, 2004). For example, Signpost provides a semitransparent map overlay that can be superimposed on mobile AR view on request (Wagner & Schmalstieg, 2003). MARA integrated a map view that is centered and oriented according to the manner that users hold the phone: when the phone lies flat, the map view is shown; when the phone is tilted upwards, the mobile AR view is visible (Schmeil & Broll, 2006).
World-in-Miniature (MIM)	World-in-Miniature (MIM) extends the 2D map to the 3D miniaturized version of the surrounding environment (Stoakley, Conway, & Pausch, 1995). MIM, a miniature bird's eye view of the environment, is used to combine with mobile AR to support situation awareness by immersing the user in the environment (Bell, Hollerer, & Feiner, 2002). Bell used head movement to control the interaction of the MIM view—tilting the head down emphasizes the MIM view, while tilting it up minimizes it; looking slightly downwards shows a bird's eye view while looking strait downwards provides a top-down view. In the MIM view, the user's position is also marked. mobile AR view and MIM view are connected together by means of sharing labels and interaction with objects by two views (Bell et al., 2002). A similar approach has been adopted using mobile AR and x-ray vision to explore the rooms of a nearby building. Once a user identifies a room of interest, the MIM view of that room is triggered, providing an exocentric view of the selected room (Bane & Hollerer, 2004). Extending this concept, Reitmayr and Schmalstieg (2003) presented a system whereby users not only can access the WIM view, but can also select the MIM view of the interested location for navigation.
Distorted camera views	By modifying the field of view of the camera, users can maintain an egocentric view of the environment, in contrast with using a map view to gain an exocentric overview (Grasset et al., 2011). Examples include a 3D virtual model that was used to distort the regular camera view to a much larger field of view (FOV) (Sandor et al., 2010), and a recent work used online-generated panorama approach to generate such view (Mulloni, Danser, & Schmalstieg, 2010).
Web browser	Some mobile AR browsers use this approach by providing a hyperlink on the mobile AR view to open web pages (e.g., a textual description) for more details (Grasset et al., 2011). For instance, an early work—The Touring Machine—enabled users to click on

	hyperlinks for further detailed information about the physical objects in a web page on the handheld device (Feiner et al., 1997; Hollerer, Feiner, Terauchi, et al., 1999).
Multiple spaces	One study shows that the combined use of egocentric and exocentric views in navigation can increase one's awareness of a location (Grasset, Lamb, & Billinghurst, 2005). To extend on this, two general types of interfaces are identified combining these different views together: spatial and temporal methods (Grasset et al., 2011). The spatial method is used to show more viewpoints from the user's view; while the temporal method is used to provide a mechanism to switch successively between different viewpoints.
Multi-modality interface	In addition to visual information, other modalities have potential in mobile AR navigation interfaces, such as audio or haptic navigation guidance, and animated guides using body gestures to direct tourist (Schmalstieg et al., 2007). One study has shown that in mixed-space collaborative navigation, visual guidance-based collaborative navigation (e.g., the representation of a hand-based gesture) is more efficient than audio cues in indicating directions for mobile users (Stafford, Thomas, & Piekarski, 2009). Therefore, further empirical studies on the effectiveness of these modalities in the context of mobile AR navigation need to be conducted.

CHAPTER 3 METHODS

3.1 Overview of Study 1 and Study 2

As can be seen in Figure 1, this research consisted of two studies, which are described below:

Study 1: Situation Awareness Theory Refinement (SA Requirements Analysis)

Study 2: Theory Application and Validation (Interface Evaluation)

Overall, a mixed-methods approach was used (Creswell, 2009; Crotty, 1998; Patton, 2002) to extend current SA theories (Endsley, 1988, 1993, 1995b; Endsley & Garland, 2000), and subsequently validate the application of an extended theory in a reality-augmented environment (both physical and digitized environments). This research was situated within the context of exploring an unfamiliar urban context. First, a qualitative methodology was utilized to conceptualize, investigate, and interpret the processes that users employ in developing situation awareness, as well as the associated requirements for achieving SA. Second, a quantitative in-lab experiment was conducted to validate the findings.

Study 1: The first study was designed to achieve two goals: 1) to explore and identify the processes that users employ to develop situation awareness; and 2) to explore and generate themes about mobile AR users' awareness requirements in an outdoor urban environment. Inquiry methods were used including observation, concurrent think-aloud sessions, and face-to-face semi-structured interviews to elicit the process that users employ to develop situation awareness in the context of mobile augmented, reality-enabled, urban exploratory navigation. Content analysis was used to elucidate the process of situation awareness development, and analyze and classify situation awareness requirements. Subsequently, user tasks in this context were identified, after which corresponding situation awareness task queries were generated for use in measuring SA during Study 2.

Based on study findings, the SA theory was extended and refined based on observed phenomenon—and in particular how the theory can be applied to the domain of reality-augmented environment in the task of exploring an unfamiliar urban context. A preliminary cognitive model in the context of mobile AR-enabled urban navigation was generated.

Interface design and development: In order to evaluate the application of this extended prototypical SA theory, SA-supported design implications for a mobile AR guidance application were derived from the findings obtained from Study 1. Specifically, users' SA requirements were transformed into a set of high-level system requirements, and subsequently into detailed design solutions. A mixed fidelity prototype was generated to demonstrate the conceptual design of the SA-supported mobile AR guidance application. Qualitative SA requirements data were then collected and analyzed. Section 3.2 discusses Study 1 in detail; further details of the design process are provided in Section 4.2.

Study 2: Two design aspects were empirically evaluated in a goal-based formative evaluation to examine if a user's situation awareness was supported by the SA-supported interface. For this purpose, the interface of a mobile AR application employed during the previous requirements-elicitation study was compared against a baseline interface with the same level of interaction as the developed conceptual design interface. SA and usability data were collected and analyzed. Section 3.3 further explains the experimental design and associated variables. The development and implementation of Study 2 was guided by the following research question:

RQ3: What are the differences between the proposed situation awareness-supported mobile AR guidance interface and a currently available interface in terms of a) the user's situation awareness b) the user's perceived usability in urban exploratory navigation?

3.2 Study 1: Situation Awareness Theory Refinement (SA Requirements Analysis)

3.2.1 Research Design

3.2.1.1 Process Identification

As noted in Chapter 2, there is a lack of available literature on the types of tasks that are possible in exploratory navigation in a mobile AR-enabled environment. Therefore, prior to identifying the process of SA development, the tasks that users perform in the context of urban exploratory navigation were identified, which we based on users' natural behaviors and their verbalized recall of experiences using mobile AR guidance systems. Specific tasks were identified under exploratory navigation. Exploratory navigation tasks were further categorized according to whether they were goal-directed exploration or exploratory browsing—although it should be noted that there wasn't always a clear-cut boundary between the two. Such a distinction depends on the level of specificity of goals that users form in a real context, which can range from vague goals (e.g., "I want to find something to do.") to specific goals ("What exhibits are currently running at the Guggenheim?")

To extend and refine the implications of situation awareness theory in the context of mobile AR-enabled urban exploratory navigation, the process by which an individual typically develops SA (i.e., according to SA theory) was identified. Namely, situation awareness begins by perceiving elements in the environment (L1 Perception), followed by comprehending their meaning (L2 Comprehension), and then ultimately being able to use that information to project the state of the environment in the near future (L3 Projection).

Level 1 encompasses the perception of characteristics and attributes of individual elements of interest. . Level 2 consists of recognizing their properties and making connections or forming patterns among these elements. Level 3 involves making a projection of the state of the task-at-hand and the present environment in the near future to aid subsequent decision-making processes. Noted that the SA development process might not involve all three processes.

3.2.1.2 SA Requirements Elicitation

The purpose of conducting an SA requirements analysis was to determine the specific elements required for SA in mobile AR navigation in an urban context. According to Endsley (1993), an SA requirements analysis should be conducted to determine what actually makes up a user's situation awareness in a specific context or environment under analysis. Due to the fact that SA is domain-specific and the characteristics of a given domain vary greatly, SA requirements have to be elicited, and measurements have to be established in each applied domain (Endsley, 1993, 2000; Endsley & Garland, 2000; Endsley & Rodgers, 1994; Li et al., 2012; Ma & Kaber, 2007; Pielot et al., 2010; Smets et al., 2011a; Smets, te Brake, Buurman, Neerincx, & van Oostendorp, 2011b; Stanton, 2005). To accomplish this task, SA queries were developed from a requirements analysis and used to assess SA. Because SA requirements analysis were used to determine which facets of users' SA were to be measured, the validity of the SA measurement technique can be ensured (Stanton, 2005). In general, these task elements tend to have few covert actions and a high cognitive content, so they are not immediately observable—meaning that it can be difficult to elicit and check that the analysis has been thorough. To overcome such difficulties in the elicitation of situation awareness information during exploratory navigation, a systematic approach was adopted and a battery of methods was applied to obtain the required information.

3.2.1.3 Fieldwork Observation

In line with Endsley's (1993) analytical procedures for determining SA requirements, Study 1 consisted of observations of participants conducting exploratory navigation tasks within a mobile AR-enabled urban context, following by semi-structured interviews. The process has been widely used in SA research in many domains (Endsley et al., 2003; Endsley, 1993; Endsley & Rodgers, 1994; Stanton, 2005), and modified for this study. An overview of the observation process is provided in Table 5.

Table 5. Stages of observation

	Stages of the observation	Description
1	Thematizing	The main purposes of the observation were the following: 1) to observe the current user experience of using mobile AR guidance system; 2) to identify processes that participants employ to develop situation awareness under such context; 3) to elicit situation awareness requirements for each task; and 4) to develop goal-directed hierarchical task analyses.
2	Designing	Participants: 6, aged 18-49, The site: Christiansburg, Virginia
3	Observation	Out-field observation lasted approximately 1 hour. A concurrent think-aloud approach was used.
4	Transcribing	All individual verbal protocols were transcribed.
5	Analyzing	The interviews were analyzed using content analysis methods.
6	Verifying	Reliability and validity checks were attempted throughout the study, including a systematic way to conduct observation (e.g., establishing audit trial), running pilot study, intra-coder reliability check.
7	Reporting	The results were analyzed and reported in the results section.

A total of 6 participants aged 18-49 were recruited from the university using a purposeful sampling method, namely criterion sampling. Prospective participants were required to 1) have owned and used a Smartphone for at least six months; 2) have previously used mobile AR guidance applications, and 3) consider technology as necessary in their daily lives (see Appendix B for the recruitment flyer). Further details can be found in Section 3.2.2.

The observation session was carried out in the downtown area of Christiansburg, Virginia. The first step in an SA requirements analysis was to clearly define the tasks under analysis in order to ensure the elicitation of relevant SA requirements. Specific questions and Google Street Views were provided to participants as the query tasks they would undertake using mobile augmented reality. An existing mobile AR guidance application served as a concrete physical representation of a mobile AR technology, thereby elucidating some of its functional, aesthetic and interactional characteristics. This “concreteness” facilitated a user’s understanding of abstract and unfamiliar technological concepts (Anastassova, Megard, & Burkhardt, 2007). This was thought to be essential to the research, since the more radical an innovation, the harder it would be for a user to understand what it should look like and how it should be used (Leonard & Rayport, 1997). In other words, when a user can barely imagine what it might be possible to do with a new technology, he/she is not likely to express specific needs. These unexpressed needs are called “undreamed of requirements” (Robertson, 2001). However, we also note that designing to support a user’s SA almost inevitably must go beyond the confines of this or any particular mobile AR application itself, its technical characteristics, and logical structure. The observation session lasted approximately 1 hour. It was video-recorded and audio-recorded (see Appendix E for the script). Detailed procedure is described in Section 3.2.5.

3.2.1.4 Ethnographic Methods in HCI

Observation is one of techniques of ethnography, which as a research methodology comprises a series of techniques (e.g., observation and interviews). These techniques have shown to be effective in eliciting user requirements for products, services, and systems development (Prabhala, Loi, & Ganapathy, 2011). In a lab setting, experimental design often treats context either as a set of interfering or confounding variables that need to be controlled for, or as a factor to be manipulated by other control variables that are experimentally contrived in order to identify cause-and-effect relationships. By contrast, as a qualitative research methodology, ethnographic observation focuses on understanding the context of individuals, their processes and practices (Harvey & Myers, 1995; Lazar, Feng, & Hochheiser, 2009), making it more beneficial to a systems philosophy. This method is well suited to providing researchers with “thick descriptions” (Geertz, 1973) and rich insights into the human, social and organizational aspects of system development and application (Harvey & Myers, 1995). Because it deals with actual practices in real-world situations, ethnographic observation allows for relevant issues to be explored and an appropriate framework to be established (Harvey & Myers, 1995).

Historically, ethnography emerged in the early 1940s with the development of cultural anthropology (Angrosino et al., 2008; Geertz, 1973; Lazar et al., 2009; Patton, 2002). Since that time, however, ethnography has been evolving (Patton, 2002). For example, early ground-breaking work was conducted by Suchman (1987) and Zuboff (1988), resulting in ethnography being more widely used in the study of information-related systems (Harvey & Myers, 1995; Hughes, Randall, & Shapiro, 1992; Suchman, 1987; Zuboff, 1988). The notion and practice of ethnography differs according to discipline (Prabhala et al., 2011). As a variation, “applied ethnography” has emerged as a way to understand social problems in modern society (e.g., technological diffusion, the gap between rich and poor), problems of industrial democracies in organizational and educational studies, or to serve as a program evaluation tool in applied educational research (Chambers, 2000).

More recently, in the field of HCI, ethnographic methods have been widely used across a variety of settings (e.g., home, work, educational, mobile) to address two main purposes. First, HCI researchers are using ethnographic approaches to gain a more detailed and nuanced understanding of how users interact with computer-based technologies, which often cannot be provided via other methods (Lazar et al., 2009). Ethnographic observation attends to actual user experiences in real-world situation. In simple terms, the goal is “understanding” how is technology used. How do design features influence people’s use of the system? What is the user experience of using a certain technology? Additionally, it addresses many of the concerns about the validity of empirical findings (although the presence of an observer may also influence people’s behavior) (Rosson & Carroll, 2002). The usefulness of applying exploratory ethnographic methods has been discussed in research designed to understand Chinese users’ experiences with online games (Wang & Mainwaring, 2008). Similarly, it has been used to explore a driver’s interactions with the environment using in-car GPS navigational systems (Leshed et al., 2008). Second, an ethnographic approach is particularly useful for designing new technology to be used in the field (Gaver, Boucher, Pennington, & Walker, 2004). Knowledge of what actually happens in the field can provide critical information to challenge and explore some of the assumptions gained from a mainly experimental or theoretical-based body of knowledge. For example, Hughes et al. (1992) showed how their ethnographic studies led them to question some widely accepted assumptions about systems design. They found that the information provided through an ethnographic approach revealed a deeper understanding of the problem domain, and that conventional principles previously thought as a “good design” were in fact inappropriate and needed a re-design.

However, several researchers have noted the limitations involved with using observations in general as a tool for data collection. For example, DeWalt noted that observation is conducted by a biased human who serves as the instrument for data collection; thereby the researcher must understand how his/her gender, sexuality, etc. may affect observation, analysis, and interpretation (DeWalt & DeWalt, 2010).

3.2.1.5 Concurrent Think-aloud Method

As stated previously, the outcome of SA development is a mental process that does not readily emerge in observable actions, thus making easy identification difficult. To address this challenge, the Concurrent Think Aloud (CTA) method was used during the observation study, which requires people to think aloud while they are performing a task. Verbal protocols (i.e. verbal reports) that emerge from the Think Aloud method essentially help to map out the mental processes people use during a task to help researchers identify cognitive elements—either while people are doing the task (“on line” concurrent approach called CTA), or after the task (“off line” retrospective approach called Retrospective Think Aloud, aka RTA) (Ericsson & Simon, 1980, 1984). CTA tends to provide more insight into the decision-making process since it affords more procedural information as it occurs; in contrast, RTA provides more explanation and retrospective information about the final choice (Kuusela & Paul, 2000).

Traditionally, the Think Aloud method was used to study cognitive processes in psychology (Anderson, 1987); however, it has now become a valuable research method in many applied non-psychology disciplines, including HCI (Boren & Ramey, 2000; Denning, Hoiem, Simpson, & Sullivan, 1990). Specifically, the CTA method is generally recognized as a major source of data on subjects' cognitive processes. For example, Ericsson and Simon (1984) found no reliable evidence that thought processes changed when participants were instructed to think aloud concurrently. Studies also found no significant difference in performance between CTA and silence (Dianne & Donald, 1990). It should be noted that there are some factors that might compromise the validity of concurrent verbal protocols, such as giving a verbal protocol itself, giving it under time constraints, influences by social biases, information given being non-verbal (e.g., visual information, automatic or perceptual-motor skills) (Ericsson & Simon, 1980, 1984). However, in spite of these factors, many studies in psychology have shown that this method can produce valid and reliable data (Ericsson & Simon, 1980, 1984).

In this study, the CTA method was used during observation, which required participants to continuously verbalize why they were doing what they were doing (i.e., thinking and reasoning). In addition, during the course of observation, participants were prompted to provide verbal protocols if they were not verbalizing or were not focusing on a certain aspect of the task. The concurrent probing approach was used to elicit valuable information when it was still in their short-term memory (Ericsson & Simon, 1980, 1984).

3.2.1.6 Semi-structured Interviews

Interviews are one of the commonly-used methods in HCI to ascertain user needs (Lazar et al., 2009). Taylor and Bogdan (1998) defined interviews as "face-to-face encounters between the researcher and the informants directed toward understanding the informants' perspectives on their lives, experiences, or situations as expressed in their own words" (p. 88). After observations were concluded, semi-structured interviews were conducted with the same six participants who took part in the observation study. The interviews lasted approximately one hour and were carried out in the Assessment and Cognitive Ergonomics lab, 530 Whittemore Hall. Detailed procedures can be found in Section 3.2.5. Table 6 provides a schematic overview of the seven-stage interview inquiry approach that was used in this study (Kvale & Brinkmann, 2008).

Table 6. Overview of stages of interview

	Stages of the interview	Description
1	Thematizing	The main purposes of the semi-structured interview are the following: 1) to identify and describe tasks of urban navigation in the mobile AR-enabled environment; 2) to understand the process of SA development in mobile AR-enabled navigation; 3) to elicit SA information requirements of users in the task of mobile AR-enabled urban navigation; 4) to triangulate results obtained from observation phase, thereby increasing validity, which is known as *data source triangulation* (Lazar et al., 2009; Patton, 2002; Stake, 1995); and 5) to develop goal-directed task analysis for user's goals in such context (see Appendix F for the script).
2	Designing	Participants: the same six participants Interviews were conducted in the lab. The script of interview questions was designed based on research questions (see Appendix F)
3	Interviewing	A detailed script was used for the individual interview, each of which lasted approximately one hour.
4	Transcribing	All individual interviews were transcribed verbatim.
5	Analyzing	The interviews were analyzed using content analysis methods.
6	Verifying	Reliability and validity checks were attempted throughout the study, including a systematic way to design interview questions, running pilot study, intra-coder reliability check.
7	Reporting	The results were analyzed and reported in the results section.

The interview included background questions, an audit of past experiences and knowledge in terms of exploratory navigation of unfamiliar places, decision-making processes with or without mobile AR guidance application, general usage of mobile AR guidance application, and task simulation of four task scenarios with different goal levels in exploratory navigation (see Appendix F for the script). Past experiences and the knowledge audit identified ways in which the process of situation awareness is developed in mobile AR-enabled urban exploratory navigation and provides examples based on actual experience. The knowledge audit draws directly from a specific method, namely Applied Cognitive Task Analysis (ACTA) (Laura, 1998), to elicit cognitive processes that associated with task execution in mobile AR-enabled urban exploratory navigation. The knowledge audit involved a series of probes designed to describe knowledge related to mobile AR-enabled urban exploratory navigation tasks and designed to elicit appropriate examples.

The scenario simulation allowed the researcher to better understand users' cognitive processes within the context of a challenging task scenario. The simulation interview was based on presentation of a task scenario to the user. Participants were asked to elaborate on what they were thinking as they experienced a simulation in a task scenario. During the interview, participants were encouraged to talk as freely as possible about what they felt where the most relevant and important information needs in mobile AR-enabled exploratory navigation. Probes (i.e. prompts) were used when necessary to deepen the response to a question, increase the richness and depth of responses, and encourage participants to provide more details or to expand on issues (Patton, 2002). Additional questions were used to clarify the themes that emerged during the interviews.

As suggested by Endsley (1993), to ensure thoroughness, the researcher mentioned topics of potential interest during the interview if the participants had not covered them. Additionally, at the end of the interview each participant was also asked if there was anything else that he/she wished to discuss. Notes were taken during each interview, after which the researcher wrote brief notes under each of the pre-determined research objectives and research questions to record the main points raised in the interview. This technique is designed to improve the accuracy of analyzing recorded interviews, even when verbatim transcription is also employed (Rallis & Rossman, 2011; Wengraf, 2001).

3.2.2 Participants

A total number of 6 participants aged 18-49 were recruited from the university using a type of purposeful sampling known as the criterion sampling method (Patton, 2002). The point of criterion sampling is to study and understand specific cases that meet some predetermined criterion of interest (Patton, 2002).

In order to identify potential participants, recruitment flyers and emails were sent to a likely group of participants via the university's email list serve. In order to take part in this study, participants had to meet the following criteria: 1) have owned a Smartphone and used it for at least six months, 2) have installed any mobile AR guidance applications on said device, and 3) considered technology as necessary to their daily lives. Those who replied to the solicitation were screened using a screener. These criteria were considered essential to ensure that anyone who took part in this study had a good concept of a mobile AR's technological feasibility. For instance, the rationale for excluding someone without any Smartphone experience was that he/she might be distracted by the novelty of the device and its usage (e.g., direct manipulation by touching the screen or via verbal commands), as well as the sophistication of its functionality (e.g., enabled by various mobile applications) compared to an earlier-generation cell phone. In addition, studies show that there tends to be a gap between users aged 18-49 and those aged 50-65 in mobile usage for a number of functions (e.g., mobile Internet usage compared to other functions, email, banking, etc.) (Westlund & Bohlin, 2008). Since there was no prior research reporting age differences in handheld or any mobile AR usage, we adopted these general mobile usage patterns and only recruited people aged 18-49 to reduce unwanted variations that otherwise might have been introduced by including older participants.

In qualitative inquiry, there are no hard and fast rules for sample size. Decisions about sample size and sample strategies completely depend on the purpose of the inquiry, what will be useful, what will have credibility, and what can be done with available time and resources (Patton, 2002).

Eventually, a total of six participants aged 18-49 were recruited from the university using a type of purposeful sampling known as criterion sampling (Patton, 2002). The point of criterion sampling is to study and understand specific cases that meet some predetermined criterion of interest (Patton, 2002). A screener and background information collection form is provided in Appendix D. In terms of general experience using a mobile AR guidance application, both novices and expert or “power” users (i.e., people with mobile AR-related knowledge such as computer science students specializing in mobile AR research) were recruited for this study (Tullis & Albert, 2008). In contrast, “novices” are people who have used mobile AR guidance applications on a Smartphone before, but without extensive experience. The reason to include both groups was that no prior research has indicated that prior experience or skill level using mobile AR technology has impacted performance or cognitive ability or skill level. A breakdown of participant characteristics (Table 7) shows that with respect to usage behavior and attitude recruited participants included 1 technically savvy individual, 3 frequent users who used the mobile AR whenever they needed guidance, 1 infrequent critical user, and 1 infrequent but promising user.

Due to the fact that widely-accessible mobile AR guidance applications are still at their infancy (or perhaps “toddlerhood”) in terms of technology and user acceptance, the reasons that participants first started using mobile AR guidance applications are also documented (see Results Section).

Table 7. Background of participants in Study 1

Participant no.	Type	Background description	Attitude towards mobile AR guidance application
2	Technically savvy individual	Majored in computer science and keeps following updates on mobile AR technology and related applications.	Currently considers mobile AR technology to be relatively new, but has great potential.
3, 4, 6	Users employing it whenever they need guidance		Using mobile AR guidance application in new or unfamiliar places to know more about their surroundings and guide their decisions on POIs.
1	Critical user		"It's too soon." "Not ready yet." Using mobile AR guidance application in new or unfamiliar places.
5	Not frequent but promising user	One would like to use the mobile AR application more often than they do now.	"Mobile AR hasn't gone to the point where I am completely sold."

3.2.3 Equipment

3.2.3.1 Video Recorder

One Point-Of-View (POV) 1.5 head-mounted video recorder was used during the observations. Each participant wore the POV device by attaching the camera head to a cap (see Figure 9). This camera captured the view from the participant's point-of-view on the physical or digital elements that they gazed upon. The POV 1.5 video recording system is a high-quality (720 x 480 resolution at 30fps), hands-free wearable video recorder that is convenient and easy-to-carry. The avoidance of using a handheld video recorder facilitated note taking, eliminated the need for a videographer, and reduced unwanted, third person "observer effects."

Although the camera recorder was able to record verbal protocols, an audio recorder was used as a secondary source of information. The audio recorder was held by the researcher to capture the verbal protocol (e.g., think aloud) and responses to the post-observation interview questions. Written permission was obtained in advance for both video and audio recordings.

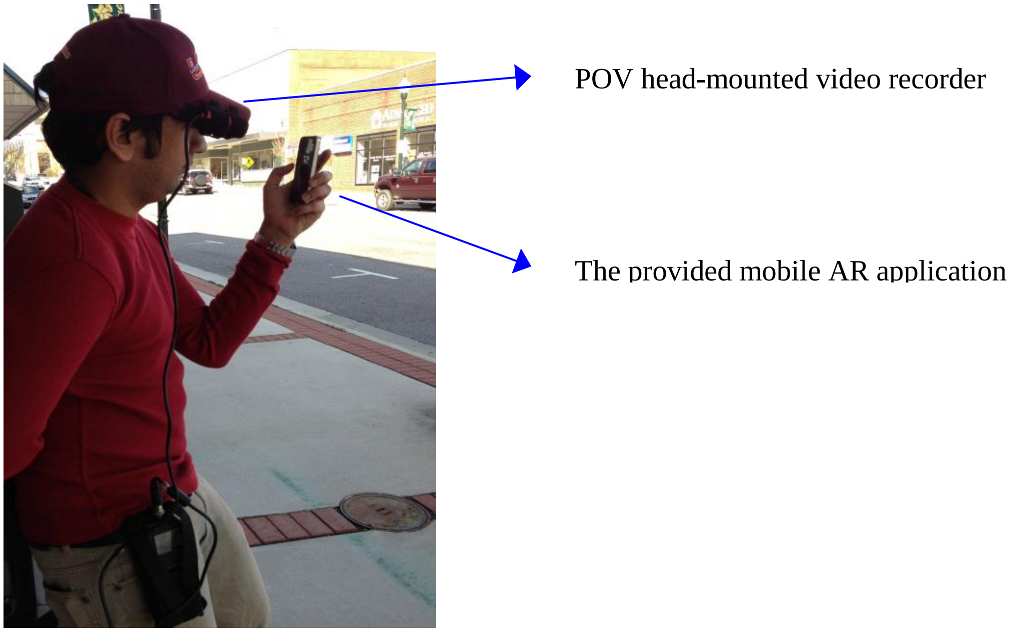

Figure 9. Equipment used in outfield observation

3.2.3.2 Artifacts

Artifacts are often used in the domain of HCI to elicit user needs to provoke responses from end users(Lazar et al., 2009). This study utilized Google Street view and Wikitude mobile AR guidance application as artifacts.

Google Street View

In this study, in order to “situate” users in a metropolitan context and generate important data, four views with different geographical information provided by Google Street View[28] (GSV) on the Smartphone

[28] Google Street View is a technology that provides panoramic views from positions along many streets in the world. It was launched in 2007 and its coverage areas have been 48 countries, dependencies, and autonomous regions. This service can be accessed by anyone anywhere at http://www.google.com/help/maps/streetview/learn/using-street-view.html. It enables users to view and navigate through 360 degree horizontal and 290 degree vertical panoramic street level images of various cities around the world. The Street View feature can be used to take virtual walks, explore landmarks or find shops, restaurants and hotels. Google is not allowed Google Street View to be used in print or video. No screenshots will be printed. Google Maps content rules and guidelines can be accessed at: http://support.google.com/maps/bin/static.py?hl=en&ts=1342531&page=ts.cs

were utilized, which showed the participant certain street-level views. This screen view can orient according to a user's physical rotation, which is considered similar to the environment one could be using with a mobile AR application. Recent research has indicated that navigation using this type of street-level view is visually similar to the navigation experience on foot; in other words, the user can "walk" along the street, look around, and find locations of interest in a given urban settings (Kopf, Chen, Szeliski, & Cohen, 2010). By using GSV as a study tool, an essential level of reliable urban street context was provided to participants to facilitate the elicitation. In short, each participant was able to "move" forward, backward, to the left, and to the right to navigate his or her surroundings in GSV.

Different activated Google Street Views were provided to each participant on a Smartphone to identify user tasks in different urban contexts. The criteria for selecting street views included the following factors: (1) each view should have *path(s)* and *note(s)*, or (2) each view should have one *visual landmark* (i.e., a visually distinctive object), or (3) a *cognitive landmark* (i.e., a culturally or historically important object), or (4) a *structural landmark* (i.e., an object playing an important role e.g., a bank). Two additional factors were considered: familiarity with the environment (foreign vs. US), and the density of the urban environment (crowded metropolitan area vs. less crowded/less busy area). Upon consideration of these criteria and factors, street views were selected. Prior to turning over the GSV-enabled Smartphone to each participant, agreements from two independent graduate students were obtained to check the validity of matches.

<u>Wiktude Mobile AR Guidance Application</u>

An existing mobile AR guidance application, Wikitude[29], was used in this study. Wikitude can show a mobile user a desired location with information on nearby POIs (e.g., nearest coffee house). It also enables the user to access photographs (from Flickr and Panaromia), activities and events (through Becks Gig Finder and Stella Bar finder), Google, Yelp, Wikipedia, Twitter, share locations with friends, and provides other information. Similar to other mobile AR guidance applications, when users activate it they can select a channel of interest and see virtual labels superimposed over the real world through their camera view. Users can select from one of the following views: a mobile AR view, a list view of POIs, or a map view where POIs are shown on a map (e.g., Google map).

3.2.4 The Site for Outfield Observation

The site for outfield observations was a street in downtown Christiansburg, Virginia, which is located in Montgomery County in the southwestern part of the state. In 2011, the population was estimated to be

[29] Wikitude won the "Best Augmented Reality Browser" for 2012 (Dan, 2012).

21,030 with a population density of 1,463 persons per square mile (United States Census Bureau, (2011). Following the criteria described by United Nations (UN), Christiansburg is considered to be an urban area. This site was selected since it was sufficiently far from the university area—a site well known to participants, which might have negatively impacted their task performance of exploratory navigation—but still reachable and convenient for the researcher and participants to do the study.

According to the United Nations Demographic Yearbook (United Nations [UN], 2010), the definition of an urban area is based on criteria that include the following variables: population size, population density, distance between built-up areas, predominant type of economic activity, conformity to legal or administrative status, and urban characteristics such as specific services and facilities. No international standard definition exists because the meaning varies based on location. In the U.S., the term "urban" is defined as an area with 2,500 or more inhabitants, and with a population density of 100+ persons per square mile. Two types of urban areas are included: urbanized areas of 50,000 or more inhabitants and urban clusters of at least 2,500 but less than 50000 inhabitants (UN, 2010). These figures, therefore, place Christiansburg in the "urban" category. It must be stressed that there are a number of environmental factors that inevitably influence a study of this nature. First, there are regional/locational differences that will alter how navigation works, and thus influence a user's situation awareness. For example, navigation will be more challenging in a busy metropolitan area in comparison to a smaller urban location. To mitigate the influence of regional and physical place differences, during the follow-up interview session we utilized a metropolitan city intersection (i.e., busier and more crowded than the Christiansburg location) to "situate" participants and solicit their SA requirements. Second, the level of one's familiarity with a place (ranging from totally unfamiliar to very familiar) might affect a user's awareness. Thus, background data was collected on the degree of familiarity that a participant had about the Christiansburg location. For example, the screener asked the question shown in Figure 14 to ascertain the person's familiarity with Christiansburg. Participants who answered "daily, weekly, or monthly" were excluded from this study.

How often do you go to downtown Christiansburg?

Daily Weekly Monthly Once in 2 or 3 months Twice in a year
yearly

Figure 10. An example question regarding familiarity in screener

Although some level of familiarity with a place tends to be inevitable, it is unlikely that a person would know every item or route segment shown on the screen—even if that person was highly familiar with the space. In other words, even for a “local expert” user who has primarily learned the space either through direct navigation or experience (or both), key familiar points will mainly be landmarks—not necessarily the areas that lie between them (Haklay, 2010).

3.2.5 Procedures

3.2.5.1 Observation Procedures

Recruitment of participants: Recruiting flyers and emails (including the screener) were sent to participants via university mail list service. Individuals who expressed an interest in taking part in this study were screened based on the demographic information they provided through the background questionnaire. A screener and background information collection form is provided in Appendix D . Those who met the screening criteria were introduced to the purpose of the study and informed that they would have to take part in two sessions: an observation session and an interview session.

Pilot study: Prior to the actual field study, two pilot studies were conducted to resolve any problems with data collection procedures. This enabled participants who took part in the pilot study to ask questions and offer feedback. Task scenarios were refined based on their suggestions from the “task identification” session. The data from pilot study were not factored into data analysis. Protocols are included in Appendix E .

Out-field observation: Participants were taken individually to the observation site in downtown Christiansburg, Virginia. Upon arriving, the participants were briefed again on the purpose of the research via an IRB approved informed consent form (see Appendix A for the IRB approval and for Appendix C consent form). They were then instructed on observation protocols—such as how to “think aloud” during the session. To familiarize participants with the concurrent “think aloud” activity, they were given three minutes practice time. Each participant was then asked to wear a baseball hat attached with the head-mounted camera described previously.

<u>Introduction:</u> During this introduction session, the participant was asked to relate some of his (male pronoun used for simplification) prior experiences with exploratory navigation activities in an urban context—i.e., what he did or used (e.g., using digital maps), what he did with the mobile AR, and what information he might have needed to use a mobile AR.

<u>Task identification:</u> The participant was asked to bring his own smartphone equipped with a mobile AR application, and then asked to describe an experience in memory where a mobile AR guidance application was used and what it was used for. Then the participant was asked to show what he did on that prior

occasion, and what other tasks he might have wanted to do at that moment. This helped to identify the most natural task scenario for which the user would like to use a mobile AR guidance application.

Due to the constrains of field characters, in order to identify a user's task scenarios as fully as possible in different urban contexts, different activated Google Street Views on the Smartphone were provided for a participant's interaction. The selection of street views was detailed in the artifact section. For each street view, the participant was asked to describe the tasks that he would like to use a mobile AR guidance application in urban exploratory navigation.

The participant was then asked to address the task flow, which was intended to elicit a broad overview of the task and identify the difficult cognitive elements (Laura & Hutton, 1998). Although this preliminary interview only provided a surface-level view of the cognitive elements of the tasks in urban exploratory navigation, it enabled the researcher to focus on more in-depth questions—for example, "Think about what you do when you do exploratory navigation on street in a city or a town. Can you break this down into less than six, but more than three steps?" The goal was to get users to perform a mental walk-through in their minds, verbalizing major steps in not more than six steps to ensure that they did not delve into minute details during the preliminary interview.

<u>Performing task scenarios:</u> In the second session, the participant was asked to use a mobile AR guidance application (described in Artifact session) on the provided smartphone to conduct these task scenarios. Eight task scenarios were given. If the specific mobile AR application lacked certain features to support the task, the participant was asked to describe his expectations. This step was included because sometimes users are unaware of their needs until they see and use a specific type of technological device.

<u>Performing conception tasks:</u> At this point, the participant was asked to hold the provided Smartphone with an active built-in camera and was required to view surroundings through the active camera view. During this process, the participant was asked to imagine that if he had a "magic eye" or "magic device" that included as much information as he required—how would he conduct the above tasks. The same set of scenarios was given to each participant. During this process (performing task scenarios and conception tasks), the participant was asked to "think aloud" and describe what he would like to know while performing scenarios. This was supposed to elucidate the tacit knowledge inherent in a user's mental model to complete desired tasks. The researcher observed the participant's actions for critical incidents and asked questions after each completed the task scenario.

<u>Post-observation Questions:</u> The participant was asked to give comments on the mobile AR guidance application that he had just used—and specifically the application's advantages and disadvantages with

respect to interacting with the surrounding environment in exploratory navigation. This entire observation session, lasted approximately one and a quarter hours, was video-recorded, audio-recorded and transcribed for subsequent analysis.

3.2.5.2 Interview Procedures

Once participant observations were completed, semi-structured interviews were scheduled and conducted with the same six participants who took part in the observation study. Each semi-structured interview, which lasted approximately one hour and was audio-recorded, was carried out in the Assessment and Cognitive Ergonomics Lab, 530 Whittemore Hall, Virginia Tech. Each participant received monetary compensation ($25) upon completing the observation and the interview sessions. An interview script (see Appendix F) was followed and probing was allowed at appropriate times during the interview. The interview contained the following sections:

Introductory questions: The interview began with background questions designed to ascertain the participant's experience with visiting unfamiliar places and general mobile AR usage.

"Situate": In order to situate the participant into the street-level view, one Google street view of a metropolitan area (described in the Artifacts session) was selected before the interview and was shown on a desktop screen to the participant.

Past experiences + Knowledge audit: The participant was asked questions related to places, decision-processes involved in urban exploratory navigation with or without mobile AR guidance application, and general mobile AR usage overall. Specific points were probed on the three levels of situation awareness.

Simulation: The participant was presented with four pre-determined tasks scenarios. The simulation interview allowed the researcher to better understand users' cognitive processes within the context of a task scenario (Laura, 1998). These tasks were adapted to conform to practical constraints. Participants were asked to elaborate on how they would think and act under a certain task scenario. Questions in this section covered the topic of awareness of place, specific mobile AR usage patterns, and SA elements. If the participant did not mention situation awareness elements initially (e.g., objects, people, places, activities, events, and virtual information such as local news), the researcher probed the individual for these elements. Pen and paper were provided to the participant to facilitate note-taking and illustrations.

Closing Questions: Participants were asked to describe their ideal mobile AR guidance system in terms of interacting with their surrounding environment in urban exploratory navigation, and how they would like mobile AR guidance application to be designed to achieve these SA requirements.

3.2.5.2 Interview Questions

Verbal protocols were elicited using an interview script (see Appendix F). Interview questions were developed based primarily on two sources: the study's overarching research questions and applied cognitive task analysis modified to fit the specific domain of mobile AR exploratory navigation (it should be noted, however, that SA domains typically involve complex large-scale systems). We sought to gain knowledge on (a) users' exploratory navigation tasks in a mobile AR-enabled environment, (b) the process of SA development while conducting such tasks, and (c) SA requirements under such contexts. Therefore, the interview questions, which were carefully crafted to inspire participants to generate spontaneous and rich descriptions, were able to contribute dynamically to the interview flow, while at the same time eliciting valuable information. Research has confirmed that a single research topic can be investigated through several related interview questions, thereby obtaining rich and varied information by approaching the question from different angles (Kvale & Brinkmann, 2008). Accordingly, after the pilot study and the first several interviews were conducted, new questions were created and added as needed to capture more complete information. In other words, additional queries were added to address emerging issues during the process of qualitative data collection. The interview was an iterative process during which the interviewer provided feedback to the participant on the information recorded so far, and asked for any necessary additions and/or revisions. When the interviewer felt that the participant's input was exhausted, the interviewer brought up areas that previous participants had commented on for consideration and comment.

To address the research questions, the interview questions focused on 1) the process of SA development, and 2) SA requirements in the context of mobile AR-enabled urban navigation.

1) Questions about the process that users employ to develop SA:

In order to answer RQ1 (*What process do users employ to develop situation awareness in the context of mobile AR-enabled urban exploratory navigation*?), specific queries were asked on the three levels of situation awareness—namely, Perception, Comprehension, and Projection of the state of the environment—as well as follow-up decision-making processes. Specifically, participants were probed on 1) what they knew and would like to know; 2) what helped them or would help them achieve the task at hand; 3) what was needed or would be needed to enhance the likelihood of achieving good performance on the task.

2) Questions about SA requirements:

In order to answer RQ2 (*What are the specific user situation awareness requirements in the context of mobile AR-enabled urban exploratory navigation*?), an SA requirements analysis was conducted to determine the requirements for “perfect SA,” which is independent from whether or not that information is readily available in the present system (Endsley, 1993). To elicit SA elements for exploratory navigation task scenarios, participants were asked to describe the information elements that they considered relevant and important for tasks in the context of mobile AR-enabled urban exploratory navigation. In addition, participants were asked to describe what decision processes each SA element they listed were used for (i.e., how that piece of information would help them) (Endsley, 1993). This elaboration procedure was very useful in that it served as a “sieve” for weeding out non-important information. Specifically, it helped the researcher develop an understanding of the process that participants employed to develop SA, as well as the nature of the SA elements described by the participants (Endsley, 1993). Based on user responses, additional information was solicited for the four established components of SA: spatial, temporal, identity, and social.

3.2.6 The Coding System

As noted, qualitative data were collected during the observation sessions, and via open-ended questions during the interview sessions (Appendix E and Appendix F). The content analysis method was used to analyze the transcribed textual and action data. Both quantitative and qualitative techniques were used in the process of content analysis. A priori coding based on three levels of situation awareness and four components (described below) were used to analyze the interview responses. As noted in the literature, coding categories typically emerge from three sources: an existing theoretical framework, the researcher’s interpretation of responses, and original terms provided by the participants (Corbin & Strauss, 2008). In this study, a priori coding schema was identified based on established situation awareness theory and SA components from the proposed model. As noted earlier, SA can be categorized into three levels: perception, comprehension, and projection (Endsley, 1995a). The coding system developed for this study added a fourth—namely, decision-making Thus, in addition to the four codes related to SA processes, four additional codes were utilized pertaining to the four SA components used in the task of urban navigation—namely, Spatial, Temporal, Identity, and Social. The coding system is shown in Table 8.

Additionally, in terms of mobile AR-supported SA development, factors that had not been determined to be important to, or to have influence on, SA-supported navigation in prior analyses were also be identified (Endsley, 1993). Any contextual factors shown to have an impact on a user’s perception, comprehension, and ability to make projections of his/her surrounding environment in navigation were coded as contextual factors, emphasizing that contextual factors can adversely affect one’s ability to perform certain activities (Sears et al., 2003; Sears & Young, 2003). Examples of contextual factors are ambient noise, distractions, divided attention, impaired body motion, walking vibrations, weather (e.g., rain, snow, wind), restrictive clothing (e.g., gloves causing “fat fingers”), uneven terrain (e.g., stairs), glare, low light or darkness, encumbering baggage, confined or crowded spaces, and so forth (Kane, Wobbrock, & Smith, 2008; Lin, Goldman, Price, Sears, & Jacko, 2007; Nicolau, 2012; J.O. Wobbrock, 2006; Yamabe & Takahashi, 2007; Yesilada, Harper, Chen, & Trewin, 2010).

As shown in Table 8, under each code category, sub-codes were assigned as they emerged naturally through the coding process. The participant’s own terms were used if they described the instances vividly and accurately.

Table 8. The coding system

Code	Major Coding Categories	Sub-code
1. Per	Perception of Elements	• Searching • Locating • Orienting • Recognizing/identifying • Noticing (objects or ongoing event) • Attention to smartphone screen • Attention to environmental cues
2. Com	Comprehension of Current States	• Acquiring overview • Acquiring patterns • Quantifying/estimating amount • Acquiring relations and comparisons • Discovering order • Interpret information
3. Pro	Projection of Future States	• Projecting based on past experiences • Projecting based on real time information • Projecting based on patterns
4. Dec	Decision-making	• Improvising (experience) • Stimulation (env cues) • Facilitating a quicker decision • Change • Concerns • Difficulties • Past experiences
5. Spa	Spatial Component	• Spatial boundary • Spatial relation to oneself (location & direction) • Arranged by distance • Exocentric view • Visible/obscure objects to oneself

6. Tem	Temporal Component	• Dynamically-associated aspects • Plan according to the time available • Association of spatial motion with time • Impact of time on the usage of mobile AR • Impact of time on decision-making • Impact of time on behavior of exploratory navigation
7. Ide	Identity Component	• Type of POI • Attributes of POI- statically associated • Attributes of POI- dynamically associated • Single POI • Collection of POIs
8. Soc	Social Component	• User-summoned digital information • User-summoned physical information • Inquiring friends about POIs • Inquiring locals/other visitors about POIs
9. Con	Contextual Factors	• Situational impairment • Ergonomic constraints

3.2.7 Coding Process

To control for subjective interpretation, another graduate student with coding experience was brought in to code a portion of the qualitative data independently. As supported by the literature, the researcher was the primary coder, since coding requires both extensive knowledge of the theory on which the study is based, as well as an understanding of related literature (SA-related knowledge)—not to mention a deep understanding of the data collected (Lazar et al., 2009). To ensure accurate coding, the other coder was first given a training session (including a complete description of the study), a description and explanation of the coding system, and a trial session to make certain that the coder was comfortable and skilled with the coding process. The independent coder was given the transcripts of a randomly selected set of qualitative data. He was first asked to code the verbal protocol into nine major categories and then to assign the sub-codes. For the emergent codes, the two coders examined the set of data independently and each developed a list of key coding categories based on her/his interpretation of the data.

Once the randomly selected set was coded, the two coders met to compare their category lists, discuss the differences and the labeling of the emergent codes and sub-codes, and reach a consensus. Once the two coders achieved a consolidated list that both agreed upon, the coders went back and applied coding independently using the consolidated list. Percentage agreement of the two coders' results was 63.3%, calculated as a reliability check. It was considered a satisfactory reliability level. To facilitate the coding process, Atlas-ti[30] was used during the coding process. This program is highly developed and widely respected/used in qualitative data analysis.

3.2.8 Coding Validity and Reliability

To establish validity, the researcher first confirmed that well-documented data and procedures were in place. This included cataloging all the materials that were collected and created (e.g., photos, video clips), and documenting all procedures and products of analysis used during the course of the study. Secondly, multiple data sources (observations and interviews) were used to triangulate the data to an applicable set of responses.

As stated by Weber (1990), the goal of a reliability check is to make sure that different coders code the same text in the same way. As described above, a set of explicit coding instructions at the beginning of the coding processes (training, testing code, etc.) was developed and followed throughout the process. Inter-coder reliability was assessed by percentage agreement. A well-accepted number is 0.60, which indicates a satisfactory reliability.

3.3 Study 2: Theory Application and Validation (Interface Evaluation)

3.3.1 Research Hypotheses

In Study 2, the conceptual design of the interface, which utilized two design mockups, was empirically evaluated in comparison to two interfaces from an existing baseline product. The goal of the comparison was to determine the extent to which the user's situation awareness was supported by the SA-supported mobile AR interface. The baseline interfaces were part of the mobile AR guidance application used in the previous requirements elicitation study. Based on an evaluation of information systems provided below, a goal-based formative empirical evaluation was conducted to evaluate the prototype. The research question and related hypotheses corresponding to this phase of the study follow:

RQ3: What are the differences between the proposed situation awareness-supported mobile AR guidance interface and a currently available interface in terms of a) the user's situation awareness, and b) the user's perceived usability in urban navigation?

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[30]. More information can be found Atlas-ti homepage at http://www.atlasti.com/index.html

Two hypotheses were developed to answer Research Question 3:

> Hypothesis 1. There is a difference between the proposed SA-supported mobile AR guidance interface and a currently-available interface with respect to a user's situation awareness.

> Hypothesis 2. There is a difference between the proposed SA-supported mobile AR guidance interface and a currently-available interface with respect to a user's perceived usability.

3.3.2 Research Design, Independent and Dependent Variables

The study was designed to explore one research question and two corresponding hypotheses in mobile AR-enabled urban exploratory navigation. This quantitative evaluation consists of two in-lab experiments on two mixed-fidelity mockup interfaces: one an AR interface and the second a Map interface.

The AR interface: The AR interface experiment was a within-subjects design with Interface (Interface S: SA supported design vs. Interface B: baseline) and the number of Points of Interest (POIs) (3, 5, 7, 12) as two independent variables. For this within-subjects design, the major source of variation between users—which was considered important to this study (e.g., a user's multifaceted prior experience)—was removed to improve the likelihood of detecting differences with the same sample size (sample size =32 to match the Latin Square design). In addition, using within-subjects design, qualitative feedback for both SA supported interface and baseline interface can be obtained. The order of Interface and the Number of POIs combination administration was counterbalanced to overcome the possible learning effect carried over between interfaces and sets. Specifically, all 32 participants underwent Interface B and Interface S with Set A, B, C, D; however, the order in which they received Interface and Set differed. First, the Interface was counterbalanced. Then the Number of POIs was counterbalanced using 4 x 4 Latin Square to generate 32 combination sequences (this was due to the experimental constraints/requirement on interface administration order, in which one has to evaluate one interface after another). These 32 combination sequences were then randomized. An Excel spreadsheet was created to record the 32 combination sequences. Prior to experimentation, the 32 participants were randomly assigned into these sequences by the researcher drawing each participant's ID from a box. The sequence with the corresponding ID was then used in the experiment. The order of task queries administration was randomized.

The Number of POIs was included as an independent variable for the following reason. Based on the compared interfaces (comparing information presented in table view vs. information presented in clustered view), the effect of the Interface may depend on the number of POIs (e.g., interface S works better under the condition of fewer POIs, while interface B performs better under the condition of more

POIs). Therefore, the Number of POIs was included in this study together with Interface as independent variables. The Number of POIs has 4 levels: The number of POIs =3 (Set A), the number of POIs = 5 (Set B), the number of POIs =7 (Set C), and the number of POIs =12 (Set D).

Each participant was presented with two AR interfaces: Interface S (proposed SA-supported interface) and Interface B (a currently-available baseline interface). Both Interface S and baseline Interface B were mixed-fidelity prototypical interfaces, with high fidelity on visual presentation and restrictions on user interaction. The design of Interface S was informed by findings obtained from Study 1 (more design details can be found in Section 4.2). Interface B was considered as a benchmark interface among various currently-available mobile AR guidance applications (reasons are documented in Section 3.2.3.2). The level of interaction of Interface B was controlled to be compatible with its equivalent (Interface S). For each interface, each participant was presented with an initial task scenario and 12 task queries (24 task queries/query variants in total for the two interfaces). The task queries administration was randomized. Additional details about task queries and query variants can be found in Section 4.1.3.

The Map interface: The Map interface experiment was a within-subjects design with the SA-supported feature as the sole independent variable. The order of interface administration was counterbalanced to overcome learning effect carried over between interfaces. The task queries administration was randomized.

Each participant was presented with two Map interfaces: Interface S (proposed SA-supported interface) and Interface B (a currently-available baseline interface). Both Interface S and baseline Interface B were mixed-fidelity prototypical interfaces described previously. The design of Interface S was informed by findings obtained from Study 1. For each interface, each participant was presented with 4 task queries (8 task queries in total).

For both the AR interface and the map interface, the dependent measures were each participant’s response time and response accuracy on task queries, the score from the After-Scenario Questionnaire (ASQ), and the Software Usability Scale (SUS) score. Dependent measures and their definitions are summarized in Table 9.

Table 9. Dependent measures and measure methods used in study 2

Constructs	Dependent Measures	Definition
Situation Awareness	*Objective measures*	
	Task queries	Administering SA-related task queries
	Completion time	The time needed for the participant to complete the task query
	Response accuracy	Accuracy of the response collected as a binary measure of response success (coded as 1) or response failure (coded as 0).
Usability	*Subjective measure*	
	Questionnaires	
	ASQ	After-Scenario Questionnaire
	SUS	Software Usability Scale

Since task query completion time and response accuracy are commonly-used assessment measures in SA, for each task the query response time (for those responses that were correct) and response accuracy were interpreted as direct measures of the operator's SA.

The query response time (for those responses that were correct) was defined as the time needed for a participant to give a response while performing the pre-determined task. Response accuracy, defined as the accuracy of the response, was collected as a binary measure of response success (coded as 1) or response failure (coded as 0).

In order to perform a usability evaluation, ratings of usability were obtained using ASQ (After-Scenario Questionnaire) and SUS (Software Usability Scale). ASQ is a three-item questionnaire that probes overall ease of task completion, satisfaction with completion time, and satisfaction with support information (see Section 3.3.4 and Appendix L). The overall ASQ score is the average of the responses to these items. SUS is widely used to assess an information system's usability (see Section 3.3.4 and Appendix M). The interface's usability was quantified as an aggregated usability score. Because only the composite SUS score was considered to be meaningful, no score for each questionnaire item was quantified for SUS's calculation rules (see Section 3.3.4).

ASQ ratings and SUS ratings collection occurred at the end of task queries for each interface.

To reiterate, the following two hypotheses were developed in connection with RQ3 from Study 2 (*What are the differences between the proposed situation awareness-supported MOBILE AR guidance interface and a currently available interface in terms of a) the user's situation awareness, and b) the user's perceived usability in urban navigation?*):

> Hypothesis 1. There is a difference between the proposed SA-supported mobile AR guidance interface and a currently-available interface with respect to a user's situation awareness.

> Hypothesis 2. There is a difference between the proposed SA-supported mobile AR guidance interface and a currently-available interface with respect to a user's perceived usability.

Correspondingly, for the two sets of interfaces (AR interface and Map interface), more specific hypotheses with respect to the dependent measures were developed:

<u>Hypothesis 1. Effect of SA-supported design interface on SA</u>

<u>AR Interface</u>

Primary research hypothesis (main effect):

H1: There is a difference between the two AR Interfaces on task query completion time.

Secondary research hypothesis (interaction effect):

H2: There is a difference between the two AR Interfaces dependent on Points of Interests (POIs) on task query completion time.

H3: There is a difference between the two AR interfaces on response accuracy.

<u>Map Interface</u>

H4: There is a difference between the two Map Interfaces on task query completion time.

H5: There is a difference between the two Map Interfaces on response accuracy.

<u>Hypothesis 2. Effect of SA-supported design interface on Usability</u>

AR Interface

H_0: The two AR Interfaces differ in usability (as indicated in SUS score and ASQ rating)

H6: There is a difference between the two AR Interfaces on SUS score.

H7: There is a difference between the two AR Interfaces on ASQ rating.

Map Interface

H_0: The two Map Interfaces differ in usability (as indicated in SUS score and ASQ rating)

H8: There is a difference between the two Map interfaces on SUS score.

H9: There is a difference between the two Map interfaces on ASQ rating.

3.3.3 Analysis Methods

The SUS score was calculated by first adding the score contributions from each item, which ranged from 0 to 4. For items 1, 3, 5, 7, and 9, the score contribution is the scale position minus 1. For items 2, 4, 6, 8 and 10, the contribution is 5 minus the scale position. Finally, the sum of the scores was multiplied by 2.5 to obtain the overall value of SUS, which ranged from 0 to 100. Averaged ASQ score for each interface was calculated.

The data were summarized in means and standard deviations were reported. Dependent measures and analysis methods used are summarized in Table 10.

Specifically, to test H1 and H2, a Shapiro-Wilk's test ($p>.05$) was performed and a visual inspection of histograms and box plots showed that the residuals residual of task query completion time were not normally distributed for both SA-supported AR interface and baseline interface. Aligned Rank Transform was applied by using a tool called ARTool (Jacob O Wobbrock, Findlater, Gergle, & Higgins, 2011), followed by a two-way ANOVA analysis. ARTool was developed for nonparametric factorial analyses using ANOVA procedures. A two-way ANOVA analysis was then performed with interface and number of POIs as two independent variables, and task query completion time as the single dependent variable.

To examine H3, a nominal logistic regression was performed with interface and number of POIs as the two independent variables and response accuracy (0 vs.1) as an independent variable.

To examine H4, a Shapiro-Wilk's test ($p>.05$) was performed and a visual inspection of histograms and box plots showed that the residuals of task query completion time were not normally distributed for both SA-supported Map interface and baseline Map interface. A Wilcoxon Signed Ranks test was performed with interface as the independent variable and task query completion time as the dependent variable.

To examine H5, a Chi-square test was performed on response accuracy (1 vs. 0) with interface as the independent variable.

To examine H6-H9, normality assumptions were violated and Wilcoxon Signed Ranks tests were performed.

Table 10. Dependent measures and analysis methods in Study 2

Constructs	Hypothesis	Dependent Measures	Analysis Methods
Hypothesis 1:		*AR interface:*	
Situation Awareness	*H1,H2*	Response time	Aligned Rank Transform ＋ ANOVA
	H3	Response accuracy	Logistic regression
		Map interface:	
	H4	Response time	Wilcoxon Signed Ranks test
	H5	Response accuracy	Chi-Square
Hypothesis 2:		*AR interface:*	
Usability	*H6*	SUS	Wilcoxon Signed Ranks test
	H7	ASQ	Wilcoxon Signed Ranks test
		Map interface:	
	H8	SUS	Wilcoxon Signed Ranks test
	H9	ASQ	Wilcoxon Signed Ranks test
Correlation		*AR interface:*	
		SUS vs. ASQ	Spearman's ρ
		SUS vs. Task query completion time	Spearman's ρ
		Map interface:	
		SUS vs. ASQ	Spearman's ρ
		SUS vs. Task query completion time	Spearman's ρ

3.3.4 Participants

A total of 32 participants aged 18-49 were recruited from the university using a convenience sampling method. The following criteria were used to select participants for this study:

- Participants had to be aged 18-49;
- They had to have used a touch-screen smartphone prior to taking part in this study.

Recruitment flyers and emails (Appendix G) were sent to the public through research study participation services. The rationale for excluding someone without any Smartphone experience was that he/she might be distracted by the novelty of the device and its usage (e.g., direct manipulation by touching the screen or via verbal commands), as well as the sophistication of its functionality (e.g., enabled by various mobile applications) compared to an earlier-generation cell phone. In addition, studies show that there tends to be a gap between users aged 18-49 and those aged 50-65 in mobile usage for a number of functions (e.g., mobile Internet usage compared to other functions, email, banking, etc.) (Westlund & Bohlin, 2008). Since there was no prior research reporting age differences in handheld or any mobile AR usage, we adopted these general mobile usage patterns and only recruited people aged 18-49 to reduce unwanted variations that otherwise might have been introduced by including older participants.

3.3.5 Instruments

3.3.4.1 Evaluation Task Queries

<u>Task Queries</u>

The development of SA queries requires a detailed analysis of the task in order to identify SA requirements (Wright, Taekman, & Endsley, 2004). In other words, these queries correspond to their SA requirements. During SA measurement, the individual is typically asked a series of questions in order to determine his/her knowledge of the situation and the surrounding environment at an exact moment in time. With respect to this study, there were some challenges involved with investigating SA-supported interfaces at this stage. First, due to the fact that the prototype evaluated during the initial design phase was a low-fidelity mockup in terms of interaction (i.e., restricted interaction), the SA queries were selected from the SA queries poll generated during Study 1 (Appendix W) to fit the convenience and availability of interaction. Second, for experiments conducted in the HCI domain, researchers typically redesign an interface by changing the presentation layout of its information or by adding a new feature with existing information to make sure all answers to tasks are answerable under all conditions. Doing so can ensure that one of the interfaces is not naturally favored over the other. However, due to fact that situation awareness is enabled primarily by task-oriented information extracted from the environment, a portion of SA requirements generated in Study 1 contained SA-supported features associated with incorporating SA information into the mobile AR guidance interface. Therefore, at this stage, these types of information-related, SA-supported features cannot be readily assessed in a quantitative-oriented comparison experiment—as opposed to an experience-oriented qualitative evaluation—simply because there are no equivalents in the baseline interface with which to compare them. Given these considerations, 24 SA queries and variants were generated for AR interface comparison, and 8 queries and variants were generated for the Map interface comparison (Appendix N and Appendix P).

Validity and Reliability of SA Queries

To date, most of the existing SA evaluation measures that have been developed are used in military (infantry operations), aviation, and Air Traffic Control (ATC). In contrast, SA measures are not yet generally used in the domain of mobile computing technology. This fact does not, however, represent a significant concern for this research—mainly because the domain-specific nature affects the way it is measured (Durso & Gronlund, 1999; Endsley, 1995a; Wickens, 1999). In other words, in every new domain, situation awareness requirements need to be assessed first, after which they are used to create situation awareness queries in evaluation. In this case, validity check could be a potential threat to the evaluation.

To address the important issue of evaluation validity, a number of checks were put in place throughout this study. First, to provide SA requirements, a series of elicitation techniques (observation and interview) and methods (qualitative and quantitative) were utilized during the SA requirements elicitation study to triangulate the data. Second, the evaluation segment used a modified SA measurement technique adapted from the Situation Present Assessment Method (SPAM). As a probe technique, SPAM is an SA assessment technique originally developed for use in the assessment of an air traffic controller's SA. The SPAM technique focuses on an operator's ability to locate information in the present environment as an indicator of his or her SA—rather than recall specific information from the past. As an example, a SPAM analyst would probe an ATC's SA using task-related SA queries based on pertinent information in the environment (e.g., which of two aircraft, A or B, has the highest altitude?). This type of inquiry (as exemplified by more general questions such as "Where is the nearest XX to you?" or " What is the state of XX in your XX?") has shown to be a valid assessment strategy (Durso & Gronlund, 1999; Endsley, 1995a; Wickens, 1999). In the case of the present study, the query response time (for those responses that were correct) was taken as an indicator of the operator's SA. Each task query's response accuracy and response time were reported and analyzed. As illustrated in Table 11, it appears that most SA measurement techniques have suffered from validation issues, or their validity has been inadequately reported. Therefore, situation awareness, regardless of the particular research domain, should be further studied—with an emphasis of determining better ways to validate SA measurements.

Table 11. Partial SA measurement techniques summary from (Stanton, Hedge, Brookhuis, Salas, & Hendrick, 2004)

Method	Subjective Objective	Type of method	Domain	Advantages	Disadvantages
CARS	Subjective	Self rating technique	Military (infantry operations)	1) Developed for use in infantry environments. 2) Less intrusive than on-line techniques. 3) Quick, easy to use requiring little training.	1) Construct validity questionable. 2) Limited evidence of use and validation. 3) Possible correlation with performance.
MARS	Subjective	Self rating technique	Military (infantry operations)	1) Developed for use in infantry environments. 2) Less intrusive than on-line techniques. 3) Quick, easy to use requiring little training.	1) Construct validity questionable. 2) Limited evidence of use and validation. 3) Possible correlation with performance.
SABARS	Subjective	Observer rating	Military (infantry operations)	1) SABARS behaviors generated from infantry SA requirements exercise. 2) Non-intrusive.	1) SME's required. 2) The presence of observers may influence participant behavior. 3) Access to field settings required.
SACRI	Objective	Freeze on-line probe technique	Nuclear Power	1) Removes problems associated with collecting SA data post-trial.	1) Requires expensive simulators. 2) Intrusive to primary task.
SAGAT	Objective	Freeze on-line probe technique	Aviation (military)	1) Widely used in a number of domains. 2) Subject to numerous validation studies. 3) Removes problems associated with collecting SA data post-trial	1) Requires expensive simulators. 2) Intrusive to primary task. 3) Substantial work is required to develop appropriate queries.
SALSA	Objective	Freeze on-line probe technique	ATC	1) Removes problems associated with collecting SA data post-trial e.g.	1) Requires expensive simulators. 2) Intrusive to primary task.

				correlation with performance, forgetting etc.	3) Limited use and validation.
SASHA_L SASHA_Q	Objective	Real-time probe technique Post-trial quest	ATC	1) Offers two techniques for the assessment of SA.	1) Construct validity questionable. 2) Generation of appropriate SA queries places great burden upon analyst/SME. 3) Limited evidence of use or validation studies.
SARS	Subjective	Self rating technique	Aviation (military)	1) Quick and easy to use, requires little training 2) Non-intrusive to primary task.	1) Problems of gathering SA data post-trial e.g. correlation with performance, forgetting low SA. 2) Limited use and validation evidence.
SART	Subjective	Questionnaire technique	Aviation (military)	1) Quick and easy to administer. Also low cost. 2) Generic – can be used in other domains. 3) Widely used in a number of domains.	1) Correlation between performance and reported SA. 2) Participants are not aware of their low SA. 3) Construct validity is questionable.
SPAM	Objective	Real-time probe technique	ATC	1) No freeze required.	1) Low construct validity. 2) Limited validation report. 3) Participants may be unable to verbalize spatial representations.

3.3.5.1 After Scenario Questionnaire (ASQ)

ASQ was used to assess overall ease of task completion, satisfaction with completion time, and satisfaction with support information (see Appendix L) (Lewis, 1995). The overall ASQ score is the average of the responses to these items. Measurements of ASQ reliability have ranged from 0.9 to 0.96 (Lewis, 1991,1995; Sauro & Lewis, 2012). Use of the ASQ showed a significant correlation (r (46) = -0.4, $p < 0.01$) between ASQ scores and successful task completion, as evidence of concurrent validity and sensitivity. By an analysis of variance, a sensitivity of ASQ has been indicated with a significant main effect ($F(7, 126) = 8.92$, $p < 0.00001$) of task and a significant task by system interaction ($F(14, 126) = 1.75$, $p = 0.05$) (Lewis, 1991, 1995;).

3.3.5.2 Software Usability Scale (SUS)

A Software Usability Scale (SUS) questionnaire was used to assess usability of the prototypical interface (see Appendix M). The System Usability Scale (SUS) is a simple, ten-item Likert-scale giving a global view of subjective assessments of usability (Brooke, 1996). It yields a single number representing a composite measure of the overall usability of the system being studied. Scores for individual items are not meaningful on their own (Brooke, 1996). SUS has shown to be a valuable evaluation tool, being robust and reliable. Evidence has shown using larger samples that SUS demonstrated a reliability of 0.9 – 0.92 (Bangor, 2008; Lewis, 2009), and sensibility indicated by significant concurrent validity with a single point rating of user friendliness ($r = 0.86$) (Bangor, 2008).

3.3.6 Interface

One SA-supported AR interface and one SA-supported Map interface were generated based on findings from Study 1, and used in Study 2. One AR interface and one Map interface from Wikitude guidance application were used as baseline interfaces. Additional information regarding SA-supported AR and Map interface are provided in Section 4.2.4. Screenshots of SA-supported AR, Map interfaces, and corresponding baseline interfaces are provided in Appendix K .

3.3.7 Procedure

Study 2 was conducted in the Assessment and Cognitive Ergonomics Lab, 530 Whittemore Hall, Virginia Tech. Four pilot studies were conducted. The session began by welcoming participants and briefing them about the purpose of the research. Informed consent (see Appendix H) and demographic information were acquired (Appendix I). Each participant sat down and was presented power point mockups on a laptop screen to familiarize them with the study, after which the actual session began.

<u>Session 1: Interface Comparison</u>

First, the participant was asked to read out loud a task scenario (see Appendix J) to place him or her into the scenario. Then, due to the low-fidelity interaction of the mock up, the researcher reviewed the interface with the participant, explaining the basic design features of the interfaces and instructing him/her about the interactive/non-interactive areas on the prototypes. After completing the walk-through, the participant had about three minutes to interact with each interface and familiar himself/herself with the interface. Next, based on the pre-determined interface order and task order, the participant was presented with one of the two mobile AR interfaces and corresponding tasks queries.

For completing task queries, participants were instructed on two points. First, although they didn't have a time limit on the tasks, they needed to complete them as quickly as possible. Doing so was to minimize the speed/accuracy tradeoff. Second, to exclude the time needed to read queries and write answers—and thus only include the time that participants spent on the corresponding interface—they had to signal the researcher when they were ready to begin the task, as well as when they had completed the task.

Two practice trials were administered before beginning the actual study tasks to familiarize the participants with procedures and reduce any variants introduced by the learning effect. The task queries were then administered one by one; once one task was finished, the next one began. The researcher recorded the participants' response accuracy and response time to each query on a recording sheet (Appendix O). Upon immediate completion of the task query on each interface, participants were asked to rate the interface that they had just used with the ASQ and SUS questionnaires.

Subsequently, the second AR interface was given to participants and the session was repeated with the same procedures. The same process was utilized with the map interface evaluation as well. Map task sheet is included in Appendix P and recording sheet is in Appendix Q .

At the end of the AR session and map session, participants completed a post-session interview with open-ended questions regarding their experiences with the evaluated interfaces (see Appendix J). Their opinions and comments were collected.

Effort was made to ensure that measurement variances were as small (i.e., as precise) as possible. First, participants were confirmed to understand what they were supposed to do before beginning the evaluation by instructing them about testing procedures, and before beginning the tasks. Second, participants were familiarized with the testing situation by feasibility of prototypes, and also enabled them to become familiar with the concept of interface in "a bigger picture"—but without revealing any study-relevant information (e.g., queries). This was done because each evaluated interface was extracted from a more coherent interface; therefore, participants needed relevant information about the interface. Third, task queries were ensured to be straightforward easy to understand.

Session 2: Design Concepts Evaluation

Upon completing Session 1, the participant was asked their opinions and feedbacks on five concept design features. Screenshots of these concepts are provided in Appendix R . Additional details about development of these concepts design can be found in Section 4.2.4. Participants' verbal response was recorded.

CHAPTER 4 RESULTS

4.1 Study 1: Situation Awareness Theory Refinement (SA Requirements Analysis)

4.1.1 RQ1: Process Users Employ to Develop SA

4.1.1.1 User Tasks in Mobile AR-enabled Urban Exploratory Navigation

A goal-directed Hierarchical Task Analysis (HTA) was conducted, which is useful for analyzing the information requirements of a particular group of users, after which it can be used for interface design (Wilson, 2005). An HTA seeks to establish the following three factors: 1) the primary goals of the individual in the context of mobile AR-enabled urban navigation, 2) the sub-goals that are appropriate for meeting those goals, and 3) the SA elements for meeting these sub-goals.

A goal-tree is presented in Figure 11. This illustration provides an indication of the SA elements that would be important to an individual at any point in the process of conducting an exploratory navigation task. Specific usage tasks (use cases) that participants executed using a smartphone-based mobile AR are presented in Figure 12.

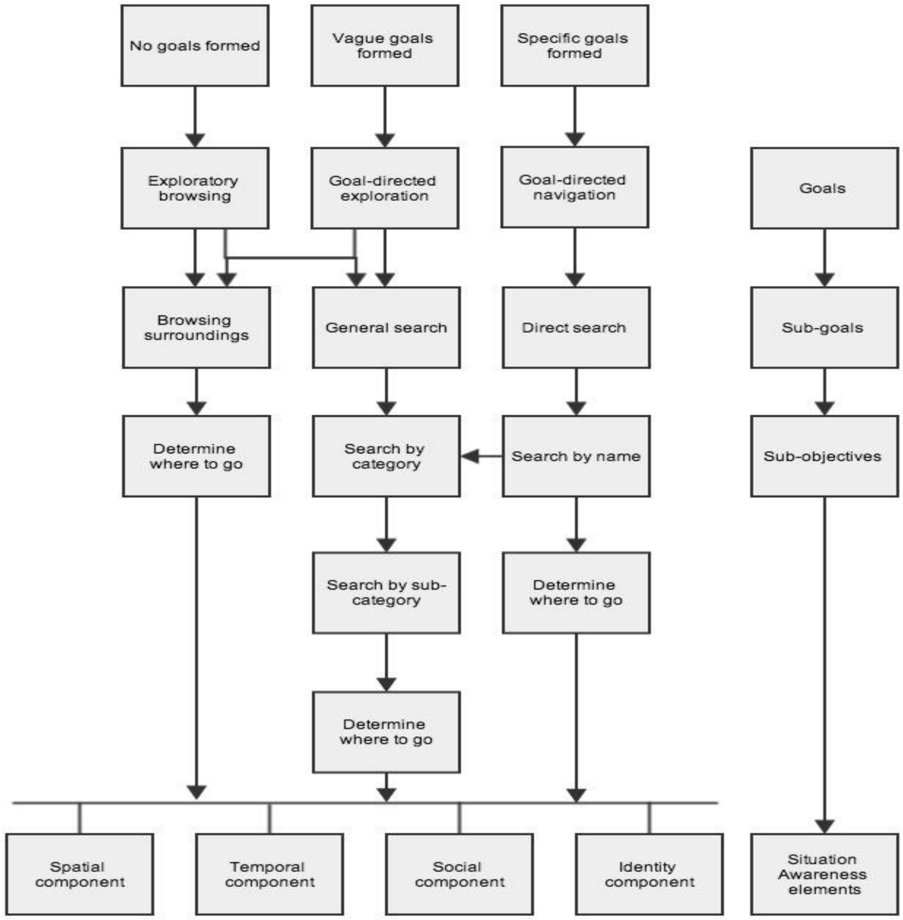

Figure 11. A hierarchical task analysis of exploratory navigation

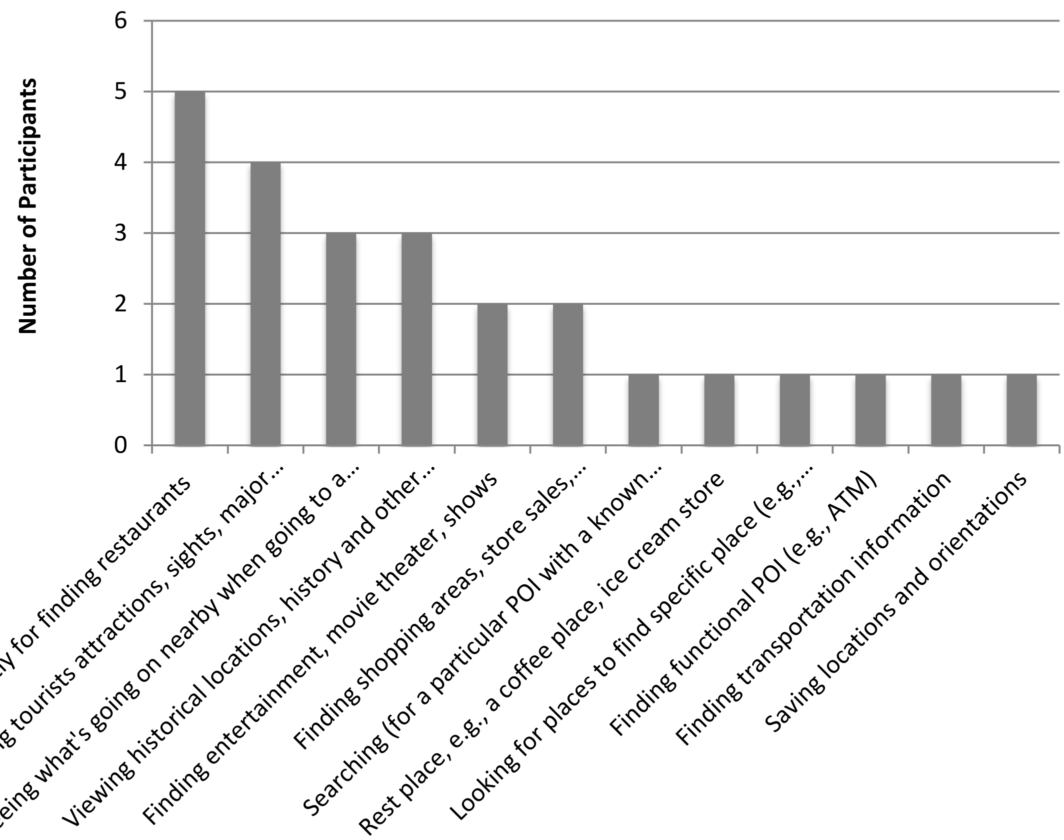

Figure 12. Smartphone-based mobile AR usage tasks

4.1.1.2 A preliminary cognitive model of the process that participants employed to develop SA

Work activity notes were extracted and organized based on content analysis categories identified during the coding process. As described by Hartson and Pyla (2012), a work activity note is used to document a single point about a single concept, topic, or issue as synthesized from raw contextual data, stated as a simple and succinct declarative point in the user's own words. A work activity note for this study is shown in Figure 13. It consists of the name of a major feature or category, a requirement statement and source ID, a rationale statement (if useful), and a commentary about this requirement (optional). These activity notes were extracted from the first round of coding (utilizing Atlas.Ti), and then combined and re-organized in an iterative process under the main functional categories of perception, comprehension, projection, decision-making, awareness of a place (in conception), user behavior, information needs for Scenario 1, 2, 3, and 4, spatial (component), temporal (component), identity (component), social (component), contextual factors, mobile AR functions, mobile AR usage tasks, mobile AR negatives, positive emotions (of using mobile AR), potentials (of mobile AR technology), differences (due to mobile

AR), role (of mobile AR), reason (of using mobile AR), Wikitude negatives (application used), and Wikitude positives. A sample of work activity notes is included in Appendix U .

Support users' perception

System shall provide users with information on visual landmarks (objects that are visually distinctive) appeared in the user's natural field of view on mobile AR view.

A users' need to know more information about visual landmarks shall be supported on the mobile AR screen(P2F:36;P2F:42).

Note: This requirement is important because a user's attention is typically drawn to such visual landmarks (e.g., uniquely shaped, old, or unusually tall architecture).

Figure 13. An example of a work activity note

The generation of activity notes, which involved combining and reorganizing codes and sub-codes, turned out to be an iterative and time-consuming process. Once these activity notes were complete, a preliminary SA cognitive model in the context of mobile Augmented Reality (AR)-enabled urban exploratory navigation (Figure 14) was generated and mapped out (see Appendix U for a sample of a work activity note). As can be seen in this preliminary cognitive model, stimuli consisting of both environmental and digital cues are taken in via the "sensory store," and subsequently undergo the perceptual processes, comprehension, and projection processes, eventually resulting in decision and response selection and response execution. In fact, these three elements are central to the SA theoretical framework: 1) the perceptual process, 2) comprehension (pattern recognition), and 3) projection.

Perception, which is a Level 1 SA, involves associating meaning to sensory stimuli. It is the process whereby an individual becomes aware of and allocates high attention to an environmental object (e.g., a building in the area), a realized object (AR cues), or a digital object on the screen and associates it with meaning. This process involves four components of SA, which are shown in Section 4.1.2 and discussed in Section 5.3. In contrast, an individual tends to allocate low attention to the general environmental atmosphere, pedestrians, moving about on the street (e.g., negotiating curbs), and see-through background on the mobile AR viewer.

Once information is perceived in L1 SA, Level 2 SA combines and interprets information in working memory. In this comprehension phase, sub-processes perform a number of tasks with respect to single elements and collections of location-based elements. Specifically, these sub-processes are performing an overview, acquiring patterns, quantifying/estimating amounts, acquiring relations and comparisons on statically-associated aspects and dynamically-associated aspects of POIs, discovering order (e.g., ranking), and interpreting information of individual POIs.

Subsequently, in the context of mobile AR-enabled urban exploratory navigation, for Level 3 SA, the user projects the likely future status of a given exploratory navigation regarding elements within the current environment. Level 3 SA entails predicting the anticipated status of individual elements and patterns of collective elements that share some common traits. To achieve L3 SA, a projection is generally based on the user's past experience (e.g., past experiences being in similar places/activities), real-time information (e.g., real-time view of a queue situation), and perceived patterns (e.g., spatial patterns of POIs on alternative paths). Finally, decision-making regarding tasks in exploratory navigation and subsequent action execution (e.g., physically navigating to the place of interest) are downstream from SA.

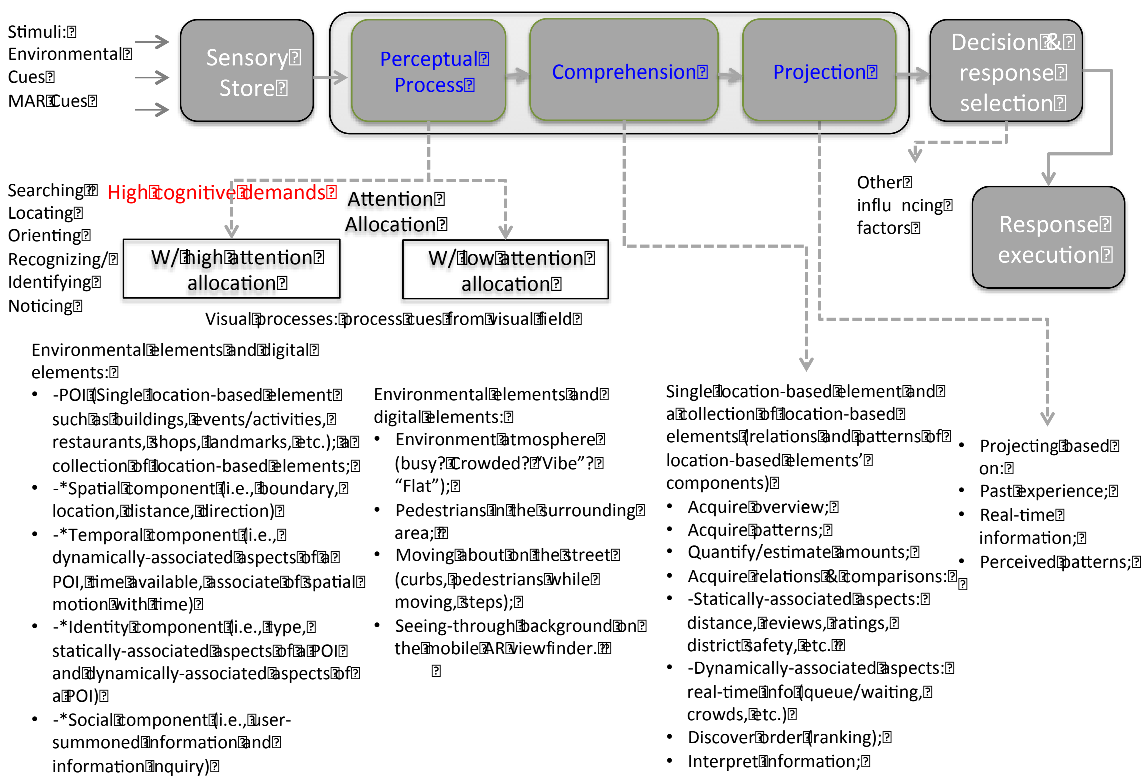

Figure 14. A preliminary cognitive model of the process that participants employed to develop SA

4.1.2 RQ2: SA User Requirements

This section addresses RQ2—namely, what are the specific user SA requirements in the context of mobile AR-enabled urban exploratory navigation. Following Hartson and Pyla (2012), interpreting the results was facilitated by building a flow model and developing work activity notes. A flow model is a diagram giving the "big picture" or overview of the activity; it emphasizes communication and information flow between roles and system components within the work practice of an organization. A flow model of the user task in mobile augmented reality enabled urban exploratory navigation is presented in Figure 15.

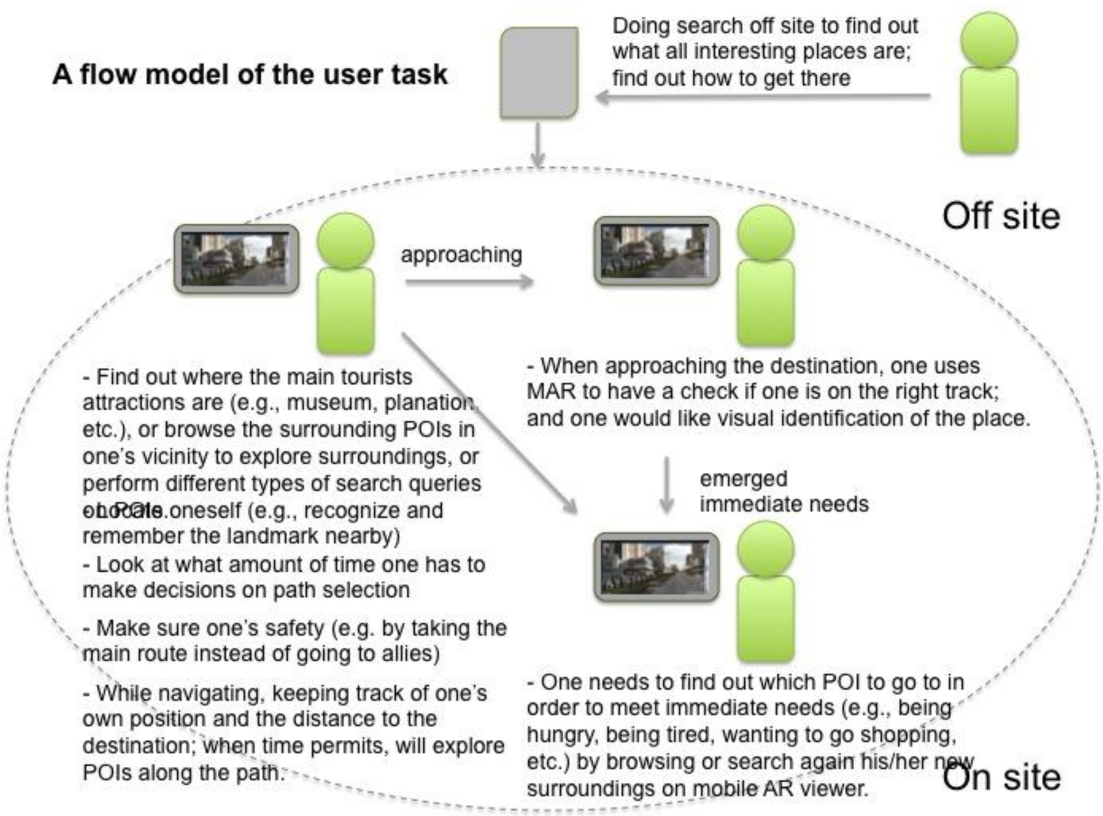

Figure 15. A flow model of user task in the context of mobile AR-enabled urban exploratory navigation

Work activity notes were then further integrated into preliminary SA user requirements. Four out of six participants who took part in Study 1 agreed to evaluate the initial set of requirements. Due to the small sample size, requirements were evaluated by asking users to provide comments and notes on the extracted requirements. If two out of the four evaluators agreed to take out a requirement, it was duly removed from the list. Eventually, 52 SA user requirements and corresponding system requirements for mobile augmented reality (AR) guidance application intended for use in urban exploratory navigation tasks were finalized and are shown in Table 12. This table is organized and categorized based on the three essential processes a user will employ to develop SA: perception, comprehension, and projection. Within each category, SA requirements were then further categorized into subcategories, including searching, locating, orienting, recognizing/identifying, and noticing for Level 1 SA; acquiring overview, acquiring patterns, quantifying/estimating amounts, acquiring relations and comparisons for Level 2 SA; and projecting based on past experience and projecting based on real-time information for Level 3 SA. Since the type of interface mediates a user's development of SA, Interface Support elicited from contextual inquiry has also been included as a part of the SA user requirements. The components of SA, identified and categorized as Spatial (Sp), Temporal (T), Attributes (A), Social (So), are shown in the "Components" column of Table 12. It should be noted that components of SA are not identifiable for these interface support requirements.

Table 12. SA user requirements and corresponding system requirements

Info Process	Sub-categories	No.	SA User Requirements	SA-supported System Requirements	Components	Note	Rationale
Perception	Goal	1	For exploratory browsing and goal-directed exploration, users shall be supported with different layers or modules of information to select at as they wish (P2:68;P4:40;P1:224;P3:148;P5:235)	*For exploratory browsing and goal-directed exploration, system shall provide users with "layers" or "modules" of information representing various categories of activities.*	N/A	Various categories of activities (e.g., “exploring everything,” “restaurants,” “attractions,” “shops,” and “events”).	This requirement is important because the layers of information should match the user's mental model of using a mobile AR viewer when they perceive categorical information.
	Goal	2	For exploratory browsing and goal-directed exploration, users shall have personalization options to set up preferences and add personal or cultural related POIs (P1:191;P5:163;P2:81;P2:94).	*For exploratory browsing and goal-directed exploration, system shall provide personalization options for users to set up preferences and add personal or cultural related POIs.*	N/A		To provide personal experience.
	Goal	3	For exploratory browsing and goal-directed exploration, users shall have an option to express and describe their needs to the system (P1:118;P2:33;P5:126).	*System shall provide an option for users to express and describe their needs directly at a particular moment.*	N/A	e.g., killing time, hungry, etc.	
	Recognizing / identifying/ locating/ orienting	4	For exploratory browsing and goal-directed exploration on mobile AR viewer, users shall be able to identify or recognize their own location and orientation, as well as obtain information about relevant POIs in their vicinity (P1:271;P4:243;PF2:44;P3:63;P3:75;P3:188;P4:78;P4:233;P5:249).	*For exploratory browsing and goal-directed exploration on mobile AR viewer, system shall provide users with information about their own location and orientation, as well as relevant POIs in their vicinity.*	Sp	Assisting information such as: Street: name, signs; Building: name, category; …	This requirement is important, because signs and street names help people locate and orient themselves.

Recognizing /identifying	5	For exploratory browsing and goal-directed exploration, users shall be supported the following specific ways (5a-c) to assist their recognition and identifying process (P1:246; P3:171;P4:224;P5:235;P5:238):	*For exploratory browsing and goal-directed exploration, system shall provide users with the following information:*		To support users mental models of knowing objects in the surrounding environment
	5a.	Prioritized and more detailed information, upon request, about POIs that are directly visible from the AR viewfinder, to assist user's "scan" activity; includes an option to reveal additional information;	*Prioritized and more detailed information, upon request, about POIs (that are directly visible from the AR viewfinder), to assist user's "scan" activity; includes an option to reveal additional information;*	Sp A	
	5b.	Less detailed information, upon request, about nearby POIs that are not directly or completely visible from the AR viewfinder; includes an option to reveal additional information;	*Less detailed information, upon request, about nearby POIs (that are not directly or completely visible from the AR viewfinder); includes option to reveal additional information;*	Sp A	
	5c.	Less detailed information, upon request, about distant POIs that are visible but vague from the AR viewfinder; includes an option to reveal additional information.	*Less detailed information upon request, about distant POIs that are visible but vague from the AR viewfinder; includes an option to reveal further information.*	Sp A	
Recognizing /identifying	6	For exploratory browsing and goal-directed exploration, users shall be supported by an image recognition feature in order to identify and highlight the requested POIs that are directly visible to the user (P1:164;P2:232;P6:285; P2:242; P1:285;P5:28;P5:274;P5F:107;P5F:124).	*For exploratory browsing and goal-directed exploration, system shall provide an image recognition feature to identify and highlight the requested POIs that are directly visible to the user.*	Sp A	

Recognizing /identifying	7	For exploratory browsing and goal-directed exploration, users shall be supported by information on "attention-catching" POIs that stand out in the environment (P3F:37;P2:208); and/or those that are goal-related (P4:327;P3:265; P1:355;P3:267;P6:366).	*For exploratory browsing and goal-directed exploration, system shall provide users information on "eye-catching" POIs that stand out in the environment (e.g., an architecturally-interesting building), as well as POIs that are goal-related.*	Sp A	"Attention-catching" objects, such as colorful and/or architecturally-distinct buildings, might not be used for navigation (different from Landmarks).	
			For exploratory browsing activity and goal-directed exploration, system shall increase the perceived visibility of user's interested POI in one's vicinity and provide its attribute information.	Sp A	(e.g., shopping for souvenirs, particularly used in contextual inquiry) (e.g., the kind of merchandise sold, pictures of items, how far the store is from current location, and expected price range).	This is an extended requirement.
Recognizing /identifying	8	For exploration and navigation, users shall be able to keep track of the following environmental cues (8a-h):	*For exploration and navigation, system shall provide environmental cues that users may keep track of:*			This requirement is important, because they help people locate and orient themselves.
	8a.	street information (e.g., street numbers/street signs) (P1:83;P2:115;P3:57;P4:74;P3:57; P4:34;P4:59);	*street information (e.g., street numbers/street signs);*	Sp A		
	8b.	store signs and company logos (P4:58;P4:74);	*store signs and company logos;*	Sp A		
	8c.	location of oneself (P5:87);	*location of oneself;*	Sp		

	8d.	direction to destination POIs (P1:94);	*direction to POIs;*	Sp		
	8e.	distance to destination POIs (P1:94;P4:127;P5:94; P5:87);	*distance to POIs;*	Sp		
	8f.	estimated time needed to reach a POI by taking into account various environmental factors (P1:94;P2:115;P5:94;P2F:78; P4:230);	*estimated time needed to reach a POI by taking into account various important environmental factors;*	T	(e.g., traffic patterns, crowded areas, and weather information)	
	8g.	dynamic pedestrian traffic (P1:133;P2:115;P5:94);	*dynamic pedestrian traffic;*	Sp T		
Recognizing /identifying	9	For exploratory browsing and goal-directed exploration, users' need to obtain more information about visual landmarks shall be supported on/from mobile AR viewer (P2F:36;P2F:42;P3:57;P3:225; P4:252; P4:255; P4:256).	*For exploratory browsing and goal-directed exploration, system shall provide users with information on visual landmarks on/from mobile AR viewer.*	A	visual landmarks (objects that are visually distinctive appeared in the user's natural field of view)	This requirement is important because a user's attention is naturally captured by distinctive visual landmarks (e.g., visually-unique, old, or tall buildings).
Recognizing /identifying	10	For exploratory browsing and goal-directed exploration, users' need to obtain more information about cognitive landmarks shall be supported on/from mobile AR viewer (P1:69;P2:134;P4F:127;P6:85).	*For exploratory browsing and goal-directed exploration, system shall provide users with information on cognitive landmarks on/from mobile AR viewer.*	A	cognitive landmarks (landmarks having unique meaning that stand out; they could be personally, culturally, or historically important)	
Recognizing /identifying	11	For exploratory and navigation, users shall have a consistent and interlinked interface among insight view and overview (P2:89;P5F:176).	*For exploratory and navigation, system shall provide a consistent and interlinked interface among insight view and overview.*	Sp A		

Search	12	For exploratory browsing and goal-directed exploration, users shall be able to perform varying types of searches within the mobile AR viewer with returned searching results (P3:58;P2F:69;P6:265;P4F:56;P5F:107;).	*For exploratory browsing and goal-directed exploration, system shall provide users search function that can perform varying types of search within the mobile AR viewer with returned searching results.*	A	search (e.g., image search and query search)	To provide search activity
Interface Support	13	For exploration and navigation, users shall be able to quickly scan information on mobile AR viewer to minimize the time spent on screen (P2:73;P5:150;P2F:75;P2F:114;P3F:83;P4F:132;P5F:59;P6F:50).	*For exploration and navigation, system shall provide users a quick and easy way to scan information on mobile AR viewer to minimize the time spent on screen.*	N/A		To prevent users from incurring physical risk. This is important because users tend to focus on the screen rather than pay attention to their surroundings.
Interface Support	14	For exploratory browsing and goal-directed exploration, users shall be supported with an adaptive interface that is constantly adapting to the user's behavior and buildup profile (P1:187;P2:55;P4F:89;P6:54;).	*For exploratory browsing and goal-directed exploration, system shall provide users with an adaptive interface.*	N/A		The time of visiting influences the user's perception of a POI from the mobile AR viewer.

Spatial boundary	15	For exploratory browsing and goal-directed exploration, users shall be able to receive spatial information that is automatically adjusted based on environmental factors (P1:188;P4:327).	*For exploratory browsing and goal-directed exploration, system shall provide users spatial information that is automatically adjusted based on environmental factors.*	Sp	environmental factors (e.g., the density of the information in the local environment)	e.g., if there are more objects in the surrounding area, the device should decrease the range to display a reasonable amount of objects on the mobile AR viewer. If there are only a few objects in the surrounding area, the device should not enlarge the range because this may distort a user's perception of spatial information
Spatial boundary	16	For exploratory browsing and goal-directed exploration, users shall be able to have and adjust the information range at will on a mobile AR viewer (P4:327; P5:133).	*For exploratory browsing and goal-directed exploration, system shall provide users a certain range as well as an option to adjust the information range at will on a mobile AR viewer.*	Sp		This requirement is important to provide users sufficient options that they can choose from and also avoid information clusters on mobile AR viewer.
Recognizing /identifying	17	For exploration and navigation, users shall be supported by a concept of "search & identify," enabled by an image recognition and identification feature in order to help users identify POIs at request, thereby assisting the natural human visual inspection activity (P1:164;P2:232;P6:285; P2:242; P1:285;P5:28;P5:274; P5F:107;P5F:124).	*For exploration and navigation, system shall provide users with a concept of "search & identify," enabled by image recognition and identification feature in order to help users identify POIs at request, thereby assisting the natural human visual inspection activity.*	Sp A		This requirement is different from Req. No.13 because it emphasizes the system's registration capability; in contrast, #13 stresses the importance of a search capability. These two could be represented in one concept" search & identify."
Recognizing /identifying	18	For exploration and navigation, users shall have an option to access the POI's visualization	*For exploration and navigation, system shall provide an option for users to access the POI's*	A		

		information, if applicable (e.g., real-time view, or photorealistic pictures) (P4:269; P5:276).	*visualization information, if applicable (e.g., real-time view, or photorealistic pictures).*			
Recognizing /identifying	19	For exploratory browsing and goal-directed exploration, users shall have an option to access specific POI attributes that cannot be easily described textually, if applicable (P3F:112;P2F:67;P4:193).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to access specific POI attributes that cannot be easily described textually, if applicable.*	A	(e.g., to gauge the atmosphere of a restaurant)	
Locating/ orienting	20	For exploration and navigation, users shall be supported by an interface to quickly check one's current location/orientation and a desired destination's location/orientation, if applicable (P2:154;P4:247;P5:145).	*For exploration and navigation, system shall provide an interface to allow users quickly one's current location/orientation and a desired destination's location/orientation, if applicable*.	Sp	(e.g., a semantic/distorted/ simplified map)	This requirement is important, because users have to check such information frequently during an exploration; and this may be intensified when the area is complex.
Noticing	21	For exploration and navigation, users shall have an option to be aware of the ongoing status of events or activities in their vicinity (P3:186;P4:234;P5:101).	*For exploration and navigation, system shall have an option to provide users with information about the ongoing status of events or activities in their vicinity.*	T		
Interface support	22	For exploration and navigation, users shall be supported with multimodal input and output to alleviate having to engage both hands in the mobile context (P1F:109;P1F:119;P2F:183;P6F:120;P4F:130).	*For exploration and navigation, system shall provide users with multimodal input and output.*	N/A	multimodal input (e.g., audio or hand-based gestural) and output (e.g., audio or haptic guidance).	This requirement is important because users tend to not engage both hands to operate a phone, especially in a street context where at least one hand might not be available. In addition, typing on a smartphone is awkward and easy to make mistakes in the

							mobile context.
	Interface support	23	For exploration and navigation, users shall have a mobile AR interface with a glare-free screen, operating properly under varying light conditions (P3F:56).	*For exploration and navigation, system shall provide users a mobile AR interface with a glare-free screen, operating properly under varying light.*	N/A		
	Interface support	24	Users shall have accurately tracked, registered and displayed augmentation on mobile AR viewer (P2F:75;P2F:114P3F:83;P4F:132; P5F:59).	*System shall provide users with accurately tracked, registered and displayed augmentation on mobile AR viewer.*	N/A		To provide people a feel of "live feed view" as a more real-time experience to match their mental model of mobile AR
Comprehension	Acquiring overview	25	For exploratory browsing and goal-directed exploration, on mobile AR viewer, users shall be supported by an overview of spatial patterns and relationships of POIs in one's vicinity regarding some aspects of attributes (P3:196;P4:243;P4:248;P5:260;P5:47;P5F:44;P4:28;P5F:50;P4F:85;P4:243;P5:260;P6:272).	*For exploratory browsing and goal-directed exploration, system shall provide users an overview of spatial patterns and relationships of POIs in one's vicinity regarding some aspects of attributes.*	Sp A So	An overview of spatial patterns and relationships can be supported by, e.g., a map, a World-in-Miniature (WIM)) of POIs regarding their attributes (e.g., names, ratings etc.) in user's vicinity.	
	Acquiring overview	26	For exploratory browsing and goal-directed exploration, users shall have an option to perceive an overview on mobile AR viewer (P2F:89;P2F:165;P2F:86).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to perceive an overview on a mobile AR viewer.*	Sp	(e.g, a combined use of egocentric and an exocentric views).	This requirement is different from Req. No. 25 in that it emphasizes the need for an overview-focused feature to be directly positioned in the AR viewer to establish spatial mapping.

Quantifying/ Estimating amount	27	For exploratory browsing and goal-directed exploration, users shall have a way to know the amount of POIs sharing one or more attributes under query in one's vicinity (P2F:44;P2F:52;P4F:49;P4F:54;P4F:57;P6F:65).	*For exploratory browsing and goal-directed exploration, system shall provide the amount of POIs sharing one or more attributes under query in one's vicinity*	A	(Attributes of a group POIs) The number of requested POIs sharing one or more attributes (e.g., same category or sub-category of POIs)	- Users struggling with quantifying places around -Users afraid of missing sites on the mobile AR viewer
Interface Support	28	For exploratory browsing and goal-directed exploration, users shall be supported with a progressively disclosed interface to gradually receive information at request (P1:66;P1:75).	*For exploratory browsing and goal-directed exploration, system shall provide users a progressively disclosed interface to reveal more detailed information upon user request.*	N/A		Progressive disclosure is useful when a significant amount of information should be presented to users.
Acquiring overview	29	For exploratory browsing and goal-directed exploration, users shall be able to have a way to know the spatial relationships of the POIs sharing one or more attributes under query (P2F:103; P3F:70;).	*For exploratory browsing and goal-directed exploration, system shall provide users the spatial relationships of the POIs sharing one or more attributes under query.*	Sp A		To provide quantities and amounts for users to choose from

Acquiring patterns	30	For exploratory browsing and goal-directed exploration, users shall be supported with information that locally-based individuals uniquely possess (P1:52;P5:61).	*For exploratory browsing and goal-directed exploration, system shall provide users with information that locally-based individuals uniquely possess.*	A S	Locally-based individuals are aware of what could be the best places to visit, the fun things to do, the best places to eat, the safe or unsafe sections of town, and specific sections of town to target based on interests.	This type of information is important, because they are not directly perceivable and accessible to users.
Acquiring relations and comparisons	31	For exploratory browsing and goal-directed exploration, users shall be supported with a ranking mechanism that can rank POIs based on one or more attributes at request (P2F:70;P5:163;P6;94;P3:211;P1:305).	*For exploratory browsing and goal-directed exploration, the system shall facilitate a ranking mechanism that can rank POIs based on one or more attributes at request.*	Sp	e.g., rank by distance from near to far	
Acquiring relations and comparisons	32	For exploratory browsing and goal-directed exploration, users shall be able to have an option to compare alternative POIs under query in a quick and easy way (P2F:70;P2F:180;P3F:64).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to compare alternative POIs under query in a quick and easy way.*	A	(e.g., 2 or 3 POIs)	To provide a mechanism to reduce users' short-term memory load when comparing
Interface Support	33	For exploratory browsing and goal-directed exploration, users shall be provided with an interactive AR view with augmentations enabling direct manipulation (P1F:18;P2:94;P2:273).	*For exploratory browsing and goal-directed exploration, system shall provide an interactive AR view with augmentations enabling direct manipulation.*	N/A	e.g., remove POI augmentations at user's will	

Acquiring relations and comparisons	34	For exploratory browsing and goal-directed exploration, users shall be supported with a view by which users can browse information semantically in a categorical way (P1F:75;P3F:75;P4F:85).	*For exploratory browsing and goal-directed exploration, system shall provide users a view whereby users can browse information semantically in a categorical way*.	Sp A	e.g., a table view
Acquiring relations and comparisons	35	For exploratory browsing and goal-directed exploration, users shall be provided with a filter mechanism (P5F:124;P1F:18;P2:273).	*For exploratory browsing and goal-directed exploration, system shall provide users with a filter mechanism.*	A	e.g., filtered by certain criteria on POI at request
Acquiring relations and comparisons	36	For exploration and navigation, users shall have an option to access alternative paths along with corresponding POI information to the destination (P3:211;P1:305).	*For exploration and navigation, system shall provide users an option to access information about alternative paths along with corresponding POI information to the destination.*	Sp A	
Acquiring relations and comparisons	37	For exploration and navigation, users shall be made aware of POIs of potential interest based on a pre-established user profile, which could serve as alternative paths to the destination (P5:163;P2;94;P3:211;P1:305).	*For exploration and navigation, system shall provide users personalized information about other POIs of potential interest that are located on the path to the pre-selected POIs.*	Sp A	
	38	For exploratory browsing and goal-directed exploration, users shall have an option to set up and receive location-based (spatial) reminders of POIs of potential interest on their way to the destination (P5:163;P2;94).	*For exploratory browsing and goal-directed exploration, system shall provide an option for users to set up and receive location-based (spatial) reminders of their potentially interested POIs on their way to the destination.*	T	This should not be intrusive (option to turn off) when the user is not in an "exploration" mode.

Acquiring relations and comparisons	39	For exploratory browsing, goal-directed exploration and goal-directed navigation, users shall be provided at will with information about POIs sharing one or more attributes *or* alternatives (if applicable) (P1:231;P1:368;P2:333; P3:320; P4:389;P4:295;P3F:71; P4:295;P5:289;P6:401).	*For exploratory browsing, goal-directed exploration and goal-directed navigation, system shall provide users at will with information about POIs sharing one or more attributes or alternatives (if applicable).*	A		
Acquiring relations and comparisons	41	For exploratory browsing and goal-directed exploration, users shall have an option to be informed of information about POIs in their current vicinity and in the vicinity of their destination(s). (P6F:101;P4F:123;P4F:165;P6F:101).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to be informed of information about POIs in their current vicinity and in the vicinity of their destination(s).*	Sp		
Acquiring relations and comparisons	42	For exploratory browsing and goal-directed exploration, users shall have information with a uniformed layout, *varied* for different types of POIs (P3:183;P5:105).	*For exploratory browsing and goal-directed exploration, system shall provide users information with a uniformed layout, varied for different types of POIs.*	A		Users have varying interests on different types of places (e.g., tourist locations vs. restaurants)
Interface support	43	Users shall be able to interact with mobile AR viewer analogous to interactions with a touch-screen-based camera (P8:89;P5F:107;P5F:124).	*System shall enable users' interaction with mobile AR viewer analogous to interactions with a touch-screen-based camera, or other similar mental models to establish a familiar user control concept.*	N/A	e.g., zooming, panning, and saving	Users tend to have a connection between a touch-screen-based camera interface and a mobile AR. Therefore, it is important to utilize the user's mental model of a more familiar concept.

	Interface support	44	Users shall be able to save POIs for later access at will (P2F:70; P2F:180; P3F:64).	*System shall provide users a feature to save POIs for later access at will.*	N/A		
	Context support	45	Users shall be supported via personal context information in their vicinity (P1:221;P3:164;P4:208; P2:176; P5:219).	*System shall provide users with personal context information in their vicinity.*	N/A	e.g., translated to a preferred language on signs and landmarks (that indicate direction and location, “attention-getting,” and instruction)	
	Interface support	46	Users shall be able to make changes and adjustment quickly on path and destination selection (P2:94;P3:74).	*System shall enable users to make changes and adjustment quickly on path and destination selection.*	N/A		
Projection	Projecting-real-time	47	For exploratory browsing and goal-directed exploration, users shall have an option to be informed of real-time crowd/pedestrian flow associated with local events (P1:133;P2:115;P3:57;P3:225).	*For exploratory browsing and goal-directed exploration, system shall provide an option to inform users of crowds/pedestrian flow associated with local events to stimulate an exploration or to provide cues of where a busy area is.*	Sp T A So		
	Projecting-past experience	48	For exploratory browsing and goal-directed exploration, users shall be supported upon request with trends that reveal or confirm information that can be used to establish a trend of experiences in one POI to assist in making projections in their (near) future visit (P1:140;P4:376;;P4F:130P5F:110; P5F:75; P5F:114;P5F:119;	*System shall provide users upon request with an option to have trends that reveal or confirm information that can be used to establish a trend of experiences in one POI to assist in making projections in their (near) future visit.*	T A So	e.g., a simplified histogram chart; information of last week's situation;	This information could help users start to “build up the image” of the POI.

			P5F:120;P5:330;P5:339).				
	Projecting-real-time	49	For exploratory browsing and goal-directed exploration, users shall, upon request, be made aware of the real-time information of a POI regarding its dynamic and interactive aspects, thereby enabling a user's projections of its future state. (P1:100;P1:363;P1:370;P2:44;P3:225;P2:337P3:320;P4:322;P4:391;P5:339;P5:326;P6:144;P6:392;P6:380;P6:407;P1F:72;P1F:82;P2F:169;P4F:145;P4F:152;P5F:112;P5F:114;P5F:115).	*For exploratory browsing and goal-directed exploration, system shall provide users, upon request, the real-time information of a POI regarding its dynamic and interactive aspects, thereby enabling a user's projections of its future state.*	T A So	-Live performance information or dining suggestions (e.g., information about the artists, the venue, etc.; updates about restaurant waiting time; a real time indicator for seat availability) -a live feed to see how busy/popular a place is	When situation is not dynamically changing and the subject matter is relatively unimportant to the user, providing real-time information is not necessarily important.
Others	Social	50	For exploratory browsing and goal-directed exploration, users shall have an option to interact with locally-based individuals or other users for spontaneous or planned social interactions (P1:334;P2:66;P5:110).	*For exploratory browsing and goal-directed exploration, system shall provide users a feature that enables social interactions with locals.*	So		To support social participation and collaboration
	Temporal	51	For exploration and navigation, users shall have an option to set up and receive temporally-relevant information reminders at will (P3:81;P5:116).	*For exploration and navigation, system shall provide an option for users to set up and receive temporally-relevant information reminders at will.*	T	e.g., going to a place at a pre-determined time; having an inflexible schedule;	

Attribute	52	Users shall be provided with safety information about neighborhoods/areas of an unfamiliar place under query (P5:87;P6:101;).	*System shall provide users with safety information about areas or neighborhoods of an unfamiliar place under query.*	A	To prevent users from getting into danger

4.1.2.1 Components of SA

In addition to user requirements, the four SA components (spatial, temporal, identity, and social) were identified. Because the research question involved identifying a user's SA requirements in the context of mobile AR-enabled urban exploratory navigation, the frequency associated with each component was not reported for two reasons: 1) the purpose was to capture a profile of each SA component as completely as possible, and 2) the frequency would matter more in a more specialized study of each individual component.

The *spatial component* of SA involves knowing the spatial boundary, location, direction, and distance of places and possibly moving objects and persons (including oneself) in surroundings.

The *temporal component* of SA consists of three aspects: 1) the dynamically-associated aspects of POIs, 2) perceived time available to oneself, and 3) association of spatial motion with time. These three aspects were applied in three ways: 1) the usage of mobile AR guidance application, 2) on exploratory navigation decision-making, and 3) on behavior of exploratory navigation.

The social component of SA involves user-summoned digital information, user-summoned physical information, inquiring friends about POIs, and inquiring locals/other visitors about POI information.

The identity component of SA requirements was organized into an identity table, shown below in Table 13. This output served two purposes: 1) it helped to single out important aspects regarding major elements required for the achieving and maintaining SA in exploratory navigation in an urban context; 2) it was found to be useful for developing queries designed to assess a user's SA in the evaluation study, which is detailed in the evaluation session.

Table 13. Identity component of SA requirements for mobile AR-enabled urban exploratory navigation

Major Elements	Major Identity Components
Tourists Attractions	Similar places, direction, distance, navigational information, transportation information, the route to the place, pricing, exact description, history, language, culture, waiting information, opening/closing hours;
Restaurants & Drinks	Local food, traditional food, pricing, reviews, ratings, menu, waiting time information, reservation service, the route to the place, the area information, information about atmosphere, live entertainment in the restaurant;
Shopping area	Temporal deal, sale, discount information, products that are available at the various stores, different shops at the mall, reviews about shopping experience by other customers;
Event	Live concert, street show, temporal exhibit, live music, band, attention-drawing things/local events happening on street;
Transportation	Information about transportation, available alternatives, real time bus schedules, estimated duration and time of arrival to the destination, ticket price;
Functional POIs	Nearby ATMs of one's bank, hotels, etc.

4.1.3 SA Queries for Measurement

SA queries (queries and query variants) were generated based on finalized user requirements in categories of perception, comprehension and projection (Appendix W). These queries (queries and query variants) were then revised in Study 2 based on the designed interfaces in interface evaluation as a measure of SA.

4.1.4 Mobile AR Interface and Related Characteristics

4.1.4.1 Usability issues of the provided mobile AR interface

Due to the fact that an existing mobile AR guidance application was used in Study 1—and the usability of this tool might have influenced the results obtained above—the usability of this specific tool was examined analytically in two ways. First, based on the results of users' think-aloud, several usability issues were identified and ranked (Figure 16). In addition, a cognitive walkthrough was performed by an independent graduate evaluator (specializing in human computer interaction and usability) to avoid the bias that the researcher would have introduced into the evaluation had it not been performed by an independent evaluator.

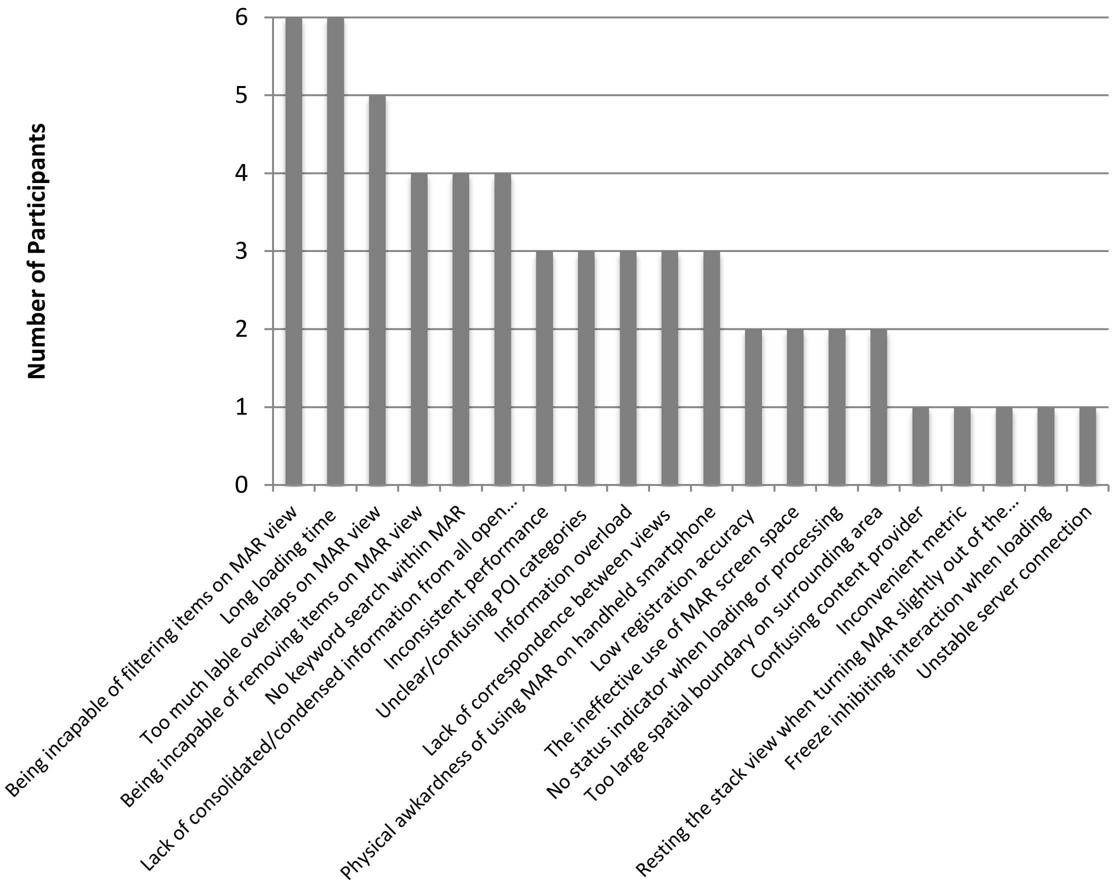

Figure 16. Usability issues of the provided mobile AR interface (i.e., the Wikitude interface)

The cognitive walkthrough, which represents a usability inspection method, is a precisely specified procedure for simulating a user's cognitive process as he/she interacts with an interface to perform a specified task. Following a widely-used method proposed by Polson (1992) over 20 years ago, the researcher prepared and provided a form with specific questions, along with an IOS smartphone, for the evaluator to perform a cognitive walkthrough on the provided interface (i.e., the Wikitude mobile AR application). The evaluator then spent approximately 10 hours using this method to inspect the Wikitude interface. Throughout the evaluation phase the evaluators recorded answers and described problems on the card. Due to the excessive length of the document originally filled out by the evaluator, only the set of questions pertaining to the cognitive walkthrough is included in Appendix V . Various usability issues concerning the interface are detailed below.

4.1.4.2 Negative feedback on the provided mobile AR interface

Reliability and response time

Reliability: Even though reliability issues are not strictly usability problems, they can lead to usability problems and thus have significant negative impacts on performance. In this instance, when the system did not work as predicted, users created workarounds and generated faulty mental models of the operation. Another issue pertaining to reliability was that there were technical difficulties when interacting with the mobile AR viewer.

Response times: Users would become frustrated when the loading time exceeded their expectations. Specifically, the loading time was up to 20 seconds when it typically only took about 5 seconds. The evaluator reported that she had to close the application and re-open it to get it to work.

Usability

Data inconsistency: Users might experience problems with data inconsistency. In other words, depending on the venue or Points of Interest (e.g., restaurant, event, historical location), there was variability in how much detail the application provided.

Lack of application of UI standards; lack of a consistent system model: Users might have problems in the following areas: (1) the labels were too small to tap; (2) the buttons (e.g., the list button and map button) were too small to tap, especially when users might be operating the application while walking; (3) the distance (or range) adjusting function was not obvious to users.

Lack of user control: The evaluator indicated that label interactions were generally inconsistent. For instance, it was difficult to tap with changing positions on the mobile AR viewer when slightly rotating to a different angle. This might result in a feeling of a lack of complete control in operating these labels. Moreover, navigation wasn't always consistent as evidenced by the fact that the "go back" button was not available all the time. Similarly, the "close" button was also not routinely available to users.

Visual design; Poor usage of real estate: The evaluator reported that the description box was not used economically and occupied too large a portion of the screen real estate. Additionally, participants felt the contrast should be enhanced with a different color scheme.

4.1.4.3 Positive feedback on the provided mobile AR interface

In contrast to negative issues associated with the provided mobile AR interface, participants did indicate some plusses. As shown in Figure 17, users indicated that it had some entertainment value, which it was more interactive, relatively simple to use, easy-to-orient, reasonably accurate, easy-to-understand, and provided some embedded information that was not shown on map (e.g., Wikipedia).

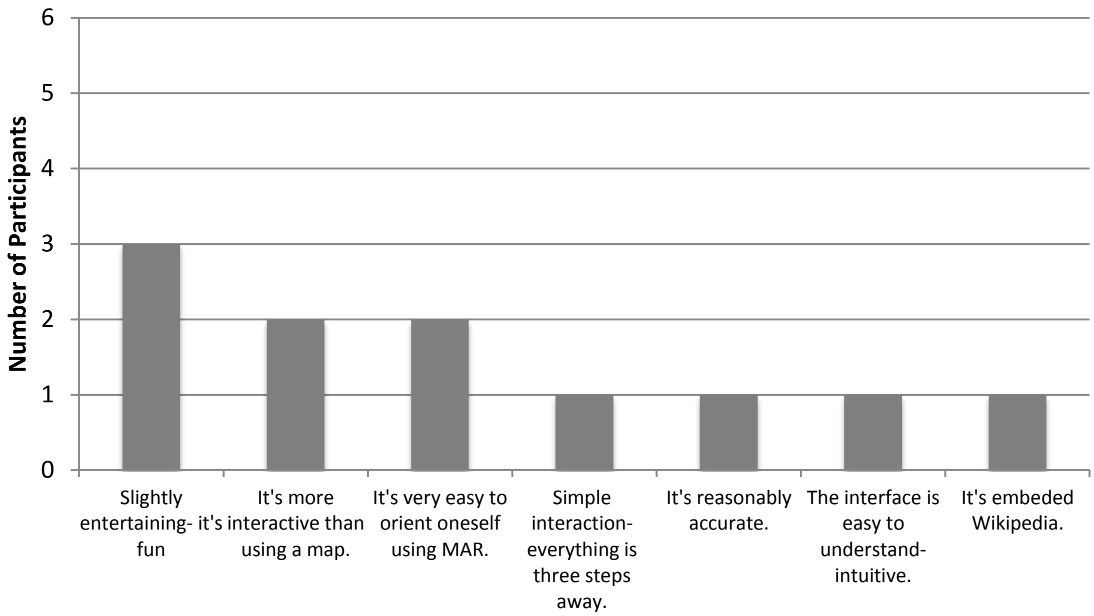

Figure 17. Positive feedbacks of the provided mobile AR interface (i.e., the Wikitude interface)

As reported by users, compared to other types of interfaces, the mobile AR guidance application was generally good in five areas: 1) providing more exploration opportunities—i.e., finding things that a user was not specifically looking for (more being aware of things); 2) providing more readily available information without searching for it during the initial step; 3) providing direction and orientation information; 4) being a visual solution for providing guidance and navigation information; and 5) being able to pinpoint where things are in browser when one is close to the place or when the sign is not clearly identifiable by natural visual inspection. A more detailed explanation for each of these advantages is provided in Table 14 and the number of participants from where these items were extracted is provided in Figure 18.

Table 14. Advantages of mobile AR

Advantages of Mobile AR	**Explanation**
Providing more exploration opportunities; finding something that a user was not looking for; being aware of things	In browsing, a mobile AR is/could be good at helping spot and identify hidden places that one might not notice without guidance, for instance, a “hole-in-the-wall” type of restaurant, some historical markers. “I find myself getting to know better an area that I already thought I knew pretty well.”
"More readily available information." "Short information right away." "Do not need to search or click for it"	Brief information on mobile AR is readily available on the AR viewer. This hints that this type of display provides short-labeled information that does not tax the user’s mental workload.
Providing direction and orientation information	Mobile AR is good for direction and orientation and conveys such information intuitively to users. “It's difficult to figure out which direction is which direction without mobile AR.”
Helping answer two questions: "Should I go there?" and "How would I go there?"	Mobile AR is actually a visual solution in terms of providing guidance and navigation information to users.
Complementing human visual inspection. "It's more a pinpointing tool."	It could be used to pinpoint where things are in browser when one is close to the place or when the sign is not clearly identifiable by visual inspection.

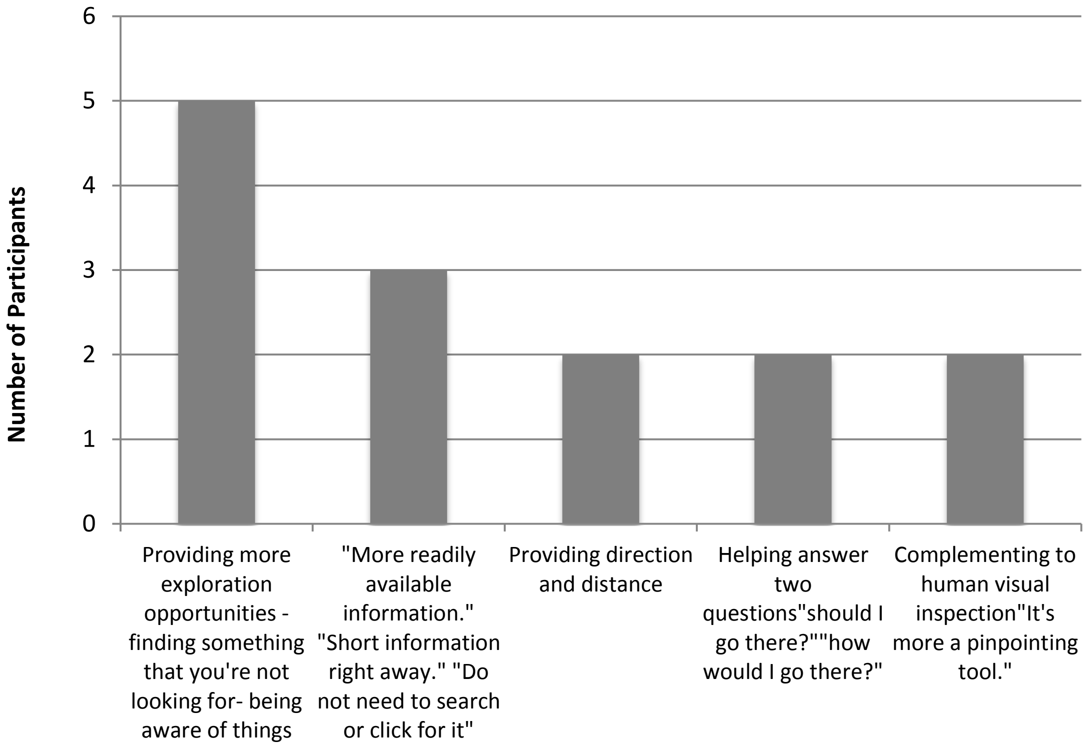

Figure 18. Differences due to mobile AR interface

As indicated by participants, the role of the mobile AR in exploratory navigation can be divided into four general categories: 1) it's more like a virtual guide that helps people decide where to go; 2) it's more like an entertainment tool that gives people a bit fun in using it; 3) it helps find things that one didn't notice before; and 4) it is used to find widely known attractions and things hard to search on maps such as Wikipedia information about an attraction. Figure 19 shows the number of participants associated with each response category.

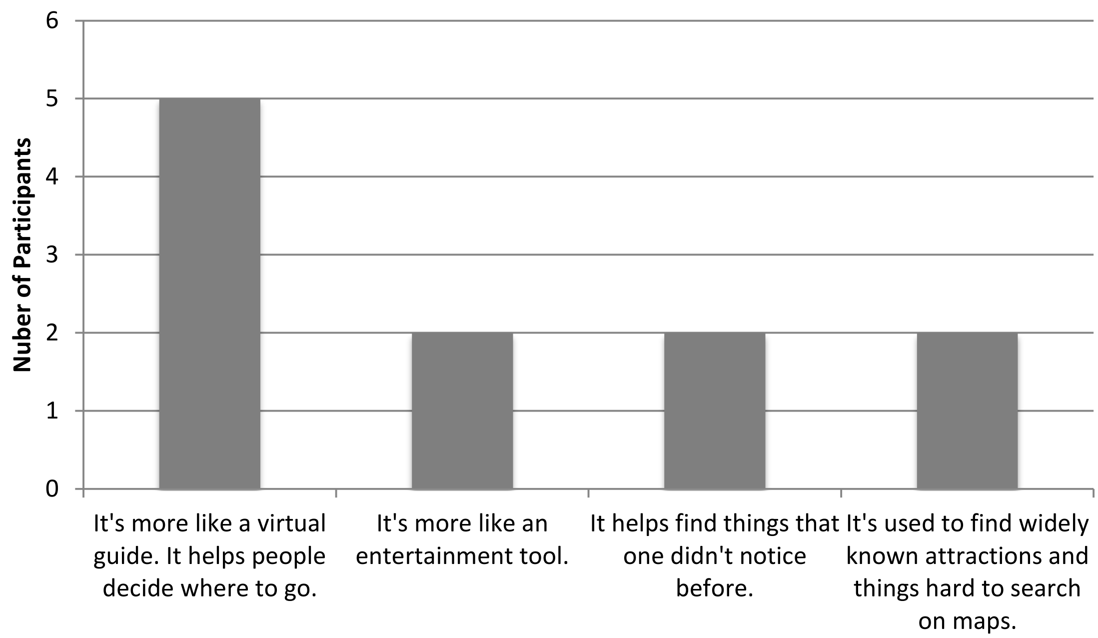

Figure 19. Role of mobile AR in urban exploratory navigation

4.2 Conceptual Design and Prototype Development

Up to this phase of the study, SA information requirements and mobile AR tasks were identified for use in urban exploratory navigation. From a design perspective, successful interface design requires researchers to develop a detailed, multifaceted understanding of user needs. Therefore, the interface should be designed to support situation awareness by augmenting the user with important and task-relevant information in such contexts, as well as to transform identified users' SA requirements into appropriate design specifications. As a first step in the conceptual design and prototype development phase, the identified information needs were used to create use scenarios employing a scenario-based design approach originally proposed by Carroll (1995). These scenarios represented mobile AR user needs in the context of urban navigation.

Designing a mobile AR interface takes significant skill and time. As indicated by Feiner et al. (1993), as the richness and variety of information that a system is able to present to a user increases, so does the design complexity. This means that in addition to the build-up of information architecture, a number of specific design solutions need to be solved. To achieve this, a variety of interface design principles and guidelines were referenced, including interface design guidelines for a mobile AR system (Furmanski et al., 2002), general interface design guidelines (Shneiderman & Plaisant, 2010), and general mobile interface design guidelines (e.g., iOS Human Interface Guidelines).

4.2.1.1 Development Procedures

To create the two prototypes (SA-supported interface and baseline interface), two locations in New York City were selected. Images were shot at the selected location and videos, which were used for concept evaluation, were filmed at different POIs. The selected locations were busy street intersections, venues such as shops and buildings, and people walking and standing in different areas. These locations were purposefully selected; they represented places where users usually go to do navigation. A set of images was captured at each selected location, after which they were edited by overlaying augmentation on the images using Adobe Photoshop[31] software. A slideshow of screens created by Power Point were used to achieve a low-fidelity interaction effect.

4.2.2 Design Lifecycle and Scenario-based Design

The translation from requirements to design is often regarded as the most difficult step in the lifecycle process. Based on established research (Hartson & Pyla, 2012), a macro view of lifecycle and its iterations in design was created (Figure 20). Each type of design has its own iterative cycle with its prototype and evaluation. The amount of and kind of design, prototyping, and evaluation were adjusted to fit the circumstances and context of this study. These activities often overlap in practice. Sample sketches and storyboard are included in Appendix T .

[31] http://www.adobe.com/products/photoshopfamily.html?promoid=JOLIW

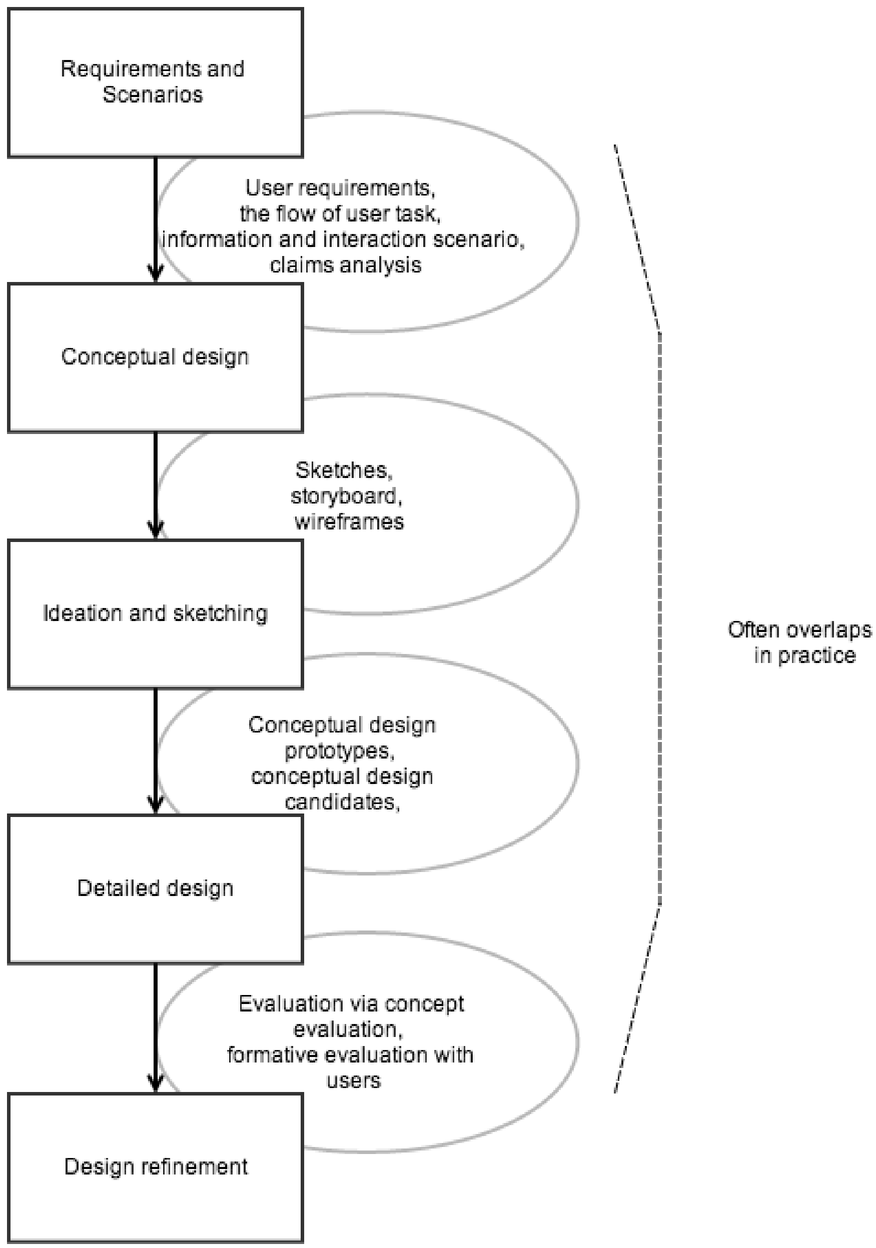

Figure 20. A macro view of lifecycle and its iterations in design

One type of information and interaction design method is scenario-based design, which is an established method that focuses on the activities in the design process of information systems (Carroll, 1995a, 2000, 2002; Go & Carroll, 2004). A scenario is a narrative description of an activity performed by an individual who occupies a specific role in a specific context (Carroll, 2000; Go & Carroll). This term also refers to a narrative of a successful path through an information system (Reeder & Turner, 2011). It describes everyday tasks in plain language, making it easier for communication and discussion of designs among designers and domain-specialists. The process of scenario-based design is shown in Figure 21.

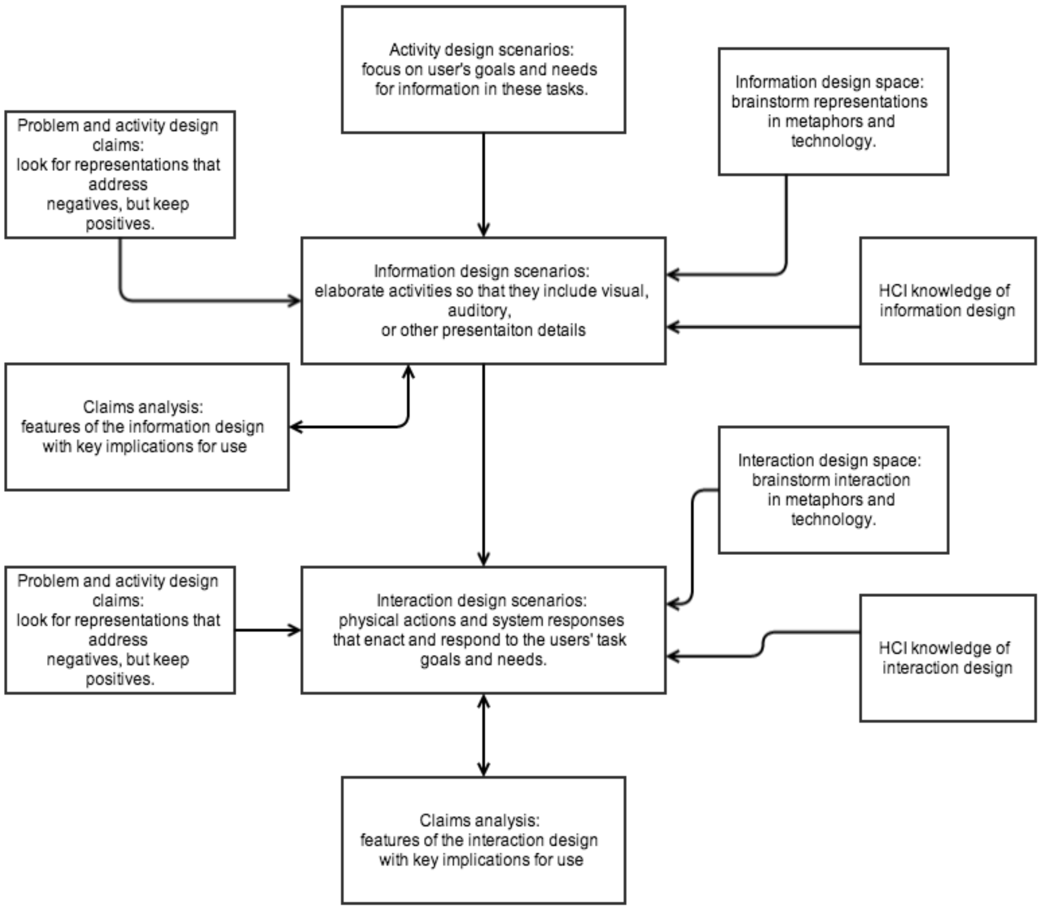

Figure 21. The process of scenario-based design

Use scenarios were constructed based on the extracted SA user requirements from Study 1. Generating design scenarios is a time-consuming and team-oriented iterative design activity. Examples of a generated problem scenario, an activity design scenario and an information/interaction design scenario are provided in Figure 22, Figure 23, and Figure 24. Once the information architecture was developed, a number of specific design questions had to be answered, such as the following two: Should a POI be represented with a floating information bubble, a billboard, a marker, or some other graphic? What methods should be available for the user to filter or search the possible results? To answer these questions, the claims analysis technique was used to generate specific information and interaction solutions (Rosson & Carroll, 2002). This method requires the designer to determine the pros and cons related to the proposed information and interaction design. For example, one concern about providing a “layers” concept was that users might be confused about the categorization of POIs. In contrast, an advantage was that it could serve as a filter mechanism. In other words, everything does not have to be displayed on the mobile AR viewer at the initial activation, thereby reducing the viewer’s visual complexity.

A full claims analysis, along with corresponding user requirements with respect to information and interaction design scenarios, is provided in Appendix S .

Example Problem Scenario

Andrew is a 20-something graduate student. He enjoys using his technology gadgets during off-work hours. He owns a cutting-edge smartphone, which is routinely updated with the latest operating system. Since he has a smartphone and he is a somewhat of a tech-lover, he checks the latest tech news every couple of days, and downloads or purchases mobile apps that attract him, which he finds with “app-recommending apps.”

As a student, Andrew doesn’t have a lot of time or discretionary income. However, he enjoys personal travel, taking part in family events, or just hanging out with friends. He especially likes metropolitan areas with their diverse architecture, varied choices in restaurants and coffee shops, and entertainment opportunities. All seem to be attractive to him.

After the semester ended, Andrew was invited to a wedding in X city, which he had never visited before. Knowing he would have some free time, Andrew wanted to plan ahead before traveling to the wedding destination, so he used his laptop to map out some “must-go” or “much-try” places that the web recommended. He also took short notes on his smartphone on where he wanted to go and what he wanted to see. He also made a rough plan on how to spend time at various places. On his way to the destination, he updated the mobile AR app that he used whenever he needed to get around a place.

Since he arrived in City X right after the semester finished, he was only able to do a little homework about the city. But given the little he does know about it, he is very excited!

Now he is in the downtown area, which is a mixed business-entertainment district. In fact, it is one of the busiest areas in the city where most people go for attractions, museums, entertainment, shops, or simply to hang out and experience the metropolitan culture. He looks at his smartphone and it’s 4PM. He feels like walking around to check out this place so he can plan out the things that he can probably do at night. Tomorrow some of his local friends will accompany him as he continues to explore the rest of the city.

Figure 22. An example of problem scenario

Example Activity Design Scenario

Andrew has just emerged from a subway station and is standing at an intersection. Because he is going to visit some major attractions tomorrow with a local friend, he decides to just walk around the downtown area but he isn't sure where to go now.

He holds the mobile AR guidance tool. He looks at the subway schedule and decides to come back around 9:50PM to catch the train. Then he turns around to browse what is around his immediate vicinity to get an idea of the place, such as nearby buildings and shops, as well as what is happening right now with some events nearby, such as live music performance, street shows, and store sales. He also wants to look at tweets that have been posted about this area to see what people generally do here, so perhaps he could join later.

He decides to walk around. With the mobile AR tool, he sees a toy store right in front of him, which is floor-upon-floor of all kinds of toys. Andrew has no particular interest in mass-produced toys, but he decides to browse anyway since he has the time and the window displays are so engaging. He then finds out from the mobile AR tool that it is a family-owned store that is big on customer service. It is also well known for its fabulous array of plush toys, games, and puzzles. "This might be a fun place to walk around for a bit." Andrew thinks. He then discovers that it has an excellent selection of handmade trucks, buses and wooden subway car replicas. "Oh that is something I've got to see! I love car replicas. All kinds!" he thinks.

Then he turns around and an interesting shaped building appears before him. It is several blocks away but still tall enough for him to see. "What is this? It looks interesting." It is a hexagon-shaped building, a little bit like a honeycomb. He finds out it is one of the city's iconic skyscrapers, representing its designer and the city as memorably as anything else. Some fast facts come to him. For starters, it only took 13 months to build. Also, there is no observatory or open area on top. The public can only get as far as the plaza level. He also finds out on the plaza level there is a bookstore, and that a new book release is occuring right now. He looks at this information and sets a "pass-by" notification on it in case he has a chance to stop by and check out the place and this event.

He keeps browsing by turning on the event/activity layer and views more events happening at that moment or later in the day. But it seems nothing else looks as enticing to him as the toy store with its wooden vehicle replicas. After viewing the tool for couple of minutes, he decides to cross the intersection and check out the toy store first.

One hour later, he emerges from the store and walks down the street, passing more shops. He now feels hungry and wants to find at least a three-star Italian restaurant—preferably one that's not too expensive and with live music. He looks it up on his mobile AR application and finds out that there are six Italian restaurants within 20 minutes walking distance from where he is. After viewing information about each of them, he decides to go to the one called "Gusto," which is an 18-minute walk, or just under a mile.

Figure 23. An example of activity design scenario

When Andrew turns on the "eye" icon on the panel of his mobile AR screen and points it to the subway, the subway schedule is shown on screen. He determines that the train he wants to take will leave at 9:50 PM, so he books the e-ticket, saves it, and sets an alarm for 8:50 PM.

While the browsing mode is active, he begins to browse his surroundings, which is displayed in pre-set layers through the AR viewer. He sees building and streets in front of him with color highlights on the viewer. He taps on one of them. A short description about "Zooba Toys" shows up, including a brief textual write-up about the store, an tappable "items" button that reveals all available categories of toys, a real-time camera view button, which when tapped reveals a real-time view of the main floor from an overhead angle (without revealing people's facial information), and a "more" button to reveal more information about the place.

When Andrew taps on the interesting shaped building down the street, a short description about the place also shows up. Among featured events listed on the building page, an events page pops up with brief textual information, a real-time camera view, and real-time tweets, such as event updates and other information posted by visitors. He sets up a pass-by notification using a "pass-by reminder" button.

He taps on the restaurant layer icon on the panel of his mobile AR screen and then taps to select the three-star requirement, the $3-$4 button (indicating affordable for a college student), and then holds it up in front of him. He filters down to 8 restaurants. He first brings up the map view with interactive radar at bottom to have an idea of where they are located in relation to him. Because he is hungry, he brings up a table view of the restaurants within 20 minutes walking distance from him by tapping on the 20-minutes ring. On each individual restaurant page, it shows hours of operation, menu, aggregated reviews, current seat availability, and reservation services in textual information; additionally a real-time camera view button shows the counter view and waiting area, while an overhead view displays more of the restaurant without revealing any facial information about customers. He chooses one out of the alternatives and sets up the navigation to that location.

Figure 24. An example of information/interaction design scenario

4.2.3 Interface Design Principles and Guidelines

To provide effective design solutions—such as answering "What font size should be displayed?", various interface design principles and guidelines were referred to and checked out in terms of conceptual design solutions on the mobile AR interface and experimental mockups. These included general interface design guidelines (e.g., Gestalt Theory, Shneiderman's Eight Golden Rules of Interface Design), design guidelines for mobile platform (e.g., iOS Human Interface Guidelines), and interface design guidelines for mobile AR system.

4.2.3.1 General Interface Design Guidelines

As indicated, a number of visual design principles have been thoroughly examined and documented in the graphic design literature. Examples include Gestalt Theory, which is comprised of a set of design principles based on human visual perception: proximity, similarity, continuity, symmetry, closure, relative size, figure and ground (Koffka, 1963), clarity (MacEachren, 2004), visual contrast, order, grouping, unity, harmony, structure & balance, focus & emphasis, and visual hierarchy. One of the best-known sets of interface design principles is probably Shneiderman's Eight Golden Rules for Interface Design (Shneiderman & Plaisant, 2010) (Table 15).

Table 15. Shneiderman's eight golden rules for interface design

No.	Rules
1	Strive for consistency
2	Cater to universal usability
3	Offer informative feedback
4	Design dialogs to yield closure
5	Prevent errors
6	Permit easy reversal of actions
7	Support internal locus of control
8	Reduce short-term memory load

The simplicity of a system (i.e., supported by a simple interaction modality) is critical to mobile system design (Jarman, 2011). This is particularly important for information systems used in an outdoor context—mainly because a mobile user is likely to use the application while moving (Borgia et al., 2012).

4.2.3.2 Design Guidelines for Specific Mobile Platform

In addition to consulting general design principles, this study also followed design guidelines provided for developers of design mobile interfaces. Specifically, in developing the conceptual prototype, the following guidelines were examined: KDE[32] (Human Interface Guideline (HIG)) or GNOME[33] interface guidelines; guidelines for the mobile interface that used a mobile platform, and iOS Human Interface Guidelines[34]. These various sources address specific design patterns regarding layout, navigation, color and typography, icons and graphics, UI elements (bars, content views, controls, temporary views), and icon and image design.

[32] KDE is an international free and open software community producing cross-platform applications, which can be accessed at http://techbase.kde.org/Development/Guidelines

[33] GNOME is a graphical user interface composing of free and open source application software, which can be accessed at http://developer.gnome.org/hig-book/stable/

[34] iOS human Interface Principles is a set of interface principles used by iOS designers and developers, which can be accessed at https://developer.apple.com/library/ios/documentation/userexperience/conceptual/mobilehig/index.html#//apple_ref/doc/uid/TP40006556-CH66-SW1

4.2.3.3 Conceptual prototype of mobile AR Information Systems

A conceptual prototype is a concrete representation with an embedded story or scenario that shows action at a very high level (Carroll, 1995; Erickson, 1995). The prototype could be a videotape or a partially interactive product demonstration, where small amounts of interactivity, animation, or soundtrack can be added (Carroll). Users may feel hesitant about criticizing a fully functional prototype since they may believe the system is completely finished and that the feedback they provide will not matter that much. Therefore, a conceptual prototype has an advantage in that users can interact with it –e.g., conducting pre-determined tasks—and feel more comfortable giving feedback or criticizing the design of the (preliminary) prototype (Lazar et al., 2009). Therefore, to provide a good conceptual prototype, the mockups used in Study 2 were prototyped to be sufficiently convincing so that end users would believe it was a realistic depiction of the end produce. Care was taken, however, to clarify to users that what was being shown was a product concept, and not the product itself (Lazar et al., 2009).

4.2.4 Interface mockups for Study 2

<u>Mixed fidelity mockups used in experiment</u>

Rather than focusing on technical development and interaction design, the prototype development for comparison with the baseline interface in Study 2 was mainly concerned with presentation of the underlying information, rather than the information itself or the interaction techniques. Thus, mockups were developed with the purpose of communicating and demonstrating the essence of the representation of the design, evaluating how it supported situation awareness in the context of mobile AR-enabled urban exploratory navigation.

As a first step, with the application of the specific extracted user requirements with the corresponding claims analysis, two interfaces were developed. In developing the AR interface, user requirements (Table 12), No. 13, 26, and 34 were applied, which are listed below. Claims analysis is in Appendix S .

> User requirement No. 13 states: “For exploration and navigation, users shall be able to quickly scan information on mobile AR viewer to minimize the time spent on screen”.
>
> User requirement No. 26 states: “For exploratory browsing and goal-directed exploration, users shall have an option to perceive an overview on a mobile AR viewer.”
>
> User requirement No. 34 states: “For exploratory browsing and goal-directed exploration, users shall be supported with a view by which users can browse information semantically in a categorical way.”

In developing the Map interface, user requirements (Table 12) No. 20, 27, and 29 were applied, which are listed below. Claims analysis is in Appendix S .

> User requirement No. 20 states: "For exploration and navigation, users shall be supported by an interface to quickly check one's current location/orientation and a desired destination's location/orientation, if applicable."

> User requirement No. 27 states: "For exploratory browsing and goal-directed exploration, users shall have a way to know the amount of POIs sharing one or more attributes under query in one's vicinity."

> User requirement No. 29 states: "For exploratory browsing and goal-directed exploration, users shall be able to have a way to know the spatial relationships of the POIs sharing one or more attributes under query."

Following the prototype categories proposed by McCurdy and coworkers (McCurdy, Connors, Pyrzak, Kanefsky, & Vera, 2006), mixed-fidelity prototypes were created, combining aspects of both low and high fidelity prototypes. In this sense, the degree of visual and aesthetic refinement was relatively high, while the interactivity remained low to medium. It offered constrained interactivity (low to medium richness), and allowed users to get some sense of flow on the evaluated aspect. It is important to note that extra care was taken when analyzing the data from the evaluation study, because it might tend to elicit more commentary on visual attributes (Landay & Myers, 2001).

As mentioned previously, there were two inevitable challenges associated with using the proposed SA-supported interfaces at this stage. First, the evaluated prototype at the initial phase of design was a low-fidelity mockup in terms of interaction (i.e., with restricted interaction). Second, for experiments conducted in the HCI domain, researchers typically redesign an interface by changing the layout of its information presentation, or by adding a new feature with existing information to make sure all task-related questions are answerable using all conditions. Doing so can ensure that one interface is not naturally favored over the other. However, due to the fact that situation awareness is enabled primarily by task-oriented information extracted from the environment, a portion of SA requirements generated in Study 1 contained SA-supported features associated with incorporating SA information into the mobile AR guidance interface. At this stage, this type of information-related SA-supported features cannot be easily assessed in a quantitative comparison experiment (as opposed to an experiential, qualitative assessment) simply because there are no equivalents in the baseline interface with which to compare.

Therefore, by following the design methods and design principles/guidelines described above, two interfaces (1 AR interface and 1 interlinked Map interface) were constructed using Photoshop, and were subsequently employed in Study 2 (see Appendix K).

Concept design interfaces

Following a similar method, five selected design concepts were generated, including (CD) 1: an image recognition feature, (CD) 2: dynamic pedestrian flow (associated with local events), (CD) 3: "Search & Identify" / varying types of search within the mobile AR viewer, (CD) 4: Visualized information/ the real-time information of a POI regarding its dynamic and interactive aspects, and (CD) 5: trend that reveals or confirms information to establish a trend of experiences. Their screenshots are provided in Appendix R .

4.3 Study 2: Theory Extension and Validation (Interface Evaluation)

4.3.1 Test of Hypotheses: Overview

RQ3: What are the differences between the proposed situation awareness-supported MOBILE AR guidance interface and a currently available interface in terms of a) the user's situation awareness and b) the user's perceived usability in urban exploratory navigation?

To answer Research Question 3, the following two hypotheses were tested in Study 2:

Hypothesis 1. There is a difference between the proposed SA-supported MOBILE AR guidance interface and a currently available interface with respect to a user's situation awareness.

Hypothesis 2. There is a difference between the proposed SA-supported MOBILE AR guidance interface and a currently available interface with respect to a user's perceived usability.

Correspondingly, for the two sets of interfaces (AR interface and Map interface), additional specific hypotheses were developed:

4.3.2 Hypothesis 1. Effect of SA-supported Design Interface on SA

4.3.2.1 AR Interface

Primary research hypothesis (main effect): *H1: There is a difference between the two AR interfaces on task query completion time.*

Secondary research hypothesis (interaction effect): *H2: There is a difference between the two AR Interfaces on task query completion time dependent on the number of Points of Interest (POIs).*

Analysis of variance showed a significant (F = 111.74, p <.0001*) interaction effect between interface and number of POIs on task query completion time. The interaction effect indicated that there was a combined effect of interface and number of POIs on task query completion time (Figure 25). Post-hoc analyses using Tukey's HSD indicated that for the number of POIs equaled 3, 5, 7, 12, task query completion time was shorter on SA-supported interface (S) than on baseline interface (B) (*p*<.0001*) (indicated in Figure 25).

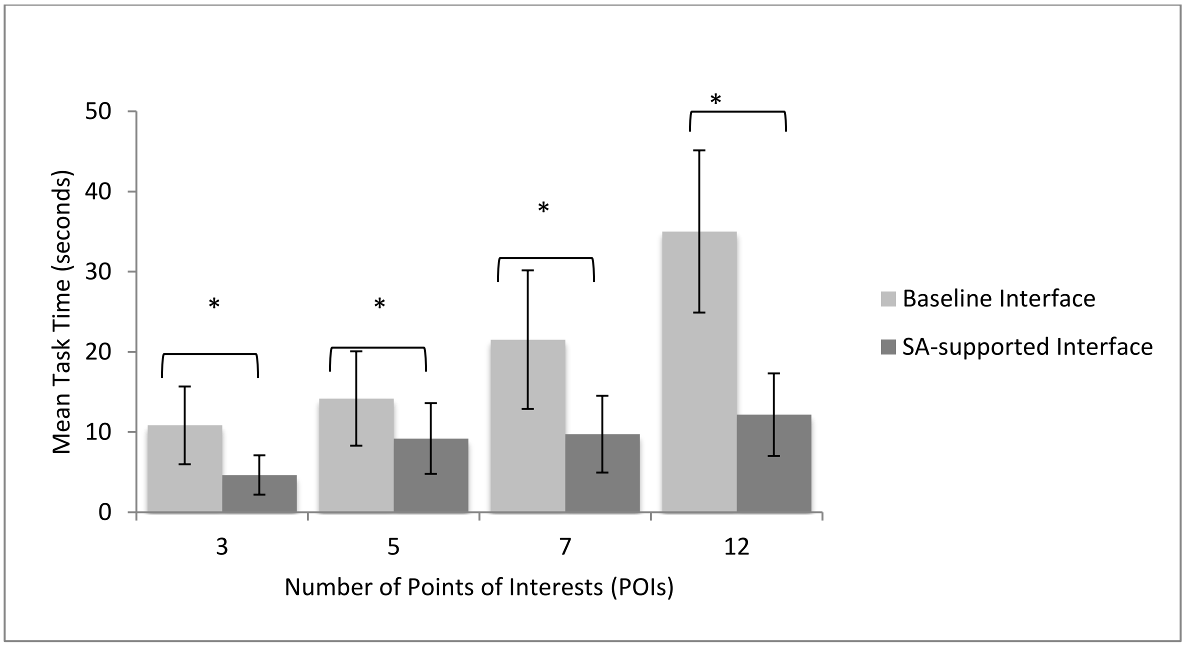

Figure 25. Means of task query time by Interface and the Number of Points of Interest on AR interface
(Error bars show standard deviation; * *p* <0.0001)

In addition to producing a statistically significant difference on number of POIs and interface (without considering interaction), practical significance was examined by calculating the effect size. By looking at effect size, indicated by Eta Squared (70.465), it showed that in addition to statistically significant differences, the number of POIs and interface as two independent variables also showed a practical significance on task query completion time.

As shown in Figure 25, the results suggested that the effect of interface on task query completion time was greater for a larger number of POIs than for a smaller number of POIs. These findings also indicated that the advantage of the effect of interface on task query completion time increased when the number of POIs increased.

H3: *There is a difference between the two AR interfaces on response accuracy.*

The response accuracy rate for baseline AR interface (B) and SA-supported AR interface (S) is plotted in Figure 26 to better understand the data. The results indicated that the overall model (two-factor as a whole) was statistically significant (LR χ^2 = 22.65, *p* =.0020). The Effect Likelihood Ratio showed that the interface variable did not contribute significantly to the model fit. No significant interaction effect between interface and number of POIs was found. Similarly, no significant difference with respect to the effect of interface on response accuracy was determined. Thus, because the effect of the interface variable did not appear to be significant, it was removed from the model. In contrast, the results showed that the number of POIs variable did have an effect on AR accuracy (LR χ^2 = 12.67, *p* =.0054).

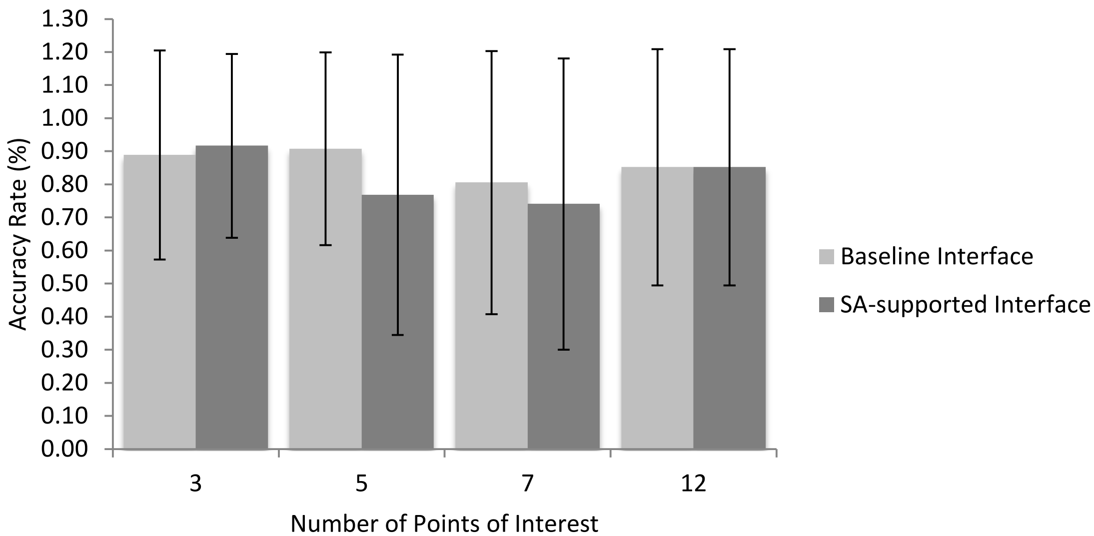

Figure 26. Response accuracy rate on AR interface (Error bars show standard deviations)

4.3.2.2 Map Interface

H4: *There is a difference between the two Map Interfaces on task query completion time.*

Mean of task query completion time on baseline Map interface (B) was 20.50 seconds (*SD* = 11.93), while on SA-supported Map interface (S) was 10.07 seconds (*SD* = 11.70). A Wilcoxon Signed ranks test indicated that situation awareness, as represented by task query completion time according to condition, was higher on SA-supported interface condition (S) (*Mdn* = 20.88) than on baseline interface (B) (*Mdn* = 9.81), Z = 7.05, *p*<.0001*.

H5: *There is a difference between the two Map Interfaces on response accuracy.*

Mean of response accuracy rating on baseline Map interface (B) was 72.22% (*SD* = 0.45) with 95% CI [0.64,0.79], while on SA-supported Map interface (S) was 89.58% (*SD* = 0.31) with 95% CI [0.83,0.94]. The results suggested a significant ($\chi^2(1)$=14.046, p <.0002) difference in situation awareness on Map interface, as represented by response accuracy data, with the SA-supported interface condition (S) enabling more accuracy than the baseline interface condition (B).

4.3.3 Hypothesis 2. Effect of SA-supported Design Interface on Usability

4.3.3.1 AR Interface

H6: *There is a difference between the two AR Interfaces on the SUS score.*

A Wilcoxon Signed Ranks test indicated that usability, as represented by SUS scores according to condition, was higher on SA-supported interface condition (S) (*Mdn* = 90.00) than on baseline interface (B) (*Mdn* = 67.50), Z = 4.44, p<.0001*. The means and standard deviations of SUS scores for AR interfaces are presented in Table 16.

H7: *There is a difference between the two AR Interfaces on ASQ rating.*

A Wilcoxon Signed Ranks test indicated that usability, as represented by ASQ ratings according to condition, was higher on SA-supported interface condition (S) (*Mdn* = 6.83) than on baseline interface (B) (*Mdn* = 5.50), Z = 4.56, p<.0001*. The means and standard deviations for AR interfaces are presented in Table 17.

Table 16. Group Means of SUS Scores on AR and Map Interfaces

SUS	N	AR		F	p-value	Map		F	p-value
		Mean	SD			Mean	SD		
Baseline interface (B)	32	65.32	17.93			68.95	15.05		
SA-supported interface (S)	32	88.64	7.85	34.06	<.0001*	81.38	13.43	15.75	.0004*

*p<.05

Table 17. Group Means of ASQ Ratings on AR and Map Interfaces

ASQ	N	AR		F	p-value	Map		F	p-value
		Mean	SD			Mean	SD		
Baseline interface (B)	32	4.83	1.37			4.57	1.40		
SA-supported interface (S)	32	6.45	0.69	32.51	<.0001*	5.89	1.22	16.40	.0003*

*p<.05

4.3.3.2 Map Interface

H8: *There is a difference between the two Map interfaces on SUS score.*

A Wilcoxon Signed Ranks test indicated that usability, as represented by SUS scores according to condition, was higher on SA-supported interface condition (S) (*Mdn* = 82.50) than on baseline interface (B) (*Mdn* = 70.00), Z = 3.42, p<.0001*. The means and standard deviations of SUS scores for Map interfaces are presented in Table 16.

H9: *There is a difference between the two Map interfaces on ASQ rating.*

A Wilcoxon Signed Ranks test indicated that usability, as represented by ASQ ratings according to condition, was higher on SA-supported interface condition (S) (*Mdn* = 6.67) than on baseline interface (B) (*Mdn* = 4.67), Z = 3.72, $p<.0001$*. The means and standard deviations for Map interfaces are presented in Table 17.

4.3.4 Correlation

Correlation between 2 usability questionnaires

Correlation between SUS vs. ASQ on AR interface

A Spearman's ρ was calculated for interface AR's SUS score and ASQ rating. There was a strong positive relationship between SUS score and ASQ rating (ρ=0.74, $p<.0001$*), indicating that an interface receiving a high SUS score also tended to receive a high ASQ rating (Figure 27).

Correlation between SUS vs. ASQ on Map interface

A Spearman's ρ was calculated for interface Map's SUS score and ASQ rating. There was a strong positive relationship between SUS score and ASQ rating (ρ=0.68, $p<.0001$*), indicating that an interface receiving a high SUS score also tended to receive a high ASQ rating (Figure 28).

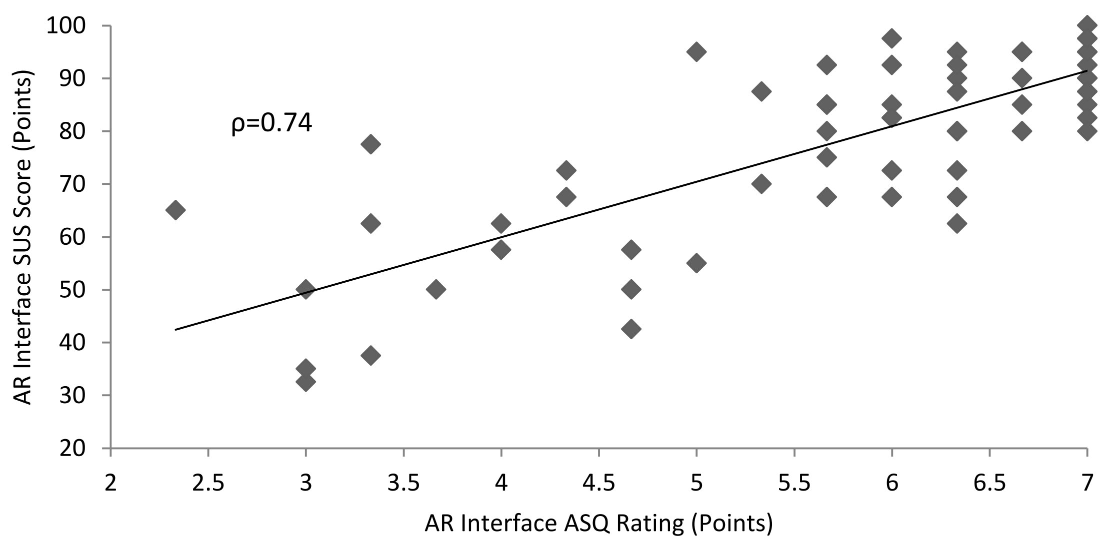

Figure 27. Correlation between AR interface ASQ rating with SUS score

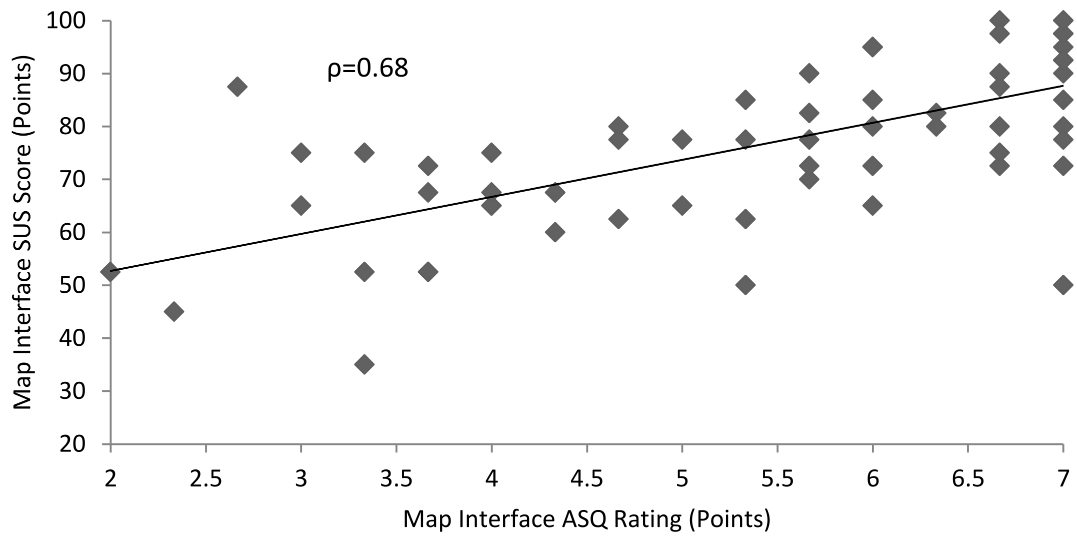

Figure 28. Correlation between Map interface ASQ rating with SUS score

<u>Correlation between usability and SA represented by task query completion time</u>

Correlation between SUS and Task query completion Time on AR interface

A Spearman's ρ was calculated for interface AR's task query completion time and SUS score. There was a moderate inverse relationship between task query completion time and SUS score (ρ=-0.45, *p*=.0002*). This finding indicates that participants with high task query completion times tended to show lower usability scores (Figure 29).

Correlation between SUS vs. Task query completion Time on Map interface

A Spearman's ρ was calculated for interface map's task query completion time and SUS score. There was a weak to moderate inverse relationship between task query completion time and SUS score (ρ=-0.40, p=.0010*). This finding indicates that participants with high task query completion times tended to show lower usability scores (Figure 30).

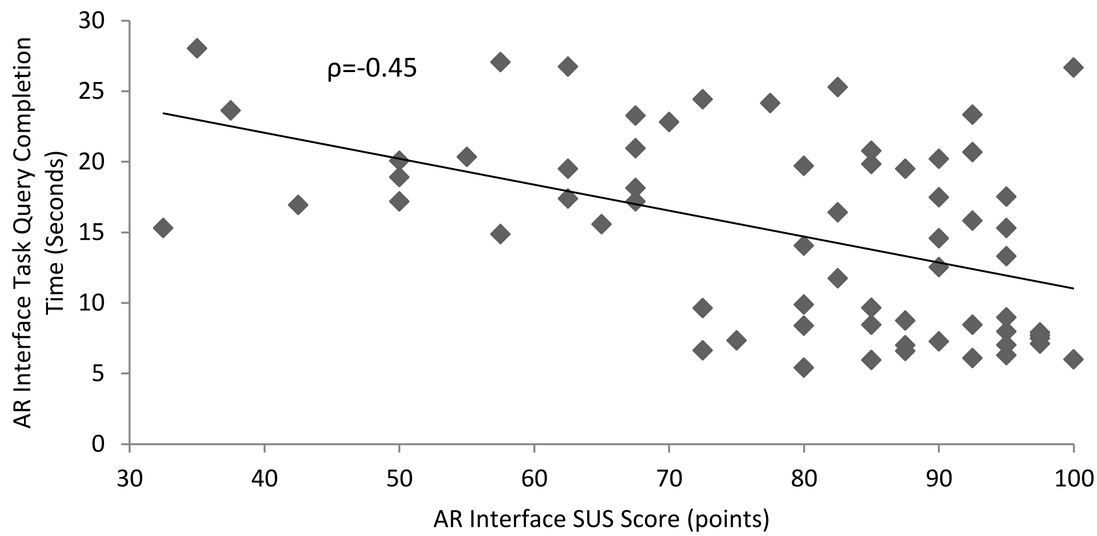

Figure 29. Correlation between AR interface SUS score and task query completion time

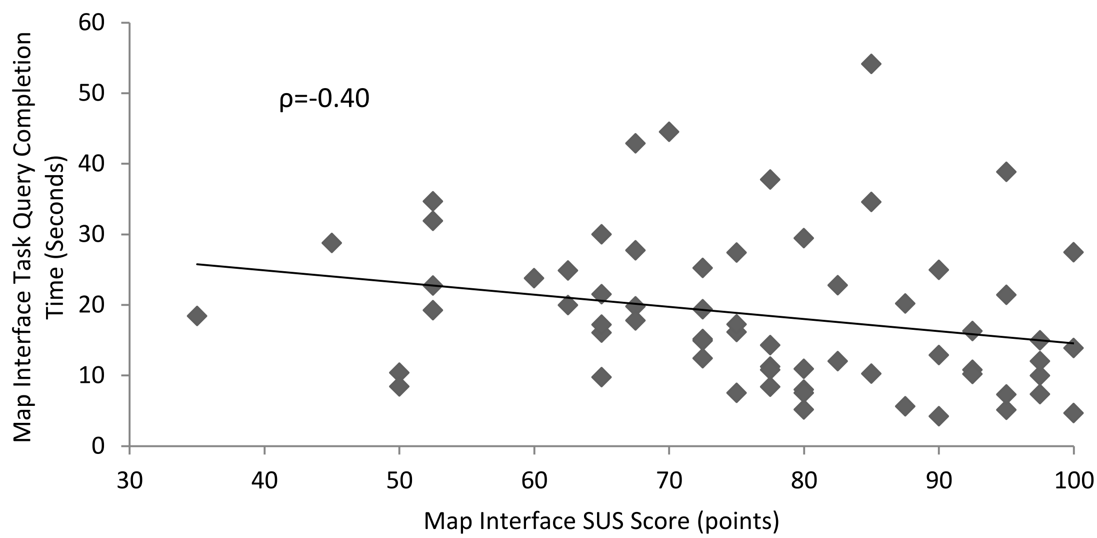

Figure 30. Correlation between Map interface SUS score and task query completion time

4.3.5 Qualitative Results

This study also includes qualitative findings, which are represented in the stated preferences and feedback that users provided regarding the AR SA-supported interface, AR baseline interface, Map SA-supported interface, and Map baseline interface. These qualitative results are provided in Table 18 through Table 21.

Table 18. Advantages and disadvantages of SA-supported AR interface

Advantage/ Disadvantage	Fr.	SA-supported AR Interface	User Comment/Quote (*Note)
+	20	Sorted information presentation (sorted by distance; could sorted by multiple options)	"It is super easy to know that which one is closest to me, and how to sort through distances". "It's easy to rule out things just by knowing the shorter things are first." "More direct and straightforward, if I'm looking for restaurants nearby" "I just want to look for something within 10 minutes. I just open it up, and scroll instead of opening up all bubbles."
+	19	Organized information	"Have all the information together in front of me"; "More practical" "More easy to use", "It's a good way to communicate all the information" "You don't have to click for everything you do it."
+	14	Detailed information	"If you're not looking for a particular place, this one is so much easier, because you have all the information in front of you immediately.
-	11	No direction communicated [or the direction indicator was not evident to users]	"For the list, you don't necessarily need to see the direction, if you see the distance, you get a general idea of where's in the radius. I don't think direction matters that much"
-	8	A lack of an "overall view"	On cluster view, I can see where things are quickly; whereas, on the list view, I cannot see that quickly. I have to scroll to see."
-	7	No economical use of screen real estate	"I could be looking at a restaurant right in front of me, but I may not know it immediately, because I see this big black box to choose information."
-	7	Unclear perspective radar	"The perspective radar doesn't give you an accurate sense of how far things are away and the relative distance in between." "When you get towards the edges, you can't really tell how far away things are" [This might be changed when the interaction: hold upright or flat to switch between views]
Suggested changes:			"The arrow direction indicators could be moved to the side, because it's crowded with other information." "The icon could be smaller. All the text fonts are appropriate." "The camera can be held vertically, so you would see more information."
Total preference:	19		
Conditional preference:	7		If there are many POIs; Preferred only when searching information;

Table 19. Advantages and disadvantages of baseline AR interface

Advantage/ Disadvantage	Fr.	Baseline AR Interface	User Comment/Quote (*Note)
+	14	Direction clear	"You have a general idea of which direction it is, instead of having a little arrow." "I like this in general with reality, the general direction the restaurant is in."
+	9	“Overall view” on screen	"You can still see everything". “Getting a feel of what's around me.” “It’s intuitive.”
+	7	Distance clear	“It has the distance very clear, and that’s the deciding factor to me.”
+	5	Visually-interesting presentation	"I like the bubbles, it's visually interesting."
+	5	Conditional preference	"When there're fewer bubbles, it's easy to use. If there're more, it's messy."
-	18	Against the principle of motion economy	“It’s time-consuming.” "You have to individually check to see every information." "There're multiple clicks to get more information." "It's wasting a lot of motion."
-	15	Disconnected spatial relationship between physical objects and realized objects	"It's confusing the way it's laid out." "It takes a lot of space, because it's spread out." “Information is not well clustered.” "It's lower, I think it's closer. It's higher, I think it's farther away. But it didn’t work out that way." "Those clusters could have helped make sense of how close things are."
-	8	Not easy to compare	"I always forgot which one is which after I clicked on several." "It's a lot harder to compare."
-	8	Incapable to sort	“I can’t sort information.” “There is no order.” "I found there's too much information to process."
-	5	Unstable interface	“It could be really sensitive to direction, so in that case, I'm ruling something out that I don't really want to rule out." "(When the camera moves) if things keep in and out, that could be confusing.
-	3	Disconnected between realized objects in AR viewer and on the radar	"I didn't see the connection between the way that they are laid out on the screen and they're on the map [radar]."
Total preference:	10		
Conditional preference:	4		When there are a few POIs; When time permits;

Table 20. Advantages and disadvantages of SA-supported Map interface

Advantage/ Disadvantage	Fr.	SA-supported Map Interface	User Comment/Quote (*Note)
+	32	Good for spatial estimation	"It's good to estimate the approximate distance from where you are." "It helps me know how far or how close they're to me." "It gives me a very easy idea of what the distance will be between each place, I don't worry about exact time it takes."
+	16	Good for comparison	"It's a lot easier to compare." "It gives you an overall view of how long is going to take to walk to somewhere, so you can automatically rule things out." "When I'm walking around DC, it's really hard to know how far something is on the map.
+	11	Good for directional reference	"I really like how it blacks out the ones that you're not facing, and highlights certain ones that you are." "It knows and shows you which direction you're facing." "When it doesn't show the direction you're facing, I often turn around and I've no idea which I should go to find the restaurant."
+	7	Good for locational reference	"A quick and dirty reference point of where you are, comparing to the restaurants"
+	4	Good for viewing a collection of POIs (compared to single POI)	"I like I can click on some of the rings and just show restaurants within a certain distance." "Good for knowing the number of restaurants within a certain distance from where you are"
+/-	N/A	Mixed feedback on accuracy*	"Accuracy would be beneficial, as long as it doesn't get too out of control. For example, when it doesn't have concentric rings, like 2 different rings, it gives it away." (*Most people don't care too much about 17 minutes or 20 minutes. An approximate distance would work for them. Some commented that the representation of the exact, accurate distance, might not be aesthetically pleasing. But some brought up the accuracy as an issue and commented on the surrounding factors might be a factor that might impact their decision. Thereby, future studies would be needed if want to decide on the accuracy factor.)
-	3	Learning curve	"It might take them a little bit to figure out all the features."
Suggested changes:			(*It should have the scale of the time or the distance to switch at user's will (time: subjective, but quickly made sense; distance: objective but for some people difficult to interpret)) (*It could change the dots to signage that can represent a certain characteristics of the POI, ratings, dollar signs, etc.) (*Rings should be on/off at will)
Total preference:	32		

Table 21. Advantages and disadvantages of Baseline Map interface

Advantage/ Disadvantage	Fr.	Baseline Map Interface	User Comment/Quote (*Note)
-	21	Against the principle of motion economy	"I have to click through all the pins to see information."
-	9	Increased mental workload	"I have to remember all these distances to compare."
Suggested changes:			(It could change the dots to signage that can represent a certain characteristics of the POI, ratings, dollar signs, etc.) (Rings should be on/off at will) (If clicking on the 20-minute ring, it could show everything within 20 minutes, instead of clicking twice.)
Total preference:	0		

4.3.6 Concept Evaluation

Five design concepts were individually evaluated, including (CD) 1: an image recognition feature, (CD) 2: dynamic pedestrian flow (associated with local events), (CD) 3: "Search & Identify" / varying types of search within the mobile AR viewer, (CD) 4: Visualized information/ the real-time information of a POI regarding its dynamic and interactive aspects, and (CD) 5: trend that reveals or confirms information to establish a trend of experiences. Results were presented in Table 22 through Table 26.

Table 22. Concept Design (CD) 1: an image recognition feature

Conceptual Design	**Advantage/ Disadvantage**	**Fr.**	**User Comment/Quote (*Note)**
Browsing	+	16	"That would be very, very useful for exploring, but not having a goal-task."
Registration	+	26	"The device can extract information for me about the environment." (*Especially good for information-centric places e.g., museums.)
Path indicator	+	29	"The path is very useful. If I look at a normal map, I often get confused with, especially the very crowded place, very dense city setting. I can't tell which street is which, like the signage may be far away." "I would use the street all the time, because it's really hard to find street signs."
Attribute information	+	23	"That's a cool building, I would wonder what's inside." (*Integrated with the place into)
Multiple layers	+	21	"If you've seen a bus going by you, and you want to take the next one. You can see when the next one's coming." (*Layers can be pre-setup.)
Uncertain use	-	3	"I could just walk around instead of having it tell me what everything is, because I can just walk next to it, and figure it out." "But maybe when you have it, you will use it."
Suggested solutions:			(*Should be transparent, should not affect your perception.)

Table 23. Concept Design (CD) 2: dynamic pedestrian flow (associated with local events)

Conceptual Design	**Advantage/ Disadvantage**	**Fr.**	**User Comment/Quote (*Note)**
Traffic	+	15	“I can see it myself for the pedestrian flow near me, but if I can see how many people in another attraction, because I could not go if there is a ton of people.” “I want to avoid the crowd.” "It would be very helpful if I'm doing something in a hurry." “Only when the crowd/traffic is so bad, got to find a different route.” “It would be helpful to know where crowds is and where should I go.” (*Most people wouldn't mind walking in crowds if it does not associate with an event. Some claimed they may navigate away the traffic, some may choose the crowd path to go, because they don't want to go to the alleyway that looks a little bit abandoned.")
Time estimation	+	9	(*Can have more accurate estimated time considering pedestrian flow.)
Limited usage	-		(*Most people found this feature with limited use cases.)

Table 24. Concept Design (CD) 3: “Search & Identify” / varying types of search within the mobile AR viewer

Conceptual Design	Advantage/ Disadvantage	Fr.	User Comment/Quote (*Note)
Perception aid	+	28	"I'm not being able to see with my naked eye, upon first glance, which my phone can pick up the data around for me, I think it's convenient." "It would be very useful, if there were a specific target in mind." "Especially in a crowded place like this, with so many things tightly packed together. I may miss a store, because they might not have a signage, or I may just completely miss it."
Economical motion	+	7	"Without me having to physically walk to every point to find information about it, whereas I would give me where I'm standing all information I need."

Table 25. Concept Design (CD) 4: Visualized information/ the real-time information of a POI regarding its dynamic and interactive aspects

Conceptual Design	Advantage/ Disadvantage	Fr.	User Comment/Quote (*Note)
Real-time view	+	25	"If it's absolutely packed, I usually wouldn't want to go." "I would rather go to somewhere that doesn't have a huge line, not waste my time, standing in line hold on." "I don't want to spend 45 minutes in line." "That'll be super helpful, that'll be helpful for the dining hall here." (*Not useful for static information, e.g., what a shop sells.)
Multimedia “static” information	+	19	(*Show uniqueness of a POI, gourmet food store, gift shop, etc.) "I want to know what it looks like before I go" (*Good for environment-related information, like to integrate a video clip about the inside view. Access specific POI attributes that cannot be easily described textually.)
	-	6	(*Customer’s privacy concern)

Table 26. Concept Design (CD) 5: trend that reveals or confirms information to establish a trend of experiences

Conceptual Design	Advantage/ Disadvantage	Fr.	User Comment/Quote (*Note)
Aggregated review	+	17	"This saves time." "Don't have to go through all the reviews." (*As long as there is a lot of them 2; and someone still scroll down to browse quickly through the first or two power "user "individual reviews to see if it's justified, in their own individual voices.) (*Reviews on some specific items, not only provide a general statement, may help.)
Trend figure	-	21	“The number of customers varies, so it doesn’t tell me anything.” (*Ratings represent a general performance of the restaurant; a general rating idea is sufficient; unless there is a huge drop;) "If they don't have the same or similar size of reviewers, that distribution may not matter to me."

CHAPTER 5 DISCUSSION AND CONCLUSION

5.1 Overview

This chapter will discuss the results of two sequential studies designed to investigate the following areas of inquiry: the SA development process, SA user requirements, a process for examining and validating the effects of SA-supported interface design on user's SA and interface usability, and a potential method for evaluating a conceptually-designed SA-supported interface. Specifically, the research utilized two successive studies to explore the following three research questions:

1. RQ1: What process do users employ to develop situation awareness in the context of mobile AR -enabled urban exploratory navigation?
2. RQ2: What are the specific user situation awareness requirements in the context of mobile AR-enabled urban exploratory navigation?
3. RQ3: What are the differences between the proposed situation awareness-supported MOBILE AR guidance interface and a currently available interface in terms of a) the user's situation awareness, and b) the user's perceived usability in urban navigation?

The first study, which was designed to answer RQ1 and RQ2, looked at situation awareness in terms of the processes that an individual employs and the essential requirements needed to develop SA in the context of mobile AR-enabled urban exploratory navigation. From the findings obtained during Study 1, SA-supported design implications for a mobile AR guidance application were developed in order to evaluate the applications of an extended prototypical SA theoretical cognitive model. Subsequently, the second study proposed a systematic, two-part method for validating findings, which involved two applications of the transformed SA-supported interface design, and evaluating five conceptual design concepts obtained from Study 1. Results of Study 1 are provided in Section 4.1.1 - Section 4.1.4, and results of Study 2 are provided in Section 4.3.1 - Section 4.3.6.

5.2 RQ1: The SA process in Mobile AR versus SA processes described in prior research.

RQ1: what process do users employ to develop situation awareness in the context of mobile AR-enabled urban exploratory navigation?

As can be seen in this preliminary cognitive model (Figure 14), stimuli consisting of both environmental and digital cues are taken in and then processed in the sensory store, which progresses through perceptual processes, comprehension, and projection processes. The sequence results in decision and response selection, and finally response execution. Accordingly, three issues are central to research on situation awareness: 1) the perceptual process, 2) comprehension (pattern recognition), and 3) projection.

Perception

Level 1 (L1) situation awareness refers to information that is perceived by an individual; in other words, L1 comprises one's perception of existing environmental elements. To achieve Level 1 SA, one has to perceive the status, attributes and dynamics of relevant elements in the environment (Endsley, 2000). Perception, the first stage in the sensory store, involves associating sensory stimuli with meaning. It is the process through which environmental objects (environmental cues) and realized objects (Mobile AR cues), as well as other formats involving digital objects on a screen, are given meaning. As described in prior research, one of the connections between a realized object on the screen and an environmental object in the environment is its spatial relationship. An important component for determining a spatial relationship is attention. According to Endsley (1995), however, a person's ability to pay full attention to sensory stimuli in the perception process presents certain inherent limitations—the main one is being able to accurately perceive multiple items in parallel. This represents a major hurdle in achieving SA.

As observed in Study 1, a user in the mobile AR context initially focused attention on the exploration task, while at the same time having to deal with many possible distractions and perception competition including competing tasks and non-relevant events (e.g., avoiding pedestrians and minding curbs). Thus, focused attention (mostly in the visual channel) was applied to an exploration task on the mobile screen or a source of environmental information. In most observed cases, the user employing the current version of a handheld mobile AR guidance application stopped while browsing on the phone, focusing attention on either the mobile screen or a source of environmental information. In instances when a user is walking and checking the mobile AR application at the same time, he/she alternates between the two tasks (walking and checking the mobile AR application). This "attention switch" is defined as the process of turning one's attention from one task to another (Wickens & McCarley, 2007), which for this study required users to visually scan from the mobile AR screen to environmental factors. In addition, because human memory is imperfect, users tended to switch attention between the physical environment and information on the mobile AR screen multiple times when engaged in a single task.

Nearby objects

In general, the human brain cannot efficiently process all the information delivered through a mobile AR viewfinder—which proved to be the case for this study. For nearby objects, users assumed they would have no problem seeing objects in front of their eyes in the physical environment. However, observations from this study confirmed that users typically experienced “inattentional blindness” with respect to information about the physical environmental viewed through the viewfinder. The principal reason for this deficit is that realized objects and environmental distant objects cannot be exactly overlapped on the viewfinder due to natural constraints in connecting the two. Inattentional blindness is a phenomenon wherein an unexpected object—regardless of how prominent it might be in one’s immediate surroundings—is overlooked due to an overload of sensory stimuli or because the individual is otherwise engaged. For example, in this study some participants were struggling to find a restaurant or shop on the mobile AR viewfinder, and as a result failed to observe the physical restaurant directly in front of them.

It should be noted that with the mobile AR platform used in Study 1, the mobile AR viewfinder could only show objects in one type of display (the cluster view); it could not accurately register nearby environmental objects. Nonetheless, there were no cues to assist users, and they were not expecting to see the objects in their immediate surroundings. As a result, users tended to misperceive nearby objects in their immediate surroundings, even when they might have been directly in front of them.

In summary, the findings (Figure 14 the preliminary cognitive model) showed that with the current handheld mobile AR platform, users could succeed at multitasking only by switching between tasks. However, if a mobile AR application were able to accurately register and represent nearby objects by actually processing them in parallel (i.e., simultaneously achieving an exact overlap (i.e., display with conformal imagery) between the realized object and the environmental object), the user may succeed at multitasking (e.g., checking the application while walking *or* seeing the environment objects and the virtual representation) and there was redundancy gain (Wickens, 1999). In such a scenario, the use would be better able to successfully divide his or her attention between different stimuli, which is discussed in the following paragraph.

This parallel processing scenario involves two levels. At the task level, “successful divided attention” means that an individual is successfully perceiving and understanding information from a mobile AR guidance application, while at the same time looking through the mobile environment background. At the perceptual level, successful divided attention may involve the parallel processing of two aspects of a stimulus (Wickens & McCarley, 2007) (i.e., the overlapping image of the realized object and the environmental object). A quick glance at a well-designed mobile AR viewfinder for accurately registered nearby objects may reveal the POI’s location, direction, and important attributes (e.g., name or category of POIs)—all understood within the single perceptual experience (all at the same time). However, the findings from this research on current handheld AR platforms suggested that users tended to be slowed down (up to 3 minutes in the observation) by switching their attention back and force on realized objects on the screen and environmental objects in the physical surrounding environment. In addition, the literature suggests that divided attention is usually faster than a purely serial allocation of selective attention (Wickens & McCarley, 2007), which has implications for designers of mobile AR devices. Therefore, for exploring tasks conducted in the mobile AR context, an accurate registration of nearby environmental objects may facilitate perception and should be encouraged for a quick processing in the mobile context. This conclusion may also be extended to similar discussions on wearable mobile AR devices.

Distant objects

Realizing distant environmental objects (i.e., objects viewed not in the same stereo depth plane) that are not easily registered accurately (in a spatial sense) on a mobile AR viewfinder may present some inherent limitations in representing a 3D physical environment onto a small-scaled 2D mobile AR viewer (limited screen real estate).

To facilitate good SA, a system should help people direct their limited attention in efficient ways to the most task-relevant and important information to gain sufficient awareness (Endsley, 2000). The mobile AR used in this study failed to provide an accurate spatial relationship between environmental objects and realized objects on the screen—except for its ability to indicate general direction. In terms of actual study outcomes, the user often felt confused and misperceived the clustered view, where one cluster expands to an array of multiple individual items when tapped, while the other clusters remain. Moreover, users often felt the view did not convey important task-relevant information to them—except for a directional indicator, which was somewhat redundant given that they were facing in that direction at the time.

Elements

In terms of elements of awareness, Endsley (2000) listed several essential elements of awareness needed for a crew: (a) current state of the system (including all the relevant variables); (b) information and knowledge required in support of the crew's current activities; (c) activity phase; (d) prioritized list of current goal(s); (e) predicted state in the "near" future; and (f) information and knowledge needed to support anticipated "near" future contexts. In the context of mobile AR-augmented reality-enabled urban exploratory navigation, elements of awareness consist of both environmental elements and digital elements, which can also be categorized as elements that require high attention allocation and ones that require low attention allocation, respectively. The elements that require high attention allocation can be further categorized into a single element or a collection of elements with respect to their composition. It must be noted, however, that not all of these elements can be realized on the egocentric view (the mobile

AR viewfinder); thus, mobile AR guidance application is a system that could and should be integrated with other embedded views (e.g., maps, World-in-Miniature (WIM), Web browser, etc.) (Pyssysalo et al., 2000; Wagner & Schmalstieg, 2003; Schmeil & Broll, 2006; Bell, Hollerer, & Feiner, 2002).

Based on study findings, elements that required high attention allocation were all Points of Interests (i.e., single location-based elements such as buildings, events/activities, restaurants, shops, landmarks, etc.). Moreover, these single location-based elements were comprised of four components: a spatial component (i.e. location and direction of a POI), a temporal component (i.e. dynamically-associated aspects of a POI and spatial-temporal information changes based on motion/navigation), an identity component (i.e. statically-associated aspects of a POI and dynamically-associated aspects of a POI), and a social component (i.e. social integration and collaboration). In contrast, elements that required low attention allocation included the environmental atmosphere, as well as pedestrians in the surrounding area who were moving about on the street and seen in the background of the mobile AR viewfinder. It could be related to peripheral vision, which has a low spatial resolution and is good at detecting motion, or that humans are simply very adept at processing visual cues—principally because our eyes move rapidly and constantly (about three times per second) focusing our fovea on selected pieces of our environment (Clark, 1998). The selected pieces of environmental information in this instance are the above-mentioned task-relevant information. Conversely, elements that are less important—i.e., less relevant to the task at hand—are less well attended.

Comprehension

Once perceived by the senses, information needs to be combined and interpreted in working memory. Level 2 SA relates to comprehension of the current status, which is achieved through the integration and synthesis of the information achieved in L1 SA. In this study, several sub-processes of the comprehension phase were identified with respect to a single element and a collection of location-based elements. These include acquiring an overview, acquiring patterns, quantifying/estimating amounts, acquiring relations and comparisons on statically-associated aspects and dynamically-associated aspects of POIs, discovering order (e.g., ranking), and interpreting information on the connection between real and virtual information. In these sub-processes, users go beyond simply being aware of the elements that are present in their environment, to an understanding of the meaning of those elements in light of their current goal(s). As described by Endsley (2000), to reach comprehension, the individual must possess an understanding of what each element means in relation to his or her situation and goals—mostly in the working memory system, which goes beyond perceiving simple information that is presented in a given situation. For example, Level 2 situation awareness would include the user's knowledge of a single element's position or a collection of elements relative to the user himself. This knowledge may require processing of display information to convert the absolute position of an element (or elements) to an understanding of its relative position to the user himself. Such an understanding of the relative position of each element to the user relates to goals and objectives of searching, for example, restaurants within 20 minutes-walking distance.

While attention directs the acquisition of information essential for Level 1 SA, in the process of Level 2 situation awareness it is long-term memory knowledge, which is stored in the form of a mental model or schemata, that directs attention to support Level 1 SA (Wickens, 2008). For example, if someone already has some knowledge of a particular landmark or a historic scene, he/she will pull from long-term memory to recognize or recall the relevant information about that place when visiting another similar location. Knowledge of structures (e.g., expectancies) aids understanding and comprehension of them via top-down processes. In this process, a user's attention (discussed previously) is directed to the most relevant environmental and digital cues, which are based on task goals and past experience in the form of mental models or schemata. In Level 2 SA, the user integrates pieces of information, as well as prioritizes the perceived information and meaning as it relates to goals and objectives. In addition, findings from this study also confirmed that a major constraint of SA is limited working memory, or working memory losses (Jones & Endsley, 1996). Sometimes, users were not able to remember where information was initially perceived when turning the mobile AR viewfinder to different directions in information acquisition.

Projection

As the third component of the situation awareness, the user projects the likely future status of a given situation (i.e., exploratory navigation), which involves predicting the anticipated state of individual elements within the current environment. If an individual can anticipate and envision the future status or actions of elements in the environment, he/she will be more likely to predict what might happen next. As Endsley (1995) noted, this includes "comprehending the meaning of that information in an integrated form, comparing it with user's goal, and providing projected future states of the environment that are valuable for decision making" (p.37). In the context of mobile AR-enabled urban exploratory navigation, to achieve L3 SA, projection typically relies on a user's past experience (e.g., past experiences being in similar places/activities), real-time information (e.g., real-time view of a queue situation), and perceived patterns (e.g., spatial patterns of POIs on alternative paths).

Decision and Response Selection

Decision-making (e.g., where to go, what to do next) and action execution (e.g., physically navigating to the place of interest) are downstream from SA. This study confirmed that decision-making can be viewed as a downstream human information process of situation-awareness formation, which was originally proposed in Endsley's SA framework (Endsley et al., 2003; Endsley, 1995b; Endsley & Garland, 2000). However, other influencing factors might impact decision-making on exploratory navigation decisions, such as the occurrence of an unexpected incident (e.g., getting a phone call from a friend).

5.3 RQ2: SA User Requirements

> RQ2: What are the specific user situation awareness requirements in the context of mobile AR - enabled urban exploratory navigation?

The users' SA requirements in terms of specialized use in mobile-AR enabled urban exploratory navigation tasks were generated and are listed in Table 12. This table was organized and categorized based on the process that users employed to develop SA: perception (subcategories, including searching, locating, orienting, recognizing/identifying, noticing), comprehension (acquiring overview, acquiring patterns, quantifying/estimating amounts, acquiring relations and comparisons), and projection (projecting based on past experiences and projecting based on real-time information).

The components of SA—identified and categorized as Spatial (Sp), Temporal (T), Attributes (A), Social (So)—are shown in the Components column of this table. For these interface support requirements, the components of SA were not identifiable; therefore, the components column is not applicable. These requirements were then translated into two SA-supported interfaces (interface design/development can be found in Section 4.2). Additional discussion about specific SA user requirements, together with results from Study 2, is provided in Discussion Section 5.4.4.

<u>SA Components</u>

It should be stressed that the scope of this research was not designed to provide a complete profile of what each component should include in terms of design implications, but rather to identify and exemplify aspects of SA in the context of mobile AR-enabled urban exploratory navigation. Further studies are needed to complete the profile of each component for more detailed information. To reiterate, situation awareness in the context of urban exploratory navigation is associated with the following components:

<u>Spatial component</u>

The spatial component helps mobile users to be aware of and understand places in the surrounding environment. This SA component involves being cognizant of spatial boundaries, location, direction, distance to places, and a general awareness of moving objects and persons (including oneself) in one's surroundings. The concept of spatial boundaries in SA corresponds to Endsley's (1998) concept of SA zones of interest, which simply means that SA elements closer to the individual may be more important than elements further away. In other words, these zones correspond to areas of immediate, intermediate, and long-term interest of the individual (M.R. Endsley, 1988). The spatial component also follows the principle of locality, which states that the relevance of a context is maximal for the location of its origin, but then decreases with increasing distance from the origin; after a specified distance from the origin the context no longer has any relevance (Reichenbacher, 2004; Schmidt & Gellersen, 2001). Requirement No. 5 in SA user requirements (Table 12) states the following: "5(a) Prioritized and more detailed information, upon request, about POIs that are directly visible from the AR viewfinder, to assist user's "scan" activity; includes an option to reveal additional information; 5(b) Less detailed information, upon request, about nearby POIs that are not directly or completely visible from the AR viewfinder; includes an option to reveal additional information; and 5 (c) Less detailed information, upon request, about distant POIs that are visible but vague from the AR viewfinder; includes an option to reveal additional information." In addition, requirement No. 16 states that "For exploratory browsing and goal-directed exploration, users shall be able to have and adjust the information range at will on a mobile AR viewer." Similarly, Julier (2001) applied this proximity principle in a system he called BARS (Battlefield Augmented Reality System) to provide soldiers with situation awareness of their surroundings. BARS is able to present the immediate environment to the user in great detail. However, when the distance between the soldier and a given landmark increases, the system provides progressively less and less information about that landmark (Julier et al., 2001).

Temporal component

The temporal component of SA corresponds to awareness about past, present, and future activities that are important to a mobile user's goals and tasks. Temporal awareness is important in temporal coordination because it helps users align their own actions to a log of past activities, to current activities, and to the anticipated future flow of activities. Both the perception of time and the temporal dynamics associated with events play an important role in the formulation of SA (Endsley, 2000). Similarly, findings from this research suggest that the temporal component of SA consists of three aspects: 1) the dynamically-associated aspects of POIs, 2) the perceived time available to oneself, and 3) the association of spatial motion with time. Their impacts on the user are as follows: 1) the usage of a mobile AR guidance application, 2) on exploratory navigation decision-making, and 3) on behavior of exploratory navigation.

For example, a mobile user who has several hours to spend in the center of the city might want to use a mobile AR application to check out places around her and plan later activities when she has sufficient time to explore the surroundings. Her decisions could be based on how much time is available for activities, the timing of an outdoor concert, queue information, seat availability, location, ticket-selling status, scheduled information update, user-generated real-time social participation and collaboration, how long it takes to reach the place, and so on. She then adjusts the allocation of time for those activities, determines activity schedules (e.g. visiting sequence) and identifies upcoming events of interest in the nearby region—or on the way to the main destination depending on, again, the dynamic aspect of the destination and the time available to her.

Identity component

The identity (attributes) component (Table 13 helps mobile users to be aware of where something is, the nature of that something, and what is happening in the surrounding environment. From this study's findings, the identity component consists of attributes that are statically associated (e.g., factual knowledge about a POI), as well as those that are dynamically associated (e.g., status of a local event). These attributes can be applied to a single element (i.e., POI) or a collection of elements (i.e., POIs). When this concept relates to the identities of a collection of elements, recognizing patterns, sorting and ranking could be important in developing a user's SA.

Social component

The social component of SA plays an important role in exploratory navigation. Results of this study showed that the social component of SA is connected with social collaborations. These social collaborations can be further categorized into user-summoned information and information inquiry. User–summoned information could be further divided into user-generated digital information and user-generated physical information. An example of user-generated digital information as mentioned by participants is peer-based social network information such as tweets and Facebook posts. User-generated physical information has to do with, for example, observed crowd flow. In an increasingly digitally-connected world, however, these two types of information are often interwoven. With respect to seeking information, participants tended to interact with friends, locals, or other visitors about POI information. This finding suggests that interactions between peer-based social networks and unacquainted individuals commonly occur in the context of urban exploratory navigation. And indeed, this finding is supported by the literature, which indicates that (1) serendipitous social networks are situation-centric, where the traveler interacts with unacquainted individuals instantaneously, or (2) peer-based long-term social networks provide opportunities for interactions between friends and acquaintances based on existing social ties (Jang et al., 2011). Both of these venues provide opportunities for information gathering, such as recommendations, opinions, factual knowledge, question topics – which include places, restaurants, current events, and shopping (Morris et al., 2010). Researchers have also indicated that mobile users like to send live queries to locally-based individuals near a place of interest to query them about their experiences in that region (Gaonkar et al., 2008). Types of information people usually exchange include the following: where people are, social events, who is doing what, what's happening locally, things about places, what's happening worldwide, another's thoughts/opinions (Counts & Fisher, 2008).

Important to note is that there could be some crossovers among above identified components. For example, dynamic pedestrian flow, as an example of user-summoned information, is generated as a combined function of the spatial component and the social component. Approaching and moving to a destination is a combined function of the temporal component and the spatial component. Some crossover examples are provided in Table 27.

Table 27. Crossovers among identified components

	Spatial Component	Temporal Component	Identity Component
Temporal Component	e.g., approaching and moving		
Identity Component	e.g., collection of POIs spatially located	e.g., queue information	
Social Component	e.g., user-generated trendy information	e.g., synchronous or asynchronous social collaboration	e.g., reviews and ratings

Contextual Factors

Situational impairment factors:

As reported in the literature, in a mobile context the user is not always fully engaged with the device (Pascoe et al., 2000); a related finding is that a user's cognitive resources are routinely under strain (Baus et al., 2005). In this study, when users were browsing information for surrounding POIs on mobile AR guidance application, all of them tended to stop or pause in a convenient place for at least a few minutes to minimize any distracting factors, such as pedestrian traffic flow, excessive sunlight that created visual difficulties, or disturbing traffic noise. In fact, two participants only operated the phone in a shadowed location to avoid screen reflection/glare and to maximize the contrast of the information on screen. Thus, our results confirmed that contextual factors influencing obtaining SA information using a mobile AR device include ambient noise, distraction, body motion, and walking vibration (Kane, Wobbrock, & Smith, 2008; Lin, Goldman, Price, Sears, & Jacko, 2007). Other examples suggested from prior research include divided attention, weather (e.g., rain water, cold temperatures), restrictive clothing (e.g., gloves causing "fat fingers"), uneven terrain (e.g., stairs), low light or darkness, encumbering baggage, confined or crowded spaces, and so forth (Kane et al., 2008; Lin et al., 2007; Nicolau, 2012; Pospischil et al., 2002; Wobbrock, 2006; Yamabe & Takahashi, 2007; Yesilada et al., 2010)

<u>Ergonomic constraints</u>:

Reports from users indicated that during the process of browsing information on their mobile AR viewers, they had to hold the phone up in the air, angle it uncomfortably upwards, or turn it around in different directions. These ergonomic constraints were due to the design of the camera on the opposite side of the display. Comments from five participants on these difficulties indicated their negative feelings toward the device. Some participants felt they were "somewhat silly," "in the way of others," or "embarrassed because they attracted others' attention in public." These constraints can hinder a user's SA development simply because SA is mediated by accessibility to the device. In other words, if accessibility is perceived to be difficult—thus standing in the way of task completion, the user might not be using the application as often as they would otherwise. Similar constraints have also been described by other researchers (Kurkovsky et al., 2012; Tokusho & Feiner, 2009), some of whom have also suggested ergonomic solutions: "freezing" the augmented view to allow the user to see it in a more comfortable position (Tokusho & Feiner, 2009), adopting a multimodal solution (e.g., haptic feedback from the device without requiring users to look at the device) (Jacob et al., 2012), or even designing a non-intrusive wearable solution (e.g., head-worn, glasses, contact lens).

5.4 RQ3: Effect of SA-supported Interface Design

5.4.1 Overview

RQ3: What are the differences between the proposed situation awareness-supported mobile AR guidance interface and a currently-available interface in terms of a) the user's situation awareness, and b) the user's perceived usability in urban exploratory navigation?

Hypothesis 1 – Effect of SA-supported Interface Design on SA

Hypothesis 2 – Effect of SA-supported interface Design on Usability

To sum up, hypotheses and results in connection with RQ3 are provided in Table 28. Also important to note is that there was a moderate inverse relationship between SA (measured by task query completion time) and usability (SUS scores) on AR interfaces, and a weak to moderate inverse relationship between SA (measured by task query completion time) and usability (SUS scores) on Map interfaces.

Table 28. Results summary from Study 2

Construct	No.	Hypothesis	Result
Hypothesis 1:		*AR interface:*	
Situation Awareness	*H1*	H1: There is a difference between the two AR Interfaces on task query completion time.	Not Supported
	H2	H2: There is a difference between the two AR Interfaces dependent on Points of Interests (POIs) on task query completion time.	Supported
	H3	H3: There is a difference between the two AR interfaces on response accuracy.	Not Supported
		Map interface:	
	H4	H4: There is a difference between the two Map Interfaces on task query completion time.	Supported
	H5	H5: There is a difference between the two Map Interfaces on response accuracy.	Supported
Hypothesis 2:		*AR interface:*	
Usability	*H6*	H6: There is a difference between the two AR Interfaces on SUS score.	Supported
	H7	H7: There is a difference between the two AR Interfaces on ASQ rating.	Supported
		Map interface:	
	H8	H8: There is a difference between the two Map interfaces on SUS score.	Supported
	H9	H9: There is a difference between the two Map interfaces on ASQ rating.	Supported

5.4.2 RQ3: Hypothesis 1 – Effect of SA-supported Interface Design on SA

5.4.2.1 AR Interface

Study 2 was designed to evaluate two SA-supported interfaces—one AR interface and one Map interface. One important goal of this study was to investigate the effects of SA-supported interface design on user's SA, measured by task query completion time. Results suggest that a user's SA—as measured by task query completion time—was affected by interface type (SA-supported interface vs. baseline interface) depending on the number of POIs presented. Specifically, the advantage of the effect of interface on user's SA, as measured by task query completion time, becomes larger when the number of POIs increases (3, 5, 7, 12). With the same number of POIs fixed on AR interfaces across all levels of number of POIs, the SA-supported interface was better than the baseline interface in terms of task query completion time. Although an interaction effect between interface and the number of POIs was present these findings still demonstrate the positive effect of SA-supported design on a user's SA. When we examined results for the AR interfaces, there was no significant difference between SA-supported interface and baseline interface in terms of response accuracy. The number of POIs, however, did have an effect on response accuracy. This outcome could be due to the fact that participants were instructed to focus on accuracy and had no time limits on task query completion. It is possible that the participants experienced a speed-accuracy trade-off. This effect is suggested from a more restricted variance in accuracy scores.

Both tested interfaces provided the same set of information (e.g., name and distance). The only difference between the SA-supported interface and the baseline interface was the information presentation—one was in table view (the SA-supported interface), while the other was in cluster view (the baseline interface). The table view interface feature was designed based on the concept of radar-map overlap, which stemmed from claim analysis on user requirement No.13, No. 26, and No. 34 (Appendix S).

Qualitative feedback obtained from participants (Table 18 and Table 19 in Section 4.3.5) suggests that the table view feature was good for "ranked information presentation (ranked by multiple options; distance as a default" (Fr.=20), "organized information" (Fr.=19), and "detailed information immediately accessible" (Fr =14). There were some downsides, however. Some users commented that the direction arrow indicator was not obvious (Fr.=11). Despite that drawback, one of the participants commented, "For the list, you don't necessarily need to see the direction, if you see the distance, you get a general idea of where's in the radius (in the mini radar). I don't think direction matters that much." Therefore, additional research on study alternatives is recommended to further explore visual details with respect to the direction indicator in table view. In addition, participants also commented that there was a lack of an "overall view" (Fr.=8), because on the cluster view, they can easily see "all" without having to scroll up and down on the table view.

Another point of concern among some users had to do with design—and specifically the inefficient use of screen real estate (Fr.=7)—as evidenced by the comment: "I could be looking at a restaurant right in front of me, but I may not know it immediately, because I see this big black box to choose information." This statement indicates that regardless of whether the physical objects can be accurately registered as realized objects on screen, users might just prefer to see more see-through background of the physical environment on the AR viewer to keep the real-time live feed sense. Another negative comment had to do with the perspective radar, although this feature was not related to the task query in the experiment. One of the users commented, "The perspective radar doesn't give you an accurate sense of how far things are away and the relative distance in between." As noted in evaluative comments, the mini radar was clearly preferred by participants.

By contrast, on the AR baseline interface, users thought the interface had "clear direction" (Fr.=14), "overall view" on screen (Fr.=9), "visually interesting presentation" (Fr.=5). Negatives associated with the baseline interface included that it was "against the principle of motion economy" (Fr.=18), where participants had to individually click on each label to see every information, and "disconnected spatial relationship between physical objects and realized objects" (Fr.=15), where half the participants were confused about the presentation of the labels in terms of attributes of real physical objects. In addition, in contrast to table view, participants had some difficulties with cluster view—mainly because this format made it more difficult to make comparisons between POIs (Fr.=8), as well as to rank POIs (Fr.=8). Lastly, due to testing constraints using PowerPoint mockups in a lab setting, some participants worried about the stable presentation of labels (Fr.=5). For instance, one commented, "(When the camera moves) if things keep in and out, that could be confusing." Specific user quotes are provided in (Table 18 and Table 19 in Section 4.3.5).

<u>User preference on AR interfaces</u>

When the 32 participants were asked to indicate their preferred interface, 19 stated that they preferred the SA-supported interface, 10 liked the baseline interface better, and 3 had no particular preference. More interesting, among the 10 participants who preferred the baseline interface, 4 of them indicated that they would prefer the cluster view when just a few POIs were presented—but when more were available, they liked the table view better. Based on prior research, one reason for this finding could be that the cluster view layout might facilitate global perception (i.e., preattentive or holistic processing) (C.D. Wickens, 1999)—in contrast to the more "local" processing of a single specific piece of information a display's table view. Because global processing is preattentive and automatic, it can reduce attentional demand as one processes a multi-element display (Wickens, 1999). However, according to Wickens (1999, 2007), to utilize one's global perception two conditions have to be met in such a context to utilize the automatic holistic processing. First, the Gestalt principles (e.g., proximity, symmetry) or related information principles must be used to produce groups or emergent features (i.e., a global property not evident as each is seen in isolation). Second, the organization formed by the proximity of different elements on the mobile AR viewer must be compatible with the environmental elements they represent, and the user's mental representation of them.

Therefore, when considering the quantitative and qualitative results in total, we would recommend an integration of the two views (cluster view + table view) to provide the advantages of each, while minimizing the individual disadvantages of both view types. Furthermore, on cluster view design, global perception should be promoted by 1) utilizing the Gestalt principles (e.g., proximity, symmetry) or related information principles to produce groups or emergent features; and 2) forming the proximity of different elements compatible with the physical elements they represent (e.g., direction), and the user's mental representation of them. With this recommended redesign (e.g., a dual view solution), integrating a table view that supports local perception of task-important information with a cluster view that promotes global perception can support a user's SA.

5.4.2.2 Map interface

The findings from this study suggest that with the Map interfaces there was a significant difference in situation awareness, as represented by task query completion time—with SA-supported interface taking less time than baseline interface. In terms of the response accuracy, results suggest that there was a significant difference between the SA-supported interface and the baseline interface. We suspect that this outcome has to do with the fact that users paid more attention to response accuracy instead of completing the task query as quickly as possible—as they were instructed to dos.

Both tested interfaces provided the same set of information (e.g., name and distance). The only difference between the SA-supported interface and the baseline interface was in the provision of spatial cues, which were shaped as concentric circles originating from the location of the user. This spatial cue interface feature was designed based on the concept of radar-map overlap, which stems from claim analysis on user requirement No. 20, No. 27, and No. 29 (Appendix S). Qualitative feedback obtained from participants

(Table 20 and Table 21 in section 4.3.5) suggests that the spatial cue feature was “good for spatial estimation” (Fr.=32), “good for comparison” (Fr.=16), good for directional reference” (Fr. 11), “good for locational reference” (Fr.=7), “good for viewing a collection of POIs” (Fr.=4), and “less learning curve” (Fr.=3). Specific user quotes are provided in (Table 20 and Table 21 in section 4.3.5).

As a possible alternative in claims analysis (No. 20 proposed information design feature in Appendix S), the accuracy of spatial information received mixed feedback. In claims analysis, one of the proposed design feature alternatives was “providing a concept of radar-map overlap, but distorted to accommodate environmental factors, e.g., geographic factor and traffic factor.” However, the hypothesized drawbacks of the feature in claims analysis indicates that having an accurate contour “increases visual details and complexity, and may not be visually pleasing.” Because Map is an information-intensive interface, adding visual complexity—which could result in visual clusters—could become an issue of preventing users from accessing task-important information. The importance of being accessible was considered to out-weight the importance of being accurate in a more leisure context for which this application was designed. As one of the participants commented, “Accuracy would be beneficial, as long as it doesn’t get too ‘out of control’… it gives it away.” Since participants feedback was mixed, a computer algorism could be developed to develop a sort of “middle solution” to enhance both accuracy and visual clarity. In addition, a future study could be conducted to evaluate which concept (approximate spatial cue vs. accurate spatial cue) can provide better situation awareness in terms of task query completion time as well as user’s subjective preference.

User preference on Map interfaces

With respect to their interface preference, 32 out of 32 participants preferred the SA-supported Map interface over the baseline interface. As discussed previously, a more detailed study is needed to compare the approximate spatial cue and accurate spatial cue in terms of user’s SA and user’s preference.

5.4.3 RQ3: Hypothesis 2 – Effect of SA-supported Interface Design on Usability

Based on results from both the SUS scores and the ASQ ratings, the SA-supported interface was significantly different than the baseline interface with respect to perceived usability. Thus, Hypothesis 2 was supported. To further explore the relationship between SA and usability, two correlation tests were conducted. First, correlations between the SUS score and the ASQ score for both the AR and Map interfaces had a strong positive relationship. This finding indicates that the two usability scores were positively correlated, and internal validity of usability as a construct was strengthened. Second, another correlation test suggested that there was a weak to moderate inverse relationship between task query completion time and usability score on the AR interface; and a moderate inverse relationship between task query completion time and usability score on the Map interface.

Usability as a construct incorporates varying dimensions and is assessed by a wide variety of measures, such as effectiveness, efficiency, satisfaction, errors, attitude, learnability, accessibility, operability, acceptability, flexibility, memorability, ease of use, usefulness, utility, playfulness, enjoyment, acceptability, quality, reliability, attitude, security, aesthetics, utility, memorability, content, attractiveness, and so on (Coursaris & Kim, 2011). In this study, participants' satisfaction with the perceived usability of the interface was assessed using standardized questionnaires (Sauro & Lewis, 2012).

In terms of SA, as an internal construct of the human mind, Endsley (1988a) stated that SA "can be conceived of as the pilot's internal model of the world around him at any point in time" (p. 97). In essence, SA represents the current state of the mental model (M.R. Endsley & Garland, 2000). Within the context of this research, exploratory navigation is a complex behavior. Processing surrounding information such as visual landmarks, subtle environmental cues, digital information about distant objects provides users with information to browse, observe, and select between alternatives based on their goals or interests. Accordingly, in contrast to perceived usability, an SA-supported interface is a configuration of SA task-important information and the interface that presents it to the user. This means that a moderate correlation between user's SA and interface's satisfaction (i.e., perceived usability) could be used as a preliminary result to generate more research questions in the domain of SA and usability-related research.

5.4.4 Concept Design Evaluation

Five concept designs (CDs) were evaluated with specific features, as follows. (CD)1: An image recognition feature: (CD)2: Dynamic pedestrian flow (associated with local events); (CD) 3: "Search & Identify" / varying types of search within the mobile AR viewer, (CD) 4: Visualized information/ the real-time information of a POI regarding its dynamic and interactive aspects, and (CD) 5: Trends that reveal or confirm information to establish a trend of experiences. CD-specific results are listed below:

(CD)1, image recognition, received positive feedback. Participants welcomed this feature by positively commenting on its capability of enabling browsing surroundings, registration, and path indicating, information seeking, and layers to filter. Only three participants were unsure what they would use it for until they had it.

(CD) 2: Providing a dynamic pedestrian flow associated with local events received mixed feedback, principally because in most situations where time is not an issue, participants indicated that they wouldn't mind walking in crowds, and a few stated that this feature could help them estimate time more accurately in exploring a place.

(CD) 3: Providing a "Search & Identify" feature received positive feedback with participants describing it as a perception aid and "motion" saver.

(CD) 4: Providing real-time view of dynamic and interactive aspects of a POI received positive feedback, and multimedia "static" information was welcomed as well.

(CD) 5: Trend-revealing information, providing aggregated reviews, received positive feedback; in contrast, trends that figure about the performance (see Appendix R received mixed feedback. Participants expressed that they would pay more attention on the figure unless a dramatic change occurred in its performance (e.g., a dramatic drop). Otherwise they would just look for the average indicator (e.g., overall rating) to anticipate their future experience.

More specific user quotes are provided in Section 4.3.6 in Table 22 through Table 26.

Table 29. Design principles for designing systems for SA from Endsley (1993)

SA Interface Design Principles	**Interpretation**	**Example(s)**
Principle 1: Organize information around goals	Information should be organized in terms of the operator's major goals.	The SA requirements analysis provides the input needed to determine which information is required for addressing each goal.
Principle 2: Present Level 2 information directly—support comprehension	As attention and working memory are limited, the degree to which displays provide information that is processed and integrated in terms of Level 2 SA requirements will positively impact SA.	Directly portraying the deviation between a current value and its expected (or required) value is better than requiring the operator to calculate this information based on lower level data.
Principle 3: Provide assistance for Level 3 SA projections	Displays that allow operators to anticipate possible occurrences have been shown to support the operator's own ability to create accurate projections.	A trend display, graphing changes in a parameter over time, can be very useful for helping operators project future changes in that parameter
Principle 4: Support global SA	In many systems, a global SA display that is visible at all times may be needed. Global SA is critical for accurately determining which goals should have the highest priority and for enabling projection of future events. Detailed information related to the operator's current goals of interest should be provided as required.	Excessive menuing and windowing often obscures information on other windows that should signal operators to attend to other, more important information.
Principle 5: Support trade-offs between goal-driven and data-driven	Designs need to take into consideration both top-down and bottom-up processing. The design of the system	As environmental cues with highly salient features (e.g., flashing lights, bright colors, loud sounds)

processing	around operator goals (Principle 1) will support goal-driven processing. The big picture display that supports global SA (Principle 4) will support data-driven processing by directing the operator as to where to focus attention to achieve high priority goals. The key is to ensure that these two approaches complement each other.	will tend to capture attention away from current goal- directed processing, these characteristics should be reserved for critical cues that indicate the need for activating other goals, and should be avoided for noncritical events.
Principle 6: Make critical cues for schema activation salient	Those that can be verbalized and are known to be important should be coded on the display with salient cueing that supports operator decision making.	If particular fuel levels trigger different classes of situations, markers should be placed at these "breakpoints."
Principle 7: Take advantage of parallel processing capabilities	System designs that support parallel processing of information by the operator should directly benefit SA.	Designing involves using visual, auditory, and tactile designs to increase SA.
Principle 8: Use information filtering carefully	Information filtering deprives people of the global SA they need to be predictive and proactive; the operator needs to be able to respond to not only immediate crises, but to look ahead to what is coming up in order to identify developing situations (Level 3 SA); individual differences must be considered with respect to the formation of information filtering schemes.	Type of information filtering approach can actually seriously degrade SA (Endsley & Bolstad, 1993).

5.4.5 From SA User Requirements to SA-supported Design Recommendations

In this research, the proposed SA design recommendations (transformed from SA user requirements) can be interpreted as a specialized supplement to design principles for designing system for SA proposed by Endsley (1993) (Table 29). As can be seen, Endsley's SA design principles are a high-level, highly extracted set for designing complex systems for SA—which may deter designers and developers from incorporating them in actual systems design for consumers. In addition, Endsley's design principles (1993) are primarily derived for and applied to SA interface design for complex systems. However, based on the concept Endsley provided (discussed previously), designing for SA could have broader implications and more applications in system design, without strictly restricting to designing for complex system. In contrast, the proposed SA-supported design recommendations were intended to be a more specialized and detailed set that could be used by designers and developers for creating less complex—but more dimensional mobile—AR guidance applications for urban exploratory navigation.

The way this research work derived design recommendations from user requirements was to empirically evaluate the concept, either through a quantitative experiment or a qualitative evaluation. Among these evaluations, qualitative evaluation is considered as more of a first step to a follow-up quantitative experiment, although in this research both methods are used to transform the set of user requirements to design recommendations. This research (study 2) is considered as an initiation of a validation of the extracted user requirements and of a translation from user requirements into a set of design recommendations. This method is shown to be useful in other HCI research to translate user requirements to design recommendations (Lessel, Böhmer, Kröner, & Krüger, 2012). As can be seen in Figure 31, in this research four steps were involved in this translation.

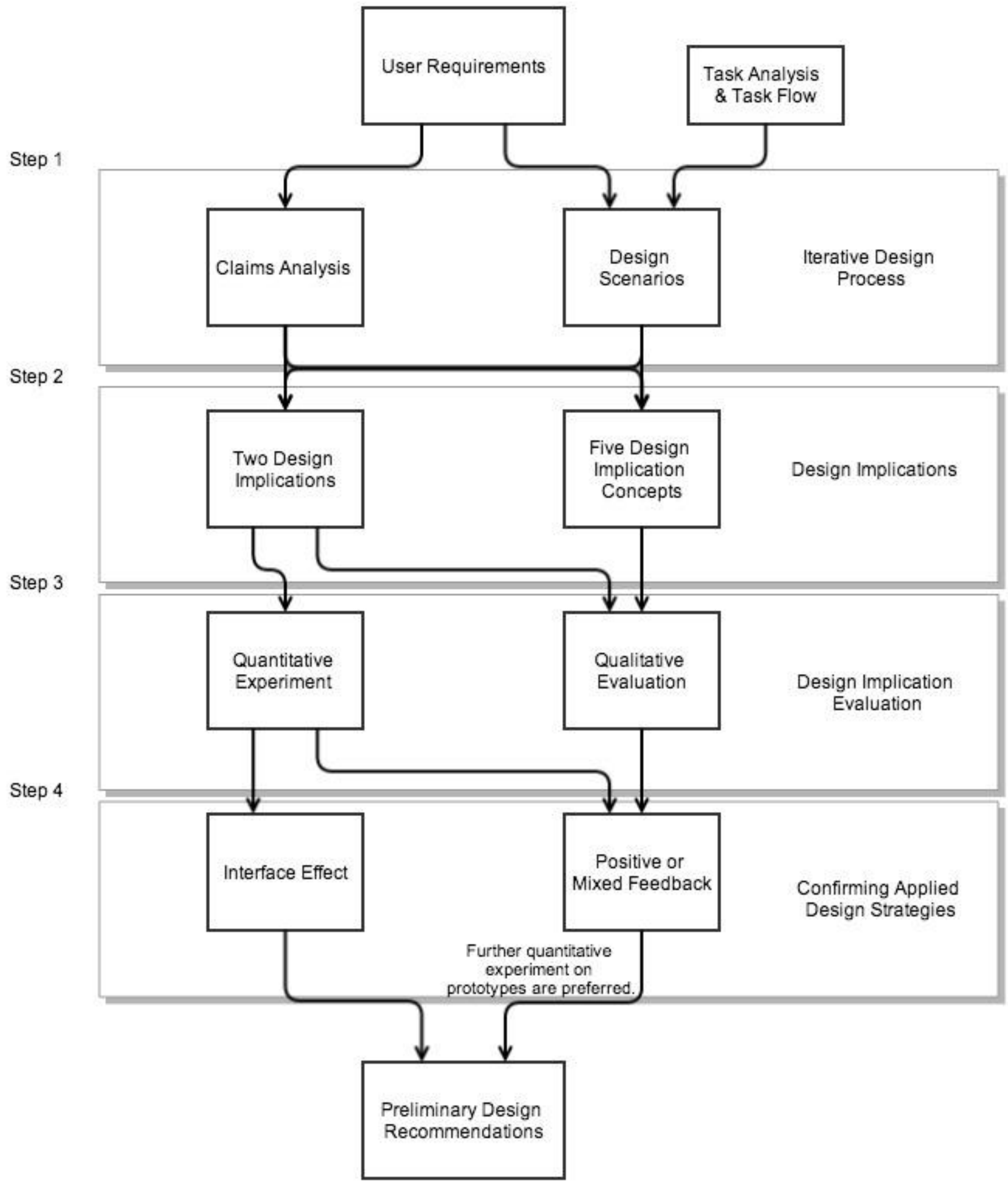

Figure 31 Translation process from SA user requirements to SA-supported design recommendations

Step 1: Based on the extracted SA user requirements, this process involved several design activities to produce specific SA-supported design strategies via claims analysis and information/interaction design scenarios (i.e., context-of-use) via scenario-based design.

Step 2: Based on results from claims analysis and designed scenarios, this step involved producing

prototypical SA-supported design implications, resulting in two concrete design implications and five design implication concepts.
Step 3: Subsequently, the third step involved investigating concrete design solutions by evaluating two design implications in a quantitative experiment and evaluating five design implication concepts in a qualitative evaluation.
Step 4: Last, based on the results from the evaluation, preliminary design recommendations were distilled by confirming the applied design strategies from design implications. Specifically, (1) based on the results from the experiment that there is a significant interface effect, the corresponding informed SA strategies are proven to be effective in supporting user's SA, and thereby the underlying SA user requirements are translated to preliminary design recommendations. (2) Based on the results from the qualitative evaluation that design concepts received positive feedback, the corresponding user requirements, embodied in informed SA strategies, are shown to be effective (to a lesser degree comparing to a quantitative experimental evaluation). It has to be noted that future studies should build concrete prototypes and conduct more rigorous quantitative examination, similar to the process used in the above-mentioned quantitative experiment, to empirically examine the underlying SA user requirements. Likewise, for the concepts that received mixed feedback, such further evaluation is needed because sometimes participants stated that they do not have a strong need or they do not need certain features but affirmed that they would use the feature if it was integrated into an evaluated prototype (Lessel et al., 2012).
Due to the constraints in this research (e.g., time), only a part of user requirements was translated into concrete design solutions in two interface design implications (i.e., AR and Map interface), and subsequently were empirically evaluated in study 2 (shown in Table 30). Specifically, in developing the AR interface, user requirements No. 13, 26, and 34 were applied. In developing the Map interface, user requirements No. 20, 27, and 29 were applied. In regards to designing implication concepts, positive results were obtained for concept 1, 2, 3 and 4, which involved, respectively, with user requirements 5a, 6, 7, 8b, 8c, 8g, 9, 10, and 33; with requirement 47, requirement 17; and with requirement 18, 19, and 49. Mixed results were obtained for concept 5, which associated with user requirement 48. No negative results were obtained from any of the concepts evaluated.

Once all the requirements in the set have been empirically assessed, the set then can be distilled and used as a set of validated design recommendations. In other words, once the evaluation process of the requirements is complete, the set of preliminary SA design recommendations as a set of specific design recommendations to add value in guiding SA-supported mobile AR guidance application design.

In addition, the proposed preliminary cognitive model entails different stages of information processing in the environment of mobile AR-enabled urban exploratory navigation. SA user requirements, subsequently transformed to interface design recommendations, are tightly related to the proposed model regarding various aspects of information processing.

In this research, a validation process was initiated for the extracted user requirements, which included conducting an interface evaluation of SA-support applied interface design, evaluating SA-support concept design, and examining related research findings from the literature. Table 30 provides a summary of this effort, with SA-support applied interface design (AR & Map interface), SA-support concept design evaluation (CD 1-5), and examining related scholarly research findings.

Table 30. A summary of an initiation of validation

Info Process	Sub-categories	SA User Req No.	SA-supported User Requirements	Comp.	Design Applied	Concept Evaluation	Related Research Findings & Design Recommendations from Literature
Perception	Goal	1	For exploratory browsing and goal-directed exploration, users shall be supported with different layers or modules of information to select at as they wish (P2:68;P4:40;P1:224;P3:148;P5:235)	N/A			
	Goal	2	For exploratory browsing and goal-directed exploration, users shall have personalization options to set up preferences and add personal or cultural related POIs (P1:191;P5:163;P2:81;P2:94).	N/A			
	Goal	3	For exploratory browsing and goal-directed exploration, users shall have an option to express and describe their needs to the system (P1:118;P2:33;P5:126).	N/A			

Recognizing / identifying/ locating/ orienting	4	For exploratory browsing and goal-directed exploration on mobile AR viewer, users shall be able to identify or recognize their own location and orientation, as well as obtain information about relevant POIs in their vicinity (P1:271;P4:243;PF2:44;P3:63;P3:75;P3:188;P4:78;P4:233;P5:249).	Sp	AR	
Recognizing /identifying	5	*For exploratory browsing and goal-directed exploration, users shall be supported the following specific ways (5a-c) to assist their recognition and identifying process (P1:246; P3:171;P4:224;P5:235;P5:238):			
	5a.	Prioritized and more detailed information, upon request, about POIs that are directly visible from the AR viewfinder, to assist user’s “scan” activity; includes an option to reveal additional information;	Sp A		CD1
	5b.	Less detailed information, upon request, about nearby POIs that are not directly or completely visible from the AR	Sp A	AR	

		viewfinder; includes an option to reveal additional information;			
	5c.	Less detailed information, upon request, about distant POIs that are visible but vague from the AR viewfinder; includes an option to reveal additional information.	Sp A		
Recognizing /identifying	6	For exploratory browsing and goal-directed exploration, users shall be supported by an image recognition feature in order to identify and highlight the requested POIs that are directly visible to the user (P1:164;P2:232;P6:285; P2:242; P1:285;P5:28;P5:274;P5F:107;P5F:124).	Sp A	CD1	Information browsing provides users with location-referenced information about objects in their surroundings, where information takes many different formats—e.g., other images, others' comments, internet-created information, etc.—and can be selected for more detailed information (Frohlich et al., 2006; Rasinger, 2009; Reitmayr & Schmalstieg, 2004a; Schmalstieg et al., 2007).
Recognizing /identifying	7	For exploratory browsing and goal-directed exploration, users shall be supported by information on "attention-catching" POIs that stand out in the environment (P3F:37;P2:208); and/or those that are goal-related (P4:327;P3:265; P1:355;P3:267;P6:366).	Sp A	CD1	

Recognizing /identifying	8	For exploration and navigation, users shall be able to keep track of the following environmental cues (8a-h):			
	8a.	street information (e.g., street numbers/street signs) (P1:83;P2:115;P3:57;P4:74;P3:57;P4:34;P4:59);	Sp A		CD1
	8b.	store signs and company logos (P4:58;P4:74);	Sp A		CD1
	8c.	location of oneself (P5:87);	Sp		CD1
	8d.	direction to destination POIs (P1:94);	Sp	AR/ Map	
	8e.	distance to destination POIs (P1:94;P4:127;P5:94; P5:87);	Sp	AR/ Map	
	8f.	estimated time needed to reach a POI by taking into account various environmental factors (P1:94;P2:115;P5:94;P2F:78; P4:230);	T	AR/ Map	
	8g.	dynamic pedestrian traffic	Sp		CD2

		(P1:133;P2:115;P5:94);	T		
Recognizing /identifying	9	For exploratory browsing and goal-directed exploration, users' need to obtain more information about visual landmarks shall be supported on/from mobile AR viewer (P2F:36;P2F:42;P3:57;P3:225; P4:252; P4:255; P4:256).	A	CD1	
Recognizing /identifying	10	For exploratory browsing and goal-directed exploration, users' need to obtain more information about cognitive landmarks shall be supported on/from mobile AR viewer (P1:69;P2:134;P4F:127;P6:85).	A	CD1	
Recognizing /identifying	11	For exploratory and navigation, users shall have a consistent and interlinked interface among insight view and overview (P2:89;P5F:176).	Sp A		
Search	12	For exploratory browsing and goal-directed exploration, users shall be able to perform varying types of searches within the mobile AR viewer with returned searching results	A		Search mechanism that provides access to relevant information (Frohlich et al., 2006; Rasinger, 2009). Mobile search has been categorized into four main areas both for on-the-go uses or for stationary uses (Church & Smyth, 2008). Navigational search refers to a class of queries where the

		(P3:58;P2F:69;P6:265;P4F:56;P5F:107;).			immediate intent is to reach a particular site, such as a company. Transactional search occurs whenever the user seeks further interactions such as shopping, gaming, or downloading files (e.g., images, videos, music, adult-related queries). Information search involves situations in which users attempt to find information online, while leisure search has an orientation towards entertainment and discovery options to organize a user's private time (Westlund et al., 2011).
Interface Support	13	For exploration and navigation, users shall be able to quickly scan information on mobile AR viewer to minimize the time spent on screen (P2:73;P5:150;P2F:75;P2F:114;P3F:83;P4F:132;P5F:59;P6F:50).	N/A	AR	
Interface Support	14	For exploratory browsing and goal-directed exploration, users shall be supported with an adaptive interface that is constantly adapting to the user's behavior and buildup profile (P1:187;P2:55;P4F:89;P6:54;).	N/A		The system should provide personalized recommendations to adapt the presentation of information depending upon the patterns of human motion, such as usage history (e.g., information that visitor has already seen), people's movement patterns through an area and geographic layout of the space (Ludford et al., 2006), the time of day, duration of stay, amount of pre-planning (Ludford et al., 2006), on inferences of a user's likely current interests and preferred activities from

user profiles and patterns of past user behavior (Bellotti et al., 2008), to deliver messages in ways that fit patterns of human motion (Cheverst et al., 2000). For example, the system should narrow the information delivery radius for stationary users; if the visitor makes a return visit, the information should reflect that and adapt its presentation, such as providing a welcome back message (Cheverst et al., 2000). The system infers the interests of the user based on the user's behavior and presents relevant augmented information based on such behavioral information. If the user shows further interest in the AR content, the system detects it and provides progressively more information (Ajanki et al., 2011). This functional requirement is one of the solutions to the information overload problem when the user may not have an explicit query in mind or may not even be searching. Therefore, the mobile AR system will display information based on the system's inferences on the user's behavior (Ajanki et al., 2011). However, the disadvantage associated with implicit input is that it needs a complete and thorough user profile and an accurate model of user behaviors.

Spatial boundary	15	For exploratory browsing and goal-directed exploration, users shall be able to receive spatial information that is automatically adjusted based on environmental factors (P1:188;P4:327).	Sp		Location-based applications will identify and adjust to crowded areas and traffic patterns because traffic patterns and distractions in dense urban areas can distort a person's perception of distance (Ludford et al., 2006). For example, these applications will deliver messages that take into account the locale, where dense urban areas feel smaller.
Spatial boundary	16	For exploratory browsing and goal-directed exploration, users shall be able to adjust the information range at will on a mobile AR viewer (P4:327; P5:133).	Sp		Users should be able to see locations within a certain range of the current position (immediate surroundings), such as accessing the name of the POI and the distance to it (Yang, 2011). Users might need to access other information in their surroundings, such as transportation information (e.g., for mass transit riders).
Recognizing /identifying	17	For exploration and navigation, users shall be supported by a concept of "search & identify," enabled by an image recognition and identification feature in order to help users identify POIs at request, thereby assisting the natural human visual inspection activity (P1:164;P2:232;P6:285; P2:242; P1:285;P5:28;P5:274; P5F:107;P5F:124).	Sp A	CD3	

Recognizing /identifying	18	For exploration and navigation, users shall have an option to access the POI's visualization information, if applicable (e.g., real-time view, or photorealistic pictures) (P4:269; P5:276).	A	CD4
Recognizing /identifying	19	For exploratory browsing and goal-directed exploration, users shall have an option to access specific POI attributes that cannot be easily described textually, if applicable (P3F:112;P2F:67;P4:193).	A	CD4
Locating/ orienting	20	*For exploration and navigation, users shall be supported by an interface to quickly check one's current location/orientation and a desired destination's location/orientation, if applicable (P2:154;P4:247;P5:145).	Sp	
Noticing	21	*For exploration and navigation, users shall have an option to be aware of the ongoing status of events or activities in their vicinity (P3:186;P4:234;P5:101).	T	

Interface support	22	For exploration and navigation, users shall be supported with multimodal input and output to alleviate having to engage both hands in the mobile context (P1F:109;P1F:119;P2F:183;P6F:120;P4F:130).	N/A	In addition to a visual interface, in an outdoor environment other interaction models (e.g., speech and voice recognition) will occur (Schmeil & Broll, 2006). Users will be more cognizant of the surrounding environment as a result of delivered information that users can perceive and comprehend, such as audio and haptic notifications (Frohlich et al., 2006; Jacob et al., 2012). Other modalities have potential in mobile AR navigation interfaces, such as audio or haptic navigation guidance, and animated guides using body gestures to direct tourist (Schmalstieg et al., 2007); unobtrusive implicit input from the user—specifically, eye movement patterns (e.g., selecting icons by looking at them) (Schmalstieg et al., 2007) and speech and other implicit feedback data—can be used for information filtering (A. Ajanki et al., 2011).
Interface support	23	For exploration and navigation, users shall have a mobile AR interface with a glare-free screen, operating properly under varying light conditions (P3F:56).	N/A	

	Interface support	24	Users shall have accurately tracked, registered and displayed augmentation on mobile AR viewer (P2F:75;P2F:114P3F:83;P4F:132;P5F:59).	N/A		
Comprehension	Acquiring overview	25	For exploratory browsing and goal-directed exploration, users shall be supported by an overview of spatial patterns and relationships of POIs in one's vicinity regarding some aspects of attributes (P3:196;P4:243;P4:248;P5:260;P5:47;P5F:44;P4:28;P5F:50;P4F:85;P4:243;P5:260;P6:272).	Sp A So	AR/ Map	One study shows that the combined use of egocentric and exocentric views in navigation can increase one's awareness of a location (Grasset et al., 2005). To extend on this, two general types of interfaces are identified combining these different views together: spatial and temporal methods (Grasset et al., 2011). The spatial method is used to show more viewpoints from the user's view; while the temporal method is used to provide a mechanism to switch successively between different viewpoints.
	Acquiring overview	26	For exploratory browsing and goal-directed exploration, users shall have an option to perceive an overview on a mobile AR viewer (P2F:89;P2F:165;P2F:86).	Sp	AR	

Quantifying/ Estimating amount	27	For exploratory browsing and goal-directed exploration, users shall have a way to know the amount of POIs sharing one or more attributes under query in one's vicinity (P2F:44;P2F:52;P4F:49;P4F:54;P4F:57;P6F:65).	A	AR
Interface Support	28	For exploratory browsing and goal-directed exploration, users shall be supported with a progressively disclosed interface to gradually receive information upon request (P1:66;P1:75;P4:90;P6:139).	N/A	AR
Quantifying/ Estimating amount	29	For exploratory browsing and goal-directed exploration, users shall be able to have a way to know the spatial relationships of the POIs sharing one or more attributes under query (P2F:103;P3F:70;P4F:145).	Sp A	AR

Acquiring patterns	30	For exploratory browsing and goal-directed exploration, users shall be supported with information that locally-based individuals uniquely possess (P1:52;P5:61).	A S			
Acquiring relations and comparisons	31	For exploratory browsing and goal-directed exploration, users shall be supported with a ranking mechanism that can rank POIs based on one or more attributes at request (P2F:70;P5:163;P6;94;P3:211;P1:305).	Sp	AR		
Acquiring relations and comparisons	32	For exploratory browsing and goal-directed exploration, users shall be able to have an option to compare alternative POIs under query in a quick and easy way (P2F:70;P2F:180;P3F:64).	A	AR		
Interface Support	33	For exploratory browsing and goal-directed exploration, users shall be provided with an interactive AR view with augmentations enabling direct manipulation (P1F:18;P2:94;P2:273).	N/A		CD1	Urban environments are rich in potential targets for annotation (Tokusho & Feiner, 2009). An interactive mobile AR view could serve as an interface to additional, more detailed information about a POI via online databases (Davies et al., 1999; Kahari & Murphy, 2006; J. Wither et al., 2009; Wither, 2009). In addition, users can interact with the

					information presented to them by creating, adding, editing, deleting annotations to specific physical locations and objects (Frohlich et al., 2006), in formats of visual textual annotations (Feiner et al., 1997; Thomas et al., 1998b) or multimedia information (Hollerer, Feiner, & Pavlik, 1999), or multi-modal interaction (e.g., accessing by voice activation) (Gabbard et al., 2002). Four types of interactivity with respect to mobile AR annotation exist (Wither et al., 2009): 1) static and offline (e.g., hyperlinks); 2) interactive (e.g., "clickable") but not editable; 3) editable; and 4) user-created annotation. For example, for textual annotation only keywords are provided. Selecting one provides more detailed information in a popup window (Schmalstieg et al., 2007).
Acquiring relations and comparisons	34	For exploratory browsing and goal-directed exploration, users shall be supported with a view by which users can browse information semantically in a categorical way (P1F:75;P3F:75;P4F:85).	Sp A	AR	
Acquiring relations and comparisons	35	For exploratory browsing and goal-directed exploration, users shall be provided with a filter mechanism	A		The option to filter information or layers based on several factors, such as user interests (e.g., weather and terrain, distance) to present information in an uncluttered way so that it is easy to interact with (Ajanki, 2011; Gabbard et al., 2002;

		(P5F:124;P1F:18;P2:273).			Julier et al., 2000; Tsai et al., 2012). A set of rules of prioritization should be generated. Specifically, task-related data must prevail over neutral data, nearby information must prevail over distant information, and more important information must take precedence over minor information (Neuhofer et al., 2012).
Acquiring relations and comparisons	36	For exploration and navigation, users shall have an option to access alternative paths along with corresponding POI information to the destination (P3:211;P1:305).	Sp A		
Acquiring relations and comparisons	37	For exploration and navigation, users shall be made aware of POIs of potential interest based on a pre-established user profile, which could serve as alternative paths to the destination (P5:163;P2;94;P3:211;P1:305).	Sp A		
	38	For exploratory browsing and goal-directed exploration, users shall have an option to set up and receive location-based (spatial) reminders of POIs of potential interest on their way to the destination (P5:163;P2;94).	T		The tourist may miss out on important or interesting information, especially in information-rich urban settings (Cheverst et al., 2001; Rasinger, 2009). “Push” notification has a role to play in location-based systems, where immediately relevant information is “pushed” to users. These virtual reminders are associated with physical locations for

				spatially- or temporally-relevant information, such as social messaging (e.g., E-Graffiti), community announcements (e.g., GeoNotes),venue information (e.g., PlaceMail) or life-critical information in the battlefield (Gabbard et al., 2002). This is also called opportunistic reminders, which provides a early "just-in-time" or "just-in-place" prompt and task details later, telling the user to take spatially or temporally relevant action (Ludford et al., 2006).
Acquiring relations and comparisons	39	For exploratory browsing, goal-directed exploration and goal-directed navigation, users shall be provided at will with information about POIs sharing one or more attributes *or* alternatives (if applicable) (P1:231;P1:368;P2:333; P3:320; P4:389;P4:295;P3F:71; P4:295;P5:289;P6:401).	A	
Acquiring relations and comparisons	41	*For exploratory browsing and goal-directed exploration, users shall have an option to be informed of information about POIs in their current vicinity and in the vicinity of their destination(s). (P6F:101;P4F:123;P4F:165;P6F:101).	Sp	A system should enable people to discover new places because tourists may wish to explore available information about their surroundings with or without pre-defined task (goal/criteria) (Ajanki, 2011; Yang, 2011).

Acquiring relations and comparisons	42	For exploratory browsing and goal-directed exploration, users shall have information with a uniformed layout, *varied* for different types of POIs (P3:183;P5:105).	A	The system should enable visitors to control their pace of interaction with the system, for example, stopping or interrupting the tour when needed (Cheverst et al., 2000). Freezing the camera image (mobile AR view) when desired, while keeping the overlaid graphics live, support manipulating the interface and visualization without having to keep the device pointed at the scene. Once the display is frozen, direct manipulation (e.g., touching the screen to show information) is useful.
Interface support	43	Users shall be able to interact with mobile AR viewer analogous to interactions with a touch-screen-based camera (P8:89;P5F:107;P5F:124).	N/A	
Interface support	44	*Users shall be able to save POIs for later access at will (P2F:70; P2F:180; P3F:64).	N/A	
Context support	45	Users shall be supported via personal context information in their vicinity (P1:221;P3:164;P4:208; P2:176; P5:219).	N/A	The system needs to create a personal context for every user (Suomela & Lehikoinen, 2000). Personal context needs to be considered: visitor's interest, e.g., history or architecture, and visitor's current location, the user's profile, the age, the technical background of the visitor, and their preferred reading language (Cheverst et al., 2000).

	Interface support	46	*Users shall be able to make changes and adjustment quickly on path and destination selection (P2:94;P3:74).	N/A	
Projection	Projecting	47	For exploratory browsing and goal-directed exploration, users shall have an option to be informed of real-time crowd/pedestrian flow associated with local events (P1:133;P2:115;P3:57;P3:225).	Sp T A So	CD2
	Projecting	48	For exploratory browsing and goal-directed exploration, users shall be supported upon request with trends that reveal or confirm information that can be used to establish a trend of experiences in one POI to assist in making projections in their (near) future visit (P1:140;P4:376;;P4F:130P5F:110;P5F:75; P5F:114;P5F:119; P5F:120;P5:330;P5:339).	T A So	CD5

	Projecting	49	For exploratory browsing and goal-directed exploration, users shall, upon request, be made aware of the real-time information of a POI regarding its dynamic and interactive aspects, thereby enabling a user's projections of its future state. (P1:100;P1:363;P1:370;P2:44;P3:225;P2:337P3:320;P4:322;P4:391;P5:339;P5:326;P6:144;P6:392;P6:380;P6:407;P1F:72;P1F:82;P2F:169;P4F:145;P4F:152;P5F:112;P5F:114;P5F:115).	T A So	CD4	The system needs to stay informed about the current physical environment (e.g. via dynamic information retrieval from application servers) (Hollerer, 2004). The system should also support information that user requires on-the-fly (e.g., randomly picked opening hours, local weather, traffic news), which cannot be supplied in advance and thereby needs to be capable of dynamic change(Cheverst et al., 2000; Davies et al., 1999). For example, in visiting Lancaster Castle, the castle was closed initially to the public because the courtroom (situated within the castle) was in session. If the court session were to finish early, the visitor would then be notified that the castle was open to the public (Davies et al., 1999). Dynamic mobile AR content can be accessed using the system and delivered at appropriate times (e.g., before the place, not after) and published and updated frequently (e.g., newspapers, brochures, public displays).
Others	Social	50	For exploratory browsing and goal-directed exploration, users shall have an option to interact with locally-based individuals or other users for spontaneous or planned social interactions (P1:334;P2:66;P5:110).	So		Mobile AR can also support collaboration among mobile users. Such interactions can also support collaboration among mobile users, which can be achieved by sharing information. A mobile collaborative augmented reality application is one that allows multiple users to share an AR experience using their mobile devices (Reitmayr & Schmalstieg, 2001). The AR content can be shared among face-to-face or remote users, at the same time (synchronous collaboration) or at different

				times (asynchronous collaboration) (Billinghurst & Thomas, 2011). Examples are BARS (Julier et al., 2001), Shared Space project (Billinghurst, Weghorst, et al., 1998), Human Pacman (a collaborative mobile AR game) (Cheok et al., 2003), the Augmented Stroll (a mobile collaborative mobile AR services to archeologists in field works).
Temporal	51	For exploration and navigation, users shall have an option to set up and receive temporally-relevant information reminders at will (P3:81;P5:116).	T	(*Related research was provided in Req. 38)
Attribute	52	*Users shall be provided with safety information about neighborhoods/areas of an unfamiliar place under query (P5:87;P6:101;).	A	

*Requirement with * indicated future empirical evaluation is needed to confirm the corresponding requirement.*

5.5 Limitations

The first limitation of this research is that Study 1 relied on the input of participants who all happened to be college students—and thus represented a more homogenous group with respect to age and experience. Although the researcher endeavored to elicit the perspectives of participants with diverse experiences and knowledge in terms of using mobile AR guidance applications, the diversity of participants could not be maximized in this study due to time and budgetary constraints. Future studies should include a more varied group of participants so that differing levels of knowledge and application familiarity are included. For example, an expanded study could include professional mobile AR designers or developers.

Furthermore, Study 1 used an existing mobile AR guidance application (Wikitude) as the principal interface for contextual inquiry. Although the application's usability was evaluated and taken into consideration during the course of data analysis, the risk of relying on a single application does present some inherent limitations in contextual analyses. Therefore, using multiple mobile AR applications may help to expand findings. The risk of pursuing this multi-application, however, is that it may distract users from focusing on assigned tasks and activities and instead evaluate the more "feel-and-look" aspects of the application.

A third limitation of this research is connected with the outfield observational study. Given that it occurred in a specific location, certain environmental factors inevitably influenced study results. In other words, a location-specific observational study could easily have altered a user's perception as to how exploratory navigation works in general, as well as influenced their situation awareness in exploratory navigation. For example, using a mobile AR guidance application in a less crowded, less busy town is no doubt different than exploring in a busy metropolitan city. In spite of study design efforts to mitigate the influence of regional differences—e.g., during the follow-up interview session a metropolitan city intersection (i.e., busier and more crowded than the Christiansburg location) was used to "situate" the participants and to solicit their SA requirements—existing field characteristics may still have influenced the data obtained in this study. Future studies on different degrees of field characteristics could possibly supplement findings from this study.

Last but certainly not least, interface mockups with mixed fidelity utilized in Study 2 posed a restriction in evaluating SA-supported interfaces. Specifically, a hyperlink (which was used to create an interaction flow) was added to a shape on a PowerPoint slide. However, the system automatically changed the color scheme of that shape to make the hyperlink obvious. This color change may have influenced a participant's perception of those interfaces. For instance, the added hyperlink made the color of the “cancel” button and clusters of items appear somewhat indistinguishable. Thus, subsequent studies with other testing platforms featuring more advanced components or other more specialized testing platforms are recommended to minimize the influence posed by the testing platform utilized herein.

5.6 Contribution of the Current Research

The anticipated contributions to the literature are four-fold:

1. Extending the application of situation awareness theory in a preliminary cognitive model in the environment of mobile AR-enabled urban exploratory navigation by identifying users’ SA processes and requirements for exploratory navigation tasks (Figure 14 and Table 12);
2. Initiating a validation of the application of the extracted SA user requirements in the environment of mobile AR-enabled urban exploratory navigation by adopting a systematic approach (Table 30);
3. Detailing how the extended theory can be used to inform mobile AR guidance systems design (Section 4.2); and
4. Providing a set of preliminary design recommendations regarding mobile AR guidance systems, which could be used by designers and developers in the design phase of mobile AR guidance applications.

The contributions of this study have further implications. Supporting situation awareness in the mobile AR navigation environment will not only be beneficial to decision-making processes for public use devices (e.g., in leisure tourism), but may also shed light on SA-supported mobile AR systems for other domains. For example, it could be refined for use among “mobile professionals” who engage in disaster relief, emergency response, or hazard abatement. For instance, maintaining awareness of the environment and of incoming messages would be essential to law enforcement personnel engaged in mobile patrol tasks (Streefkerk, McCrickard, Esch-Bussemakers, & Neerincx, 2012). For these emergency response domains, the use of mobile AR navigation guidance systems can help professionals react faster while providing a good situation awareness of their surroundings. Such capabilities would also be extremely useful in a number of other domains: (1) the battle environment, where mobile AR systems can assist with a commander’s situation awareness of military tasks; (2) for healthcare providers, where mobile AR-based dynamic information of a patient can be displayed to aid diagnosis; and (3), as mentioned above, police-firefighting work, where first-responders can rapidly assess hazardous, changing disaster situations.

5.7 Conclusion and Future Direction

In this research, the SA theory is extended from a highly strict information environment, primarily military environment to a more generic and mainstream information environment. The theory-extending environment in this research work, specifically, is a reality-augmented urban environment, built on a vision that an increasingly significant amount of information will be (if not yet) created in a fast-pace user-summoned way. In addition, to extend the SA theory, this research work provides sub-processes for each of the three SA processes (i.e., perception, comprehension, projection). Previous research in traditional SA theory-applying domains did not specifically identify these sub-processes. However, based on the findings in this research, the identification is shown to be useful in understanding user's SA and producing SA-supported design strategies.

Furthermore, this research investigated the design of an SA-supported interface, which resulted in a number of SA-supported strategies extracted and translated from user requirements to enhance user's situation awareness. Based on statistical results and qualitative data generated from this two-study research, it is clear that designing an SA-supported interface is possible when systematic approaches are implemented. Even though most of the SA-supported design changes suggested in this study are restricted to interface design changes—principally due to the experimental design in comparing an SA-supported interface to a baseline interface—those design modifications turned out to be helpful based on user performance in the experiment and responses in the post-session interview.

With these points in mind, the transformed system requirements, which are based on extracted SA user requirements, are proposed as a set of preliminary recommendations for designing mobile (specifically smartphone-based) guidance applications in the context of mobile AR-enabled urban exploratory navigation. Continuing this avenue of inquiry—along with additional validation from subsequent empirical studies on SA-supported interface and implementation of the validated recommendations—is likely to facilitate the continued improvement of mobile AR guidance applications that meet users' information requirements needs, as well as encourages more human factors research in this field.

In terms of future directions, typically, a new domain for a construct will initially be studied at the shallow levels, after which research on the domain will gradually move to deeper levels. For example, research on usability was initially studied to explore effectiveness and efficiency of using a particular website; in recent years, most research on this domain in HCI has focused on identifying various dimensions of usability, such as satisfaction, learnability, ease-of-use, utility, quality, etc. The most recently usability studies have started to be applied to the settings of, for example, e-commerce mobile site design, gaze and gestural control, and ubiquitous computing. Hence, the big heading directions for future research on SA as a construct include pushing existing domains deeper down the hierarchy to study SA's relationship with other constructs (e.g. usability and mental workload) and SA-supported interface design applications.

Addition to the general directions to promote SA research, the reminder document lays out some of these more immediately accessible avenues for future research. These future research directions are organized in Table 31 based on the outcomes resulted from this research work, and are categorized into four principle groups: to reduce limitations introduced by the method used and by the process involved, to continue on the current research, and to explore future applications of the outcomes. Subsequently, discussions on several most promising directions are offered in more details.

Table 31 Future research directions categorized based on outcomes resulted from this research work

Outcomes	To reduce limitations introduced by the method used	To reduce limitations introduced by the process involved	To continue on the current research	To explore future applications of the outcomes
(RQ1) SA cognitive model	Utilize less intrusive observation methods and less constrained tasks (e.g., Natural observation);	- Conduct observations in two (or more) locations to reduce the influence introduced by the field characteristics; - Involve a group of target participants with a more diverse mobile AR experiences;	Continue to investigate specific items in each sub-process of 3-stage process (e.g., searching, identifying, noticing);	- Apply to other mobile AR guidance platforms (e.g., wearable); - Extend to other handheld AR guidance domains (e.g., military, tourism, navigation, and entertainment;
(RQ2) SA user requirements	Same as the above;	Explore and implement other alternative design solutions *or* design solutions resulted from the remaining SA user requirements;	Continue to complete the evaluation of each SA user requirements to produce a set of validated SA-supported design recommendations;	To be applied with modifications to other mobile AR guidance platforms or handheld mobile AR guidance systems in other domains;
(RQ3) Evaluation results of the informed interface designs	Quantitative experiment and qualitative evaluation for alternative design solutions resulted from all user requirements;	Produce testing mockups using a more advanced prototype platform;	- Continue to evaluate other alternative design solutions or design solutions resulted from the remaining SA user requirements; - Continue to explore a combined solution integrated table view into cluster view (e.g., a dual view solution combined table view with cluster view) on SA-supported AR interface; - Investigate accuracy of the spatial cues used on SA-supported map interface;	Employ the systematic approach used in this research work to design and evaluate SA-supported interface strategies;

This research work introduces the SA theory as a theoretical framework to study user's interactions with his/her surrounding environment in a reality-augmented context. It lays out a theoretical foundation of studying user's interaction with surroundings using mobile AR guidance systems. Because SA is a widely accepted cognitive construct, it simply does not confine itself to the research domain of tourism (which is the testing bed in this research work). Thereby, researchers should continue to explore this cognitive construct in various domains, such as military, navigation, and entertainment.

For example, a recent paper presented a proposal of an awareness tool to display relevant information surrounding a person in an emergency situation based on arrows and aggregation of information types (Siu & Herskovic, 2013). It integrated information about distance, direction, and the type of off-screen POI, allowing users to quickly assess the relevant information surrounding the emergency site. This research approached and tried to improve first responder's *presence awareness*, allowing users to obtain information about the presence of others or objects, and helping users understand their *context* and find emergency site's information. However, based on the SA definition, *presence awareness* and the *context* could be viewed as parts of a user's SA. If the research adopts the SA cognitive model resulted from this research, more in-depth analysis could perhaps be offered. For instance, the author could investigate such type of awareness from a SA three-stage perspective and target specific SA-support design techniques for each stage. Such analysis may lead to a richer understanding of first responder's awareness with surroundings in an emergency site using a mobile AR device. In addition, because the systematic method used in this research work to extract SA user requirements, design and evaluate SA-supported interfaces is shown to be effective, the researcher could utilize the same procedures to yield more alternative design solutions for such AR devices.

The SA cognitive model introduced in this dissertation can provide a guide to future research on user's SA development process in the mobile AR environment. Much research remains to be done on topics related to the handheld AR systems, such as wearable mobile AR systems. This topic can be studied by adopting the proposed SA theoretical model with certain modifications. Specifically, 3-level SA model would still hold simply because the fundamental and original research on SA theoretical model still holds. Certain modifications are expected. For instance, this model can be studied by modifying level 1 SA (i.e. perception) in SA cognitive model to reflect an expected change from "focused attention switch?" to the "successful divided attention" (a.k.a. a parallel process). This parallel process is enabled by the capability of having a more accurate registration between environmental objects and realized objects on wearable AR viewfinder. This modification is expected simply based on attention research in human information processing that attention behavior is influenced by the degree of image conformity. The rest of the model would, assumably, still hold unless an individual's comprehension process (e.g. pattern recognition) and projection process (e.g. making a projection based on a prior experience) would change based on the platform's change.

Third, one of the limitations of this research work is the constrained function and interaction technique embedded in the interface mockups. We advocate that future research utilize other more advanced techniques or platforms to create mobile AR prototypes for an in-lab comparison experiment, such as a prototypical 3D environment for prototyping of AR applications interface (Berning et al., 2013). If a more advanced mobile AR prototype platform is used, participants' SA measurement could be assessed more precisely with fewer unwanted distractions introduced by the prototype itself.

APPENDIX A IRB APPROVAL LETTER

VirginiaTech

Office of Research Compliance
Institutational Review Board
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, VA 24060
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: April 2, 2013

TO: Tonya Smith-Jackson, Na Mi

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires May 31, 2014)

PROTOCOL TITLE: Extending Situation Awareness Theory in the Context of Mobile Augmented Reality-Enabled Urban Navigation

IRB NUMBER: **13-236**

Effective April 2, 2013, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 6,7**
Protocol Approval Date:	**April 2, 2013**
Protocol Expiration Date:	**April 1, 2014**
Continuing Review Due Date*:	**March 18, 2014**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

APPENDIX B PARTICIPANT RECRUITMENT FLYER – STUDY 1

Hello,

We are looking for individuals to participate in a research study and would like to include your opinions. If you qualify for the study, you will be invited to participate in a study that will take place on [DATE] in 530 Whittemore Hal. The study will consist of one outdoor session and one-on-one interview lasting about 35 - 1 hour each. The outdoor session will take place on street in downtown area of Christiansburg. Interviews will take place in the Assessment and Cognitive Ergonomics lab, 530 Whittemore Hall. At the end of the interview, each participant will be compensated for their time by monetary compensation (a $25 gift card) or research credits. All of your answers will remain completely confidential and will be used for research purposes only.

For this particular study, we are looking for people who match specific criteria, so I would need you to meet four requirements so that I can determine you're eligible for this study.

- **Age** - age between 18-49;
- **Smartphone** - have owned and used a Smartphone for at least 6 months;
- **mobile AR app** - have experience on any Mobile Augmented Reality (mobile AR) app (e.g., Wikitude, Layar, Google Goggle mobile app, Acrossair, etc.); and
- Consider technology as necessary in their daily lives.

Thank you for considering participating into this research. Your response will be valuable information in designing a cell phone that is easier to use for older adults and for all individuals.

If you have any questions, please feel free to contact me by phone at 540-577-9153or by e-mail at na8@vt.edu.

Sincerely,
Na Mi

Ph.D candidate
Dept. of Industrial Systems Engineering
Virginia Polytechnic Institute and State University

APPENDIX C INFORMED CONSENT FORM – STUDY 1

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed consent form for participants of Research Project Involving Human Subjects

Title of the Project:

Extending Situation Awareness Theory in the Context of Urban Navigation Using Mobile Augmented Reality

Investigators: Na Mi, Dr. Tonya Smith-Jackson

I. **The Purpose of this Research/Project**

The purpose of this project is to understand how you conduct urban navigation tasks using a type of smartphone-based application, called Mobile Augmented Reality (MAR) guidance application. We would like to elicit your thoughts about tasks you might undertake by observing you conduct conducts.

II. **Procedures**

If you choose to participate in this study, we will ask you to sign one informed consent document (this document). You will keep a copy for yourself. We will then ask you to complete a demographic form, which helps us to categorize our data to make comparisons as needed. After signing the informed consent form, you will be asked to complete a demographic form. We will ask you to participate in one 1-hour out-filed observation session and 1 hour in-lab interview session in the Assessment and Cognitive Ergonomics lab, 530 Whittemore Hall, Virginia Tech, and at times and dates that are convenient for you. Transportation will be provided by the researcher.

Session 1: Out-field observation session (approximately 1 hour)

In this session, you will be asked to do some tasks on the provided MAR application and the moderator will ask you to talk out loud while doing the tasks. The moderator will describe task scenarios for each task. After the tasks, you will be asked to answer some open-ended questions. In the observation session, you will be required to wear a baseball hat attached with a small-sized head-mounted video camera. The observation session will be video and audio-taped.

Session 2: In-lab interview session (approximately 1 hour)

After an out-field session completed, an in-lab interview session will be scheduled. In this session, you will be asked to describe your past experiences of urban navigation tasks in the past. Then you will be asked to describe what you would do and think in some simulated task scenarios. The moderator will describe detailed task scenarios for each task. This session will be audio recorded and transcribed by the researcher.

III. **Risks**

Risks to you for participating in this study are minimal. It is possible that you might experience fatigue or muscle strain of the arm, while you are holding up a MAR application in your task completion. We encourage you to take breaks at any time.

IV. **Benefits of the Project**

You will probably not gain any direct benefits as a result of your participation, but you have the knowledge of having benefitted efforts to enhance the independence of individuals with severe visual impairments.

V. **Extent of Anonymity and Confidentiality**

We assure confidentiality to all participants. However, anonymity cannot be guaranteed, because we will need to have your signatures on the Informed Consent document. However, this document will be kept in a locked cabinet for 1 year and your name will not be released. At the end of the 1-year period, we will destroy the documents. Your name will not be associated with the content of this observation, but you will be assigned a three- digit number to protect your privacy. Your number is ____, and this number is also on your folder.

All data will be collected by the researcher only. No one other than the researcher will have access to the data, unless it is aggregated first. All responses will be coded so as not to include the name of the participant. The information you provide will have your name removed and only a three- digit participant number will identify you during analyses and any written reports of the research.

It is important for data collection in this project to show videos of your movements, words, and facial expressions while using MAR interface. At no time will your name be released, but your face with blocking will be shown as needed to provide information for interface redesign.

This study is being conducted solely for educational and research purposes and the resulting data and interpretations will also be the part of the researchers' academic work. Consistent with these academic purposes, any results would be freely publishable. However, to protect your identity, neither personal nor institutional names nor site names or distinguishing information will be used in any published works.

VI. **Compensation**

Compensation for participating in this study is $10.00 per hour, for a total of $25 for an observation and an interview session altogether.

VII. **Freedom to Withdraw**

Participation in the study is voluntary and the decision about whether you wish to participate is strictly your own. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Withdrawal from the study will not result in any adverse effects.

VIII. **Approval of Research**

This research project has been approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering (College of Engineering).

_________________ ______________________

IRB Approval Date IRB Expiration Date

APPENDIX D BACKGROUND QUESTIONS – STUDY 1

Background Questions:

1. **Age and gender**
   Age: _______
   Gender: Male Female

2. **Where do you currently live?** _______

3. **How long have you been living in the current place?**

   Less than 1 year 1 – 2 years 2 – 3 years More than 3 years

4. **How often do you go to downtown Christiansburg?**

   Daily Weekly Monthly Once in 2 or 3 months Twice in a year yearly

5. **Do you consider technology as necessary in your life?**
   Yes No

5. **Smartphone Usage**
   a. What type of Smartphone do you own? __________
   b. How long have you owned a Smartphone? _______ years *or* _______months

7. **Mobile Navigation Tool(s) Usage**
   a. What mobile navigational tool(s) have you ever used?
      Mobile Augmented Reality (mobile AR) Please specify: ___________________

      Mobile maps Please specify: ___________________

   b. What mobile navigational tool(s) do you often use?
      Mobile Augmented Reality (mobile AR) Please specify: ___________________

      Mobile maps Please specify: ___________________

   c. [If selected mobile AR]
      i. How often do you use mobile AR app?
         Less frequent than once every 6 months
         Every 3-6 months
         Every 1-3 months
         Once a month
         Every 2-3 weeks
         Every 1-2 weeks

Weekly

ii. How long have you been using mobile AR app? ______ years *or* ______months
iii. In what situation would you use mobile AR app? Please specify: ___________
iv. For what activity would you use mobile AR app? Please specify: ___________

d. [If selected Mobile maps]

i. How often do you use mobile maps?

Less frequent than once every 6 months
Every 3-6 months
Every 1-3 months
Once a month
Every 2-3 weeks
Every 1-2 weeks
Weekly

ii. How long have you been using mobile maps? ______ years *or* ______months
iii. In what situation would you use mobile maps? Please specify: ___________
iv. For what activity would you use mobile maps? Please specify: ___________

e. [If selected both, please answer both fields]

8. Leisure travel activities

Please indicate which leisure travel activity (activities) have you done in the past 1 year:

Visiting a familiar city/town in US
Visiting a familiar city/town outside US
Visiting an unfamiliar city/town in US
Visiting a foreign city/town outside US
Hanging out with friends on street
Seeking for leisure activities on street
Others ___________

APPENDIX E FIELDWORK OBSERVATION SCRIPT

Mobile Augmented Reality

Situation Awareness Requirement Elicitation
Fieldwork Observation Script

2012

Participant Profile:

- *Name:* ____________
- *Smartphone model* _________
- *Age* ____
- *Gender* ____
- *Leisure tourism activity* ____

Participant Profile (from screener) – Has used/how long/how often:

- *Wikitude* ____ ____ ____
- *Acrossair* ____ ____ ____
- *Layar* ____ ____ ____
- *Google Goggles* ____ ____ ____
- *Others* ____ ____ ____

Session: ____________

Location*:* ______________

Participant ID: ________________

Date*:* ______________

Participant Instructions

Thank you for participating in this study. We have scheduled this session to run approximately 1 hour. **Today I'm going to ask you to demonstrate how you do some tasks using a Mobile Augmented Reality application.** I'll also ask you a few questions before and after the tasks. The goal is to understand the way you use such type of mobile AR application, as you would normally do as if I'm not here with you.

During the session, I will ask you to do several tasks. As you go through several tasks, I'd like you to "think aloud" about what you're thinking, what you're looking at now, what you're trying to figure out. This will help me better understand what you're doing and what you're thinking without me asking you while you are doing tasks. **Don't feel awkward or have any negative feeling about anything you say. I'm only observing you to do tasks, and my purpose is only to understand.** After the tasks, I'll ask a few questions.

You'll be using a Mobile Augmented Reality app on a provided Smartphone. This app is out in market and I was not involved in the design or development of the app. One thing needs to be clear: I'm not testing this app or the Smartphone, but I'm more interested in learning what you do with such type of apps and what you would like to do with such type of apps, and what you would expect to see or to be able to do with such type of apps. So try to behave like I'm not here. **Feel free to move around, like walk and stop, as you want.**

It's also important to know that we are not watching you or testing you on your abilities and there is no such thing as a wrong answer or silly thoughts. I am recording the session today with a voice recorder and a head-mounted camera you see here. I'll ask you to wear this baseball cap while performing tasks. Recording the session allows me to review or re-listen the material if necessary. Please be aware that all the information that you provide will be kept confidential and only will be used for research purposes.

Do you have any questions before we begin?

Introductory Questions [5 mins]

[Purpose: This part of the session should be a warm-up section to put the participant at ease and provide the research with relevant background information about the participant.]

Past Experience

I'd like to ask you about some of your *experiences* on using mobile AR application.

1. What mobile AR app do you use? [from screener]
2. How often do you use it?
3. Can you tell me about the last few times you used it?
4. What are the reasons for using this mobile AR app rather than others?
5. What are the reasons for using mobile AR app rather than other types of navigational tools, such as maps?
6. What types of activities do you usually do by using such mobile AR apps? [If the described activities are not covered, ask 3 task scenarios: 1) finding a nice place to eat; 2) finding a new place to eat; 3) trying to decide what to do next in the nearby region]

Task Identification [10 mins]

Own App + Street Views + Task Diagram

1. [The participant uses his/her own app] Okay. You said you used a mobile AR guidance application before.

2. Could you show me the way that you have used this app before? (Could you describe an experience in memory where this mobile AR guidance application was used and what it was used for?)
3. What kind of tasks have you ever done using the mobile AR app?
4. [Task diagram elicitation] Think about what you do when you do exploratory navigation (i.e. exploration) on street in a city or a town. Can you break this down into less than six, but more than three steps? [ensure the users do not delve into minute details]
5. [Street Views] Here are other views of streets. Take a moment to picture yourself into the view. Imagine you are new to these places. You had planned for these trips several weeks ago. Now you're finally here. I'll show you a very brief description for each place. Describe what you might want to do in those places? [open 4 Street Views, elicit task scenarios as exhaustive as possible]

Performing Task Scenarios [25-30 mins]

Here is another mobile augmented reality app. Now let's do some tasks with this application. [open Wikitude on the Smartphone and give it back to the participant]. In doing so, you'll be asked to "think aloud" on, for example, what you're looking at and what thoughts are in your mind. Show me how you do the tasks on this app; what information you might need but it isn't there; or what you need is not provided by the current application. In simple words, anything in your mind, you say it.

1) [Explore surroundings] Imagine this is a new place to you. You have a plan to come to visit here several months ago. Before you came out, you have found a good restaurant selling authentic local food. So your plan was to go to find that restaurant and explore the streets a little bit after your meal. So you took subway

and managed to be here, where you thought you were close to the destination restaurant. But somehow you just couldn't find that place after several tries.
So now you need to find another one after exploring more about your surroundings. Show me what you would do.

2) [Find a nearby place] Let's say you still can't the destination restaurant. Now it's 12 at noon, you're somewhat hungry.
So now you need to find a place nearby to eat. Show me what you would do to find the place that you want to go.

3) [Blocking view] Let's say there is a place called Custard Corner. You're not sure you want to go there. But you know it's around here. But you can't see it directly from here.
Show me what you would do to make decision.

4) [Three quarter miles] Let's say you are interested in Crab Creek Seafood that is shown on your app but it's about three quarter miles from here. You're debating yourself whether you really want to go there.
Show me what you would do to make your decision.

5) [Environment] Let's imagine now it's early afternoon you are going to meet a long-time-no-see friend in a café shop. He is new to here too so he asked you to pick a place for you two to meet. You want to pick one place that has a quiet and causal atmosphere with some live music playing in early afternoon.
Show me what you would do.

6) [Customer traffic flow] Imagine this is a new place to you. Let's imagine it's 6:30PM and you've been hanging around here about 2 hours. So you wanted to take a rest and eat something. You already found a particular restaurant with a restful environment to have some *[you pick one]* food. It says it's at 0.7 miles from here. But you concern that when you get there, the waiting time might be longer up to 30 minutes.
You really want to go to that place, but if you have to wait that long, you would rather pick another restaurant instead. Show me what you would do to make your decision.

7) [Shopping scenarios] You came here to visit one of your close friends, but he just called you he has something to finish up and will meet you in about an hour. So you decided you want to buy a sports souvenir for your friend at home. You think it could be a baseball cap with VT's Hokie's bird logo on it.
Show me what you would do.

8) [Activity scenario] Imagine after shopping, your friend has not come yet. He called you he got stuck on his work and will be here in about another 2 hours. So now you wanted to explore your surrounding more to find something to do to kill the time.
Show me what you would do.

Imagination Tasks [5-10 mins]

Now imagine that you have "magic eyes", "magic glasses" or "a magic lens" like this or If you look at the world through the view. [hand the Smartphone with an active camera view to the participant] Describe to me what you would do now, what information you would need to see, hear, feel, etc., and what you expect the mobile AR application can do for you.

Post-observation Questions [5-10 mins]

1. General mobile AR Technology Experience

1. Based on your experience, how do you think of mobile AR technology in general?
2. For leisure activities, what, if any, do you do with mobile AR technology to explore surroundings that you couldn't do otherwise?
3. For leisure activities, how effective do you think mobile AR technology is in terms of helping you conduct tasks?

2. Particular mobile AR app Experience (Wikitude)

1. Let me now turn to your personal likes and dislikes about this particular app, what are some of the things that you have really liked?

2. What about dislikes? What are some things you don't like so much about this App?

3. Now I'd like to ask you about your recommendations about this app. If you had the power to change things about this app, what would you make different?

Thank you for all that valuable information, is there anything else you'd like to add before we end?

Thank you for participating today!

APPENDIX F INTERVIEW SCRIPT

Mobile Augmented Reality

Study 1 Interview Script **10 Oct 2012**

Participant Profile:

- *Name:* ____________
- *Smartphone model* _________
- *Age* ____
- *Gender* ____
- *Leisure tourism activity* ____

Participant Profile (from screener) – Has used/how long/how often:

- *Wikitude* ____ ____ ____
- *Acrossair* ____ ____ ____
- *Layar* ____ ____ ____
- *Google Goggles* ____ ____ ____
- *Others* ____ ____ ____

Session: ____________

Location: ______________

Participant ID: ________________

Date: ______________

Overview

The purpose of this interview is to obtain information requirements regarding how mobile AR users conduct urban navigation tasks in different situations in the context of mobile AR-enabled environment. The findings will be used to 1) refine situation awareness theory in the context of urban exploratory navigation and 2) to inform future mobile AR prototype design solutions.

Participant Instructions

Thank you for participating in this study. We have scheduled this session to run approximately 1 to 1.5 hours. Please mute your phone during the interview.

The purpose of this interview is to explore the role of mobile AR in your interaction with surrounding environment in an unfamiliar urban context in general, and how you interact with mobile AR to explore and make navigational decisions in an unfamiliar place.

The procedure goes like this. First, I'm going to ask you do describe and discuss some of your past experience of exploring places, finding places, and doing these things with and without the help of mobile AR and other tools. Then I'll ask you to describe and discuss what information you would desire to have to achieve a better performance on some simulated task scenarios. Last, I'll ask you some questions about your thoughts and opinions on mobile AR guidance apps.

I'm not testing you. I'm more interested in learning from you.

I am recording the session today with the recorder and camera you see here. Recording the session allows me to review or re-listen the material if necessary. Please be aware that all the information that you provide will be kept confidential and only will be used for research purposes.

Do you have any questions before we begin?

1. Background Questions [5 mins]

[Purpose: This part of the session should be a warm-up discussion to put the participant at ease and provide the research with relevant background information about the participant.]

1. Tell me about some recent events and activities that you have done in an unfamiliar place? [Seek specific examples.]

2. Tell me about some recent events and activities that you have done with the help of mobile AR?

3. When you think about what brought you to the mobile AR the first time, what kind of things come to mind?

4. What functions on mobile AR have you ever used?
    a. What were you favorite functions?
    b. What was it about these features that made them your favorites?
    c. When do you find these features being most important?
    d. How often do you actually use each function? [Go through each function on their frequently used mobile AR app and answer how often]

2. Past experiences + Knowledge Audit [20 mins]

Okay. Since our focus is about mobile AR. It is to help you explore an unfamiliar place, find a place, make decisions, but in order to understand how to design mobile AR to help you do that, we need to understand how you do that without any aid or with some kinds of aid. We're trying to let the mobile AR help what you do. So let's talk about what you do first.

Here is a Street View (Time Squares New York). If you have traveled this place before, try to recall the last time you were in this place. If you haven't, try to recall some similar contexts that you have been to. It's okay that the place you have recalled might not be as busy and crowded as this view looks. This view is only used to help you recall and create a feeling of "being there". Picture yourself into the view. Take a moment to think of some of your past experiences. <u>Then I'll ask you some questions about the place. And I know some of the questions may sound repetitive or overlapping, but it's important for me to ask. Please try to think about these questions and then give me your thoughts.</u>

1. Places

1. Have you been to some similar places? Where is it?

2. How do you define "explore" a new place in your own words?
3. … "getting to know" a place?
4. … "awareness" of a place?
5. … "experience" a place?

6. When you say "I'm familiar with this place", what things come to your mind first?

7. When you say "I'm <u>NOT familiar</u> with this place", what things come to your mind first?
    a. Explore = find more information about the place, find more information about a thing, find things they could buy, find things they could see that they didn't see or rarely saw it before, find restaurant in this place, find things they could do, find people they want to contact (talk/see pictures virtually or in reality)
8. Can you recall a recent exploration in an urban context that you had a strong emotional reaction to? [If yes] Please tell me about it.

2. Decision process

Now let's talk about the decision process that you go through when you are exploring and making navigational decisions on site.

1. [Past & Future] Is there a time when you go to somewhere or some streets like this, you knew where exactly you were headed? Knew what you can do? Knew where your destination is?
    a. Have you planned before you go to a new place?
    (What plans have you made before going on the spot, if any, to better help you get to know the place?)

    b. Were there any environmental cues that help you to know where exactly you were headed?

2. [Big Picture] Can you give me an example of <u>what is the most important</u> about <u>making a navigational decision</u> when you're exploring an unfamiliar place?
    Probe: And then think about <u>the big picture</u> for exploring a new place?

3. What are the major things in the environment you have to know and keep track of?
    [Traffic and pedestrian, signs, time]

a. What are the major personal concerns you have to know and keep track of?
[Safety, time]

4. [Noticing] Can you give me an example of experience, where you noticed things going on in your exploration that others didn't catch? Why noticed that? How about some on-going events, live shows, sales, discounts for a limit time, etc?

5. [Task Smarts] Can you think of an example, when you explored an unfamiliar place, you made decisions about your future activity arrangement more quickly, like where you want to go or what you might do for future arrangement?
   a. Why?

6. [Opportunities/Improvising] Can you think of an example when you improvised in exploring or noticed an opportunity to explore a destination in a different or special way?
[Street signs]

How about an example when you improvised in making a decision on where you want to go in a different or special way? [changed decisions?]

7. [Self Monitoring] Can you think of a time when you realized that you would need to change what you were doing in order to decide where you want to go?

8. Can you think of a time when you didn't have a navigational tool in your exploring a place?

(e.g., IKEA, if you're navigating a new store, new street store, without mobile AR, what you would you do?)

9. If there is no a specific plan, some people have difficulties making navigational decisions on the spot, like where to go and what to do, but others decide fairly easily. What kind of thinking did you have in making a navigational decision on the spot in an unfamiliar place?
   a. In this process, what particular things were you concerned about?
   b. What was happening on street that stimulated your decision to go somewhere or do something?

Let's talk about if you had a mobile AR or a tool (brochure, outdoor information board, map, digital guidance), would what you have just told me be changed? Now let's go through the same questions here. Tell me, when you use mobile AR or other navigational tools, what have changed?

1. [Past & Future] Is there a time when you go to somewhere or streets like this, with mobile AR or some kind of tools you knew where exactly you were headed? Knew what you can do? Knew where your destination is?
   a. Have you ever use mobile AR to plan?
   b. Were there any environmental cues augmented by mobile AR help you to do that?

2. [Big Picture] In terms of the most important things that you mentioned in exploring a new place, if you had mobile AR or some kind of tools with you, think of a time, would there be any changes?
   a. How would using a mobile AR affect that what's most important about the environment.

3. What are the major things in the environment you have to know and keep track of using mobile AR or some kind of tools?
   Traffic and pedestrian, signs, time,
   c. What are the major personal concerns you have to know and keep track of using mobile AR or tools?
   Safety, time

4. [Noticing] <u>With mobile AR or some kind of tools</u>, have you had experiences where you noticed things going on in your exploration that others didn't catch? What is an example?

   a. Is there anything that you found by <u>using mobile AR</u> but you wouldn't easily find otherwise? [Attractions, Like an event, a restaurant, notice of different places or things going on. Hole in the wall]

5. [Task Smarts] Can you think of an example, when you explore an unfamiliar place, you use mobile AR and make decisions on your future activities arrangement more quickly?

   a. Is there any decision that you made by <u>using mobile AR</u> but you wouldn't easily make otherwise?

6. [Opportunities/Improvising] Can you think of a time by <u>using mobile AR or some kind of tools</u>, you have improvised in <u>exploring</u> or noticed an opportunity to explore a destination in a different or special way? Can you think of a time by <u>using mobile AR or some kind of tool</u>, you serendipitously found some place that you wanted to go but you weren't aware of?
[Don't give them examples, Normally street signs, have you used other special ways]

7. [Self Monitoring] Can you think of a time when you realized that you would need to change what you were doing in order to decide where you want to go by <u>using mobile AR or some kind of tools</u>?

   a. At what situation in which you would <u>use mobile AR</u> to decide where you want to go, instead of other kind of tools?

8. [Device Mislead] Can you think of a time when you had to rely on experience to avoid being led astray by the tool?

9. What things in <u>exploring a place</u> might be different when you have or do not have a mobile AR aid? In what way? What do you think accounts for this difference, for you?

10. What things in terms of <u>helping you make decisions on where you want to go</u> might be different when you have or do not have a mobile AR aid? In what way? What do you think accounts for this difference, for you?

3. Mobile AR: General Usage

1. What role do you think mobile AR play in your exploration when you were at an unfamiliar place?

2. Describe to me <u>the physical location</u>: On which part of the place did you use it, who was with you

   a. <u>Use:</u> frequency, using times, who also used it, functions used just by you, functions used by you and your friends,

   b. Difficulties: what difficulties did you have for using mobile AR- either experienced or expected but yet happened difficulties? How did you work around with such difficulties?

3. What strong recollections do you have of particular things that you saw on the mobile AR?

   a. Why?

4. Describe for me, if you can, a typical using pattern of mobile AR.

   a. When, where, how, (before on site, after using other tools, before using other tools, in walking, standing), what (general browsing, having what goals, searching, recognizing things), for how long?

[Focusing on using mobile AR, or using other tools, do they explore a place first and then make a decision where to go? Or they have something to do in their mind first and then with that objective explore a place on the way to the place?]

5. What things stand out for you from the place that you visited and used mobile AR over the past few times?

6. How do you feel when you use mobile AR to explore an unfamiliar place? Mobile AR ever evoke an emotion?
   [Seek for emotional words]
   a. What things that you experienced mobile AR that make you feel XX?

7. Have there been any ways that mobile AR affected your exploration and making navigational decisions that we haven't discussed? [If yes] How? Would you elaborate on that?

3. Simulation [25 – 30 mins]

We've spent some time thinking back and talking about your past experience. To better understand how you explore your surrounding environment and make navigational decisions, now I'd like you to come back to the present and imagine yourself being into this place.

Here is a street view of a metropolitan area in Shinjuku, Tokyo, Japan, you can use the mouse to interact with this view on this screen to feel as if you are walking on the street.

I'll ask you some questions about your view of the place, the information you might need, and the way mobile AR could assist you in exploration and making decisions.

SCENARIO

Now imagine this is your first time traveling abroad and it's your first time coming to Tokyo. You stay at a place in a central business district, one of the busiest and crowded blocks where most foreigners go for attractions, museums, parks, entertainment, shops, or simply hanging out experiencing the exotic culture. Now you just came out of Shinjuku station by yourself and you have 3 hours to spend before you meet up with one of your friends. Since you came here right after your semester finished, you've only been able to do a little research before you're on the spot. You know Shinjuku is large entertainment, business and shopping district around Shinjuku Station.

Since that you don't know too much on where to go or what to do, you are excited to explore this place. At this moment, ….

TASK SCENARIO 1 [exploratory navigation]

You don't have anything planed out yet, but you know this is a busy area so you can find something to do after you come here. You decided to explore it and discover some popular places nearby, like sights, museums, parks, arts, shops, and bars. You have to decide where you want to go and what you want to do now.

1. Awareness of place

1. How would you describe this street view in your words?
   What things catch your attention? What is it that catches your attention?

2. How would you describe your surrounding environment at this point in time?

   What's your overall feeling?

   How do you define your surroundings?

3. I would be interested in learning about what might be the most important things you want to know about <u>an unfamiliar place</u>. One way to describe it is by drawing a graph. [Give the interviewee the blank paper and pen] Imagine you're standing in this conjunction. On this paper I'd like you to indicate the most important things about your surrounding environment, and draw anything you would care about in your surroundings at this moment. You need to indicate what it is and where it is. For things, you don't need to name them for me. Just indicate them by any name or concepts you come up with. [Give interviewee ample time to draw]

4. Now I'd like you to tell me about your drawing – talk me through it, if you would.

   What and where:________________________

   - Now I'd like you to indicate an area where you would consider as <u>surrounding environment</u>.
   - An area where you would consider <u>nearby</u>.
     - Does it change if you're not using a mobile AR?
   - An area where you <u>want to be aware of things</u>.
     - Does it change if you're not using a mobile AR?
   - An area where you would <u>want to receive information</u> on a mobile AR browser.

5. [Probe on any interesting finding from last Q] I notice that you consider ____. In general, what difference do you see between <u>an area where you would consider nearby and an area where you would want to be aware of things.</u>

   Based on what factors, the areas of your description might be changed?

   (Is time a factor?)

6. In this scenario, could you describe what a good awareness of your surrounding environment means to you at this moment?

7. What pieces of information led you to this awareness of surrounding environment?

   (What are some things you might care about at this moment?)

8. In your opinion, in what way you could get a good awareness of your surrounding environment at this moment?
   a. In what way you could know <u>what's around you</u> at this moment?

   b. In what way you could know <u>what's going on</u> around you at this moment? (e.g. on-going, up-to-date, soon-to-begin activities, live events, sales, etc.)?

---

9. If you want to find something to do, first you need to find where you are. How would you locate yourself on this street?
   a. What kind of strategy would you use if you got lost to come back to this area? Such as picking a starting point, that you could refer to the other reference points.
      (What would you do to pick a starting point so that you can get back to this area after you done exploring?)

   b. [Only if maps] How would you make sense the map on you phone in your surrounding area?

    c. *(ask at the 2nd time) In a digitized augmented reality context, how would you* *<u>locate yourself</u>?*

10. [How would you orient yourself? (might not need to ask this question)]
    a. How would you find your sense of directions? (This way, or that way) Spatial orientation.
    b. How do they perceive direction? (In front, behind, left, right, that way, this way)
    c. *(wait) In a digitized augmented reality context, how would you <u>orient yourself</u>?*

11. How would you identify the place where you want to go before you go?
12. How would you identify the place when you're approaching it?
    a. Choosing a personal preference one. I already know my interest.

    b. Doing a visual search task. Where do I find things. How do I find those things.
        i. How do you match that place that I'm interested in.
        ii. How do you recognize that place? (Anything looks familiar to you?)
        iii. How do you find a mall?

    c. *(wait) In a digitized augmented reality context, how would you identify the place before you go?*

    d. *(wait) How would you identify the place when you're approaching that place?*

13. Let's say you're relaxed and walk around. Like when you're searching for shops, how would you identify other shops? How would you identify other alternatives?

    a. *(wait) In a digitized augmented reality context, how would you identify the place before you go?*

14. How do you care about other options you have at this moment in your surroundings? Like when you're searching for parks, would you care about museums?

    a. *(wait) In a digitized augmented reality context, how would you identify the place before you go?*

---

15. *Let's imagine <u>you have your "magic glasses" on</u> so that you can have any kind of information as much as you would like to have. (Probing) Let's go through the same questions here. [Go through Q9-14]*

    <u>Given that you have mobile AR or magic glasses, what would anything change?</u>

2. Mobile AR

16. Could you describe the place(s) where you would most likely to use mobile AR to explore the place? You can verbally say it or draw it on the graph.
    Physical locations [I could have interviewee draw me graph.]

17. Suppose I am with you while you are using mobile AR. What would I see you doing? Could you describe to me what you would behave more specifically?
    Does your behavior change if locations change?

18. Some people say in exploring a new place, where a lot of things are going on, they would say they would care about real-time virtual information about things around them that they're interested, such as objects,

places, attractions, other viewers comments, tweets, the places marked in your social networks, trendy information, while others may not agree with some of these or at all.
How do you think? On which do you agree? Don't agree?

19. In this task scenario, what kinds of things would you expect to know from mobile AR?
    a. Features/functions
    b. What kinds of things do you count on mobile AR for?
        i. What is that communicated to you?
    c. How does time as a factor impact on this? (ample time/under time pressure)

20. If you want this information, how would you find out this piece of information? [Probing on actions]
    a. How would that communicated to you?
    b. When would you want that communicated to you?
    c. Why this information is important?

21. In this task scenario, with the magic glasses, what kinds of things do you wish to have from mobile AR?

    a. All that you wish to have, what do you think are the most important or interesting features?
    b. What do you think are the most undreamable features you would want to have on mobile AR?

3. SA elements questions

You've mentioned several things. Let me ask your opinions about each of the things you mentioned.

22. What do you think of __? [Continue to probe on important items]
    Could you describe the items that you just said?
    What is this information used for?

Now I'm going to ask you a few design features. None of these have been designed yet. I want to hear your thoughts. But I've got people tell me it's not useful at all, it shouldn't be put up there in any way, while some others said it could be useful in certain situations. Let me ask what you think.

23. In this task scenario, we might design a "real-time view" to support people's decision-making by allowing you to see the real-time views of the places that you're debating to go. What do you think of that?
    a. e.g., If you had known about the atmosphere about the place before you go to that place, would you have known?

24. In this task scenario, there is another design feature that could provide projected information, like after 30 minuets, how long the waiting time would be;

    How about if you want to go to a series of places in walking distance, maybe a park, then an art gallery, and then a museum, the device can tell you where you would be in a timeframe, how well you would enjoy each one in a certain time period if you decide to go to these three places at a time. How do you think of that?

TASK SCENARIO 2 [goal-oriented navigation: vague goal]

Along with your walk, you want to find some souvenirs for your friends.

1. Awareness of place [ask: does it change from previous answers in task scenario 1?]

1. How would you describe this street view in your words?
    What things catch your attention? What is it that catches your attention?

2. How would you describe your surrounding environment at this point in time?

   What's your overall feeling?

   How do you define your surroundings?

3. I would be interested in learning about what might be the most important things you want to know about an unfamiliar place. One way to describe it is by drawing a graph. [Give the interviewee the blank paper and pen] Imagine you're standing in this conjunction. On this paper I'd like you to indicate the most important things about your surrounding environment, and draw anything you would care about in your surroundings at this moment. You need to indicate what it is and where it is. For things, you don't need to name them for me. Just indicate them by any name or concepts you come up with. [Give interviewee ample time to draw]

4. Now I'd like you to tell me about your drawing – talk me through it, if you would.

   What and where:_______________________

   - Now I'd like you to indicate an area where you would consider as surrounding environment.
   - An area where you would consider nearby.
     - Does it change if you're not using a mobile AR?
   - An area where you want to be aware of things.
     - Does it change if you're not using a mobile AR?
   - An area where you would want to receive information on a mobile AR browser.

5. [Probe on any interesting finding from last Q] I notice that you consider ____. In general, what difference do you see between an area where you would consider nearby and an area where you would want to be aware of things.

   Based on what factors, the areas of your description might be changed?

   (Is time a factor?)

6. In this scenario, could you describe what a good awareness of your surrounding environment means to you at this moment?

7. What pieces of information led you to this awareness of surrounding environment?

   a. What are some things you might care about at this moment?

8. [Only if Q6 different] In your opinion, in what way you could get THIS good awareness of your surrounding environment at this moment?

   a. In what way you could know what's around you at this moment?

   b. In what way you could know what's going on around you at this moment? (e.g. on-going, up-to-date, soon-to-begin activities, live events, sales, etc.)?

9. If you want to find some souvenirs to buy, you might still need to find where you are. How would you locate yourself on this street in this case?

   - What kind of strategy would you use if you got lost to come back to this area? Such as picking a starting point, that you could refer to the other reference points.
     (What would you do to pick a starting point so that you can get back to this area after you done exploring?)

   a. [Only if maps] How would you make sense the map on you phone in your surrounding area?

   b. (ask at the 2nd time) In a digitized augmented reality context, how would you locate yourself?

10. [How would you orient yourself? (might not need to ask this question)]
    a. How would you find your sense of directions? (This way, or that way) Spatial orientation.
    b. How do they perceive direction? (In front, behind, left, right, that way, this way)
    c. *(wait) In a digitized augmented reality context, how would you orient yourself?*

11. Among shops, what information would you need to decide where to go?

12. In this case, let's say you've decided a shop you want to go, how would you identify the shop that you want to go before you go?
13. How would you identify the shop when you're approaching it?
    - How do you match that shop that you're interested in.
    - How do you recognize that shop? (Anything looks familiar to you?)
    - How do you find a mall?
    a. *(wait) In a digitized augmented reality context, how would you identify the place before you go?*
    b. *(wait) In a digitized augmented reality context, how would you identify the when you're approaching it?*

14. How would you identify alternative shops in your surroundings?
    a. *(wait) In a digitized augmented reality context, how would you identify alternative shops?*

25. How do you care about other options you have at this moment in your surroundings?

15. How would you know your position with respect to these shops?
16. Once you decide,
    a. How would you know the position of the searched (shop/souvenir)?
    b. How would you know the direction of the searched (shop/souvenir)?
    c. How would you know you are near the searched (shop/souvenir)?

---

17. Let's imagine you have your "magic glasses" on so that you can have any kind of information as much as you would like to have. (Probing) Let's go through the same questions here. [Go through Q1-Q9, emphasizing on Q10-14]

    Given that you have mobile AR or magic glasses, what would anything change?

2. Mobile AR

18. In this task scenario, what kinds of things would you expect to know from mobile AR?
    d. Features/functions
    e. What kinds of things do you count on mobile AR for?
        i. What is that communicated to you?
    f. How does time as a factor impact on this? (ample time/under time pressure)

19. If you want this information, how would you find out this piece of information? [Probing on actions]
    a. How would that communicated to you?
    b. When would you want that communicated to you?
    c. Why this information is important?

20. In this task scenario, with the magic eyes, what kinds of things do you wish to have from mobile AR?

c. All that you wish to have, what do you think are the most important or interesting features?
d. What do you think are the most undreamable features you would want to have on mobile AR?

3. SA elements questions

You've mentioned several things. Let me ask your opinions about each of the things you mentioned.

21. <u>What do you think of __? [Continue to probe on important items]</u>
<u>Could you describe the items that you just said?</u>
<u>What is this information used for?</u>

Now I'm going to ask you a few design features. None of these have been designed yet. I want to hear your thoughts. But I've got people tell me it's not useful at all, it shouldn't be put up there in any way, while some others said it could be useful in certain situations. Let me ask what you think.

1. In this task scenario, we might design a "real-time view" to support people's decision-making by allowing you to see the real-time views of the places that you're debating to go. What do you think of that?
   a. e.g., If you had known about the <u>atmosphere</u> about the place before you go to that place, would you have known?

2. In this task scenario, there is another design feature that could provide projected information, like after 30 minuets, how long the waiting time would be;

   How about if you want to go to a series of places in walking distance, maybe a park, then an art gallery, and then a museum, the device can tell you where you would be in a timeframe, how well you would enjoy each one in a certain time period if you decide to go to these three places at a time. How do you think of that?

TASK SCENARIO 3 [goal-oriented navigation: some level of goal]

Now you need some information to help you decide whether it's worth coming back to this district to discover the nightlife nearby, like clubs, shows, theaters, etc.

REPEAT QUESTIONS FOR SCENARIO 2

TASK SCENARIO 4 [goal-oriented navigation: specific goal]

Now let's imagine it's 6:30PM. It's the last night before you're leaving Tokyo. You and your friend want to go to a very popular local restaurant selling authentic local food, called Tai, that you heard before you came here. Then you plan to go to watch a local show after meal. So it seems you only have 1 hour to eat. It's not far away from this station. But you're afraid of not be able to catch the show if you take too long in eating, so you're deciding whether you should go to this place to eat or maybe just find some other places.

Considering the current surrounding environment, the navigation, walking distance, the walking time, the traffic, the waiting line, the surrounding, the operating hour of the restaurant, the atmosphere, the location, the rush hour, the menu, your typical preference, other similar types of restaurants, any other restaurants that may not sell the similar food.

REPEAT QUESTIONS FOR SCENARIO 2

4. Closing Questions [5 mins]

You've told me your thoughts and information needs in a simulated scenario. We only have several questions left.

1. Some people would argue that in an unfamiliar city, they would be more enjoyable to explore a place by themselves without any aid of technology and make navigational decisions by simply checking out places on their way by following a map, however, others would argue that technology could provide more useful information about things that they're interested in and desired to know in a much easier way so that they could experience the place better and plan better. What are your thoughts on it?

2. Tell me about any recent information or news that you've had known about mobile AR. [Let the participant describe information or news about mobile AR in general, i.e., technology advances, the new gadget in the market, etc.]

3. How would you describe yourself as a mobile AR user? Why?

4. This question may be difficult to answer, but I'd like to get your thoughts on it. You've told me that your imaged mobile AR in helping you explore a place and make decisions.
   How do you think you might be different, if you have access to mobile AR as you described?
   [Give the interviewee time to think about this.]

Okay. You've been very helpful. Are there other thoughts or feelings you would like to share with me to help me understand how you're seeing xx.

Thank you for participating today!

APPENDIX G PARTICIPANT RECRUITMNET FLYER – STUDY 2

You Are Invited to Participant in a Study about Mobile Augmented Reality Interface Evaluation

---

We are looking for individuals to participate in an interface evaluation study about Mobile Augmented Reality (mobile AR) guidance application mockup(IRB 13-236).

- The study will last 1 hour in lab 530 Whittemore Hall.
- You will be compensated 10 dollars for your time.

Requirements:

1- You must be aged 18-49; and

2- You have used a touch-screen smartphone.

Please contact Na Mi if you're interested:
na8@vt.edu
or
540-577-9153

APPENDIX H INFORMED CONSENT FORM – STUDY 2

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed consent form for participants of Research Project Involving Human Subjects

Title of the Project:

Extending Situation Awareness Theory in the Context of Urban Navigation Using Mobile Augmented Reality

Investigators: Na Mi, Dr. Tonya Smith-Jackson

I. **The Purpose of this Research/Project**

The purpose of this project is to understand how you conduct urban navigation tasks using a type of smartphone-based application, called Mobile Augmented Reality (MAR) guidance application. We would like to elicit your thoughts about tasks you might undertake by observing you conduct conducts.

II. **Procedures**

If you choose to participate in this study, we will ask you to sign one informed consent document (this document). You will keep a copy for yourself. We will then ask you to complete a demographic form, which helps us to categorize our data to make comparisons as needed. After signing the informed consent form, you will be asked to complete a demographic form. We will ask you to participate in one 1 hour evaluation session in the Assessment and Cognitive Ergonomics lab, 530 Whittemore Hall, Virginia Tech, and at times and dates that are convenient for you. Transportation will be provided by the researcher.

Part 1: interface comparison

In this session, you will be asked to do some tasks on the provided interface mockups. You'll give answers on the task card and you'll be timed on the tasks. After the tasks, you will be asked to fill out 2 questionnaires.

Part 2: design concepts evaluation

After a comparison session completed, you will be asked to evaluate several design concepts. This session will be audio recorded and transcribed by the researcher.

III. **Risks**

Risks to you for participating in this study are minimal.

IV. **Benefits of the Project**

You will probably not gain any direct benefits as a result of your participation, but you have the knowledge of having benefitted efforts to enhance the independence of individuals with severe visual impairments.

V. **Extent of Anonymity and Confidentiality**

Virginia Tech Institutional Review Board Project No. 13-236
Approved February 2, 2014 to April 1, 2014

All data will be collected by the researcher only. This study is being conducted solely for educational and research purposes and the resulting data and interpretations will also be the part of the researchers' academic work. Consistent with these academic purposes, any results would be freely publishable. However, to protect your identity, neither personal nor institutional names nor site names or distinguishing information will be used in any published works.

VI. **Compensation**

Compensation for participating in this study is $10.00 per hour.

VII. **Freedom to Withdraw**

Participation in the study is voluntary and the decision about whether you wish to participate is strictly your own. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. Withdrawal from the study will not result in any adverse effects.

VIII. **Approval of Research**

This research project has been approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Department of Industrial and Systems Engineering (College of Engineering).

________________ ____________________

IRB Approval Date IRB Expiration Date

IX. **Participant's Responsibilities**

Upon signing this form below, I voluntarily agree to participate in this study. I have no restrictions to my participation in this study.

X. **Participant's Permission**

I have read and understand the Informed Consent and conditions of this study. All of my questions have been answered. I agree to participate in this project.

__________________________ ___________________

Participant's Signature Date

Should I have any questions about the research or its conduct, I may contact:

Ms. Na Mi Email: na8@vt.edu Phone: (540) 577-9153

Dr. Tonya Smith- Jackson Email: smithjack@vt.edu Phone: (540) 231-4119

Dr. David M. Moore, Email : moored@vt.edu Phone: (540) 231-4991

Chair, IRB

APPENDIX I BACKGROUND QUESTIONS – STUDY 2

Background Questions

9. Age and gender
Name: : _______ Age: _______ Gender: ☐ Male ☐ Female

10. Smartphone Usage

a. For the touchscreen-based Smartphone, manufacturer _______ and/or model _____
b. How long have you owned this Smartphone? _____years *or* _____months

11. Mobile Navigation Tool(s) Usage

a. What mobile navigational tool(s) have you <u>ever</u> used (if any)?
☐Mobile Augmented Reality (mobile AR) apps (if any)Please specify: ___________________
☐Mobile map apps(if any) Please specify: ___________________

b. What mobile navigational tool(s) do you have on your phone currently(if any)?
☐Mobile Augmented Reality (mobile AR) apps(if any) Please specify: ___________________
☐Mobile map apps(if any) Please specify: ___________________

c. What mobile navigational tool(s) have you used <u>most often</u> comparing to others(if applicable)?
☐Mobile Augmented Reality (mobile AR) apps (if any)Please specify: ___________________
☐Mobile map apps(if any) Please specify: ___________________

d. (If answered question c) Regarding the most often used Mobile Augmented Reality (mobile AR) app:

i. How often do you use this mobile AR app?
☐ Less frequent than once every 4 months
☐ Every 2-4 months
☐ Every 1-2 months
☐ Once a month
☐ Every 2-3 weeks
☐ Every 1-2 weeks
☐ Weekly

ii. How long have you been using this mobile AR app? ______ years *or* ______months
iii. In what situation did use this mobile AR app? Please specify: ___________
iv. For what activity did you use this mobile AR app? Please specify: ___________

e. (If answered question c) Regarding the most often used mobile map app:

i. How often do you use this mobile map?
☐ Less frequent than once every 4 months
☐ Every 2-4 months
☐ Every 1-2 months
☐ Once a month
☐ Every 2-3 weeks
☐ Every 1-2 weeks

☐ Weekly

ii. How long have you been using this mobile map app? _____years *or* ______months
iii. In what situation did you use this mobile map app? Please specify: ___________
iv. For what activity did you use mobile maps? Please specify: ___________

12. Leisure travel activities

a. Have you done any leisure activities (e.g., travel to another country/city/ town, hang out on street, try to find a restaurant) in the past 1 year?

☐ Yes ☐ No

b. Please indicate which leisure travel activity (activities) have you done in the past 1 year:

☐ Visiting a familiar city/town in US
☐ Visiting a familiar city/town outside US
☐ Visiting an unfamiliar city/town in US
☐ Visiting a foreign city/town outside US
☐ Hanging out on street (yourself or with friends)
☐ Seeking for leisure activities on street (e.g., events, live music, etc.)
☐ Seeking for places (e.g., hotels, conference buildings, etc.)
☐ Others Please specify: ______________________

Mobile Augmented Reality (Study 2 Script)

Session: ____________

Location*:* ______________

Participant ID: ________________

Date*:* ______________

Participant Profile:

- *Name:* ____________
- *Smartphone model* _________
- *Age* ____
- *Gender* ____
- *Leisure tourism activity* ____

Mobile Augmented Reality

SA-Supported Interface Evaluation Script

Overview

The purpose of this session is to compare interfaces regarding how mobile AR users conduct urban navigation tasks in the context of mobile AR-enabled environment. The findings will be used to 1) help us understand which one works better in regards to usability and situation awareness (two measures) and 2) to inform future mobile AR prototype design solutions.

Participant Instructions

Thank you for participating in this study. We have scheduled this session to run approximately 1 hour. Please mute your phone during the period.

The purpose of this evaluation is to compare four low-fidelity mockup interfaces to help us know which one works better, and thereby design better interfaces for mobile Augmented Reality guidance application.

The procedure goes like this. First, I'm going to ask you to perform a series of tasks on the task card with using different interfaces. These tasks will be presented to you shortly.

As you go through several tasks, I'll time you and record the time that you take to complete these tasks. Although you don't have time limit on these tasks, you do need to work out them as quickly as possible.

Don't feel awkward or have any negative feeling about these tasks. I'm only observing you to do tasks, and my purpose is only to evaluate the interfaces, not you. After the tasks, I'll give you two questionnaires to fill out.

After completing tasks on the interfaces, I'm going to have you comment on several design features we're considering to incorporate into the interface. Some people think they're useful, some thing they're completely useless. We just want to have your honest opinions on them.

It's also important to know that we are not testing you on your abilities and there is no such thing as a wrong answer or silly thoughts. I am recording the session today with a voice recorder to help me analyze after the experiment.

Again, I'm not testing you. I'm more interested in learning from you.

Please be aware that all the information that you provide will be kept confidential and only will be used for research purposes.

Do you have any questions before we begin?

TASK SCENARIO

SCENARIO

Now imagine this is your first time traveling to this city. You're very excited to explore this place, so you came to this place by subway, right after you just got here.

This is a somewhat business and entertainment district, one of the busiest and crowded blocks where most people go for attractions, museums, entertainment, shops, or simply hanging out experiencing the metropolitan culture.

Now it's 6PM. You feel like walking around to check out this place and planning out things that you can probably do at night. Tomorrow your local friends will meet you and take you to continue exploring the rest of the city.

Since you came here right after your semester finished, you've only been able to do a little homework about this place before you're on the spot. Also for that reason, you are very excited!

Task scenario: You'd like to find a restaurant in your walking distance using this mobile app. Using the app, you just filtered down your options to a few Italian and Japanese restaurants. Now…

[Task queries begin..]

Feedbacks on interface (for each interface):

1. In terms of helping you understand your surroundings, how do you think of this interface?
2. Which one would you prefer?
3. Is there anything you would want to change on this interface?

Thank you for participating in the study!


AR-Interface B
Search
Masu Sushi
1.5 mile
Mirakutei
0.3 mile
Biwa
0.6 mile
Mirakutei
0.3 mile / 6 min ★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More
Masu Sushi
1.5 mile / 30 min ★★★ $$$
239 Tremont St, Los Angeles, CA 90336
More
Biwa
0.6 mile / 12 min ★★★★ $$$
517 Normal St, Los Angeles, CA 90336
More
Redwood
1.5 mile
Kornblatt's
0.3 mile
Nam Loc Deli
0.5 mile
Burgerville
0.3 mile
Good Taste
0.4 mile
SABRET
Redwood
1.5 mile / 30 min ★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More


Search
SABRETT
Redwood
1.5 mile
Kornblatt's
0.3 mile
Nam Loc Deli
0.5 mile
Burgerville
0.3 mile
Good Taste
0.4 mile
Kornblatt's
0.3 mile / 6 min ★★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More
Good Taste
0.4 mile / 8 min ★★ $$
6324 Morgan St, Los Angeles, CA 90336
Nam Loc Deli
0.5 mile / 10 min ★★ $$
6324 Morgan St, Los Angeles, CA 90336
Burgerville
0.3 mile / 6 min ★★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Swingers
1.2 mile
Cancel
Langer's
1.4 mile
Grassa
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Vie
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Search
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Cancel
Swingers
1.2 mile
Langer's
1.4 mile
Grassa
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0.9 mile
Aoi
0.3 mile / 6 min ★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More


Search
Rico's Tacos
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Taco Time
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Swingers
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Grassa
0.4 mile / 8 min ★★★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More


Search
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Cancel
Swingers
1.2 mile
Langer's
1.4 mile
Grassa
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Vie
0.9 mile
Rico's Tacos
0.2 mile / 4 min ★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More


Search
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Cancel
Swingers
1.2 mile
Langer's
1.4 mile
Grassa
0.4 mile
Vie
0.9 mile
Vie
0.9 mile / 18 min ★★★★ $$
6324 Morgan St, Los Angeles, CA 90336
More


Search
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Cancel
Swingers
1.2 mile
Langer's
1.4 mile
Grassa
0.4 mile
Vie
0.9 mile
Taco Time
1.3 mile / 26 min ★★★★ $$
6324 Morgan St, Los Angeles, CA 90336
More


Search
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Cancel
Swingers
1.2 mile
Langer's
1.4 mile
Grassa
0.4 mile
Vie
0.9 mile
Swingers
1.2 mile / 24 min ★★★ $$
6324 Morgan St, Los Angeles, CA 90336
More

Search
Rico's Tacos
0.2 mile
Taco Time
1.3 mile
Aoi
0.3 mile
Swingers
1.2 mile
Cancel
Langer's
1.4 mile
Grassa
0.4 mile
Vie
0.9 mile
Langer's
1.4 mile / 28 min ★★★★ $$
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Gallo Nero
0.2 mile
Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2 mile
Joe's Cellar
1.3 mile
Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2 mile
Joe's Cellar
1.3 mile
Brunch Box
0.2 mile / 4 min ★ $$
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2 mile
Joe's Cellar
1.3 mile
Gabagool
0.8 mile / 16 min ★★★★★ $$
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2 mile
Joe's Cellar
1.3 mile
Ava Gene's
1.1 mile / 22 min ★★★★★ $$$
6324 Morgan St, Los Angeles, CA 90336
More

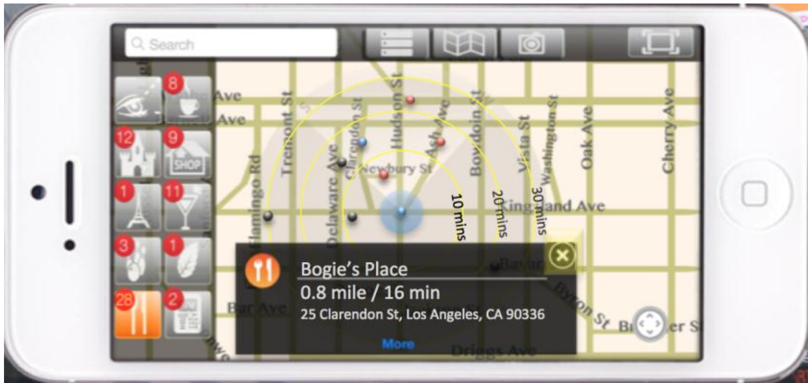

Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2mile
Joe's Cellar
1.3 mile
Truss
0.2 mile / 4 min
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2 mile
Joe's Cellar
1.3 mile
Ned Ludd
0.4 mile / 8 min
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Ned Ludd
0.4 mile
Gabagool
0.8 mile
Cancel
Gallo Nero
0.2 mile
Ava Gene's
1.1 mile
Truss
0.2 mile
Joe's Cellar
1.3 mile
Joe's Cellar
1.3 mile / 26 min
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Gallo Nero
0.2 mile
The Roxy
1.2 mile
Cancel
Gino's
1.5 mile
Olive it
1.3 mile
Pazzo
1.4 mile
Yorkshire Grill
1.3 mile
Search
Brunch Box
0.2 mile
Gallo Nero
0.2 mile
The Roxy
1.2 mile
Cancel
Gino's
1.5 mile
Olive it
1.3 mile
Pazzo
1.4 mile
Yorkshire Grill
1.3 mile
Gino's
1.5 mile / 30 min
6324 Morgan St, Los Angeles, CA 90336
More
Search
Brunch Box
0.2 mile
Gallo Nero
0.2 mile
The Roxy
1.2 mile
Cancel
Gino's
1.5 mile
Olive it
1.3 mile
Pazzo
1.4 mile
Yorkshire Grill
1.3 mile
Pazzo
1.4 mile / 28 min
6324 Morgan St, Los Angeles, CA 90336
More

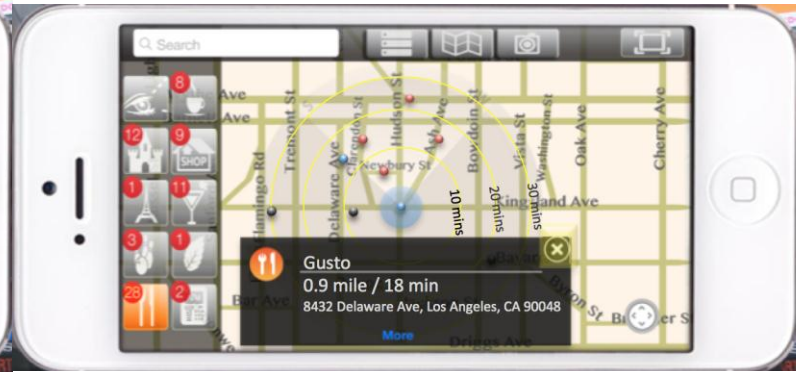
AR- Interface S

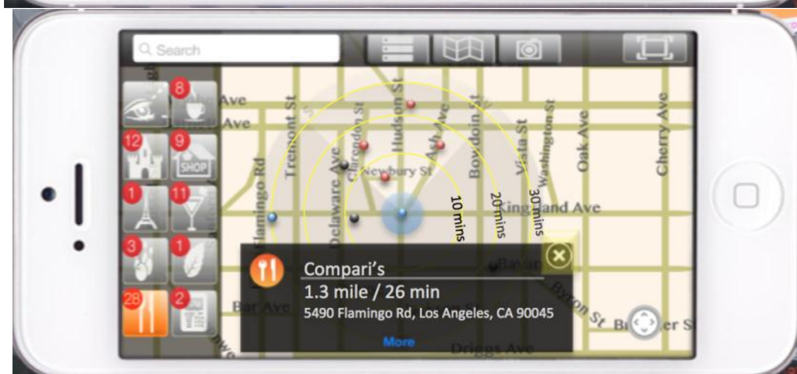

Search
Restaurants (5)
Mirakutei 0.3 mile / 6 min
Gusto 0.5 mile / 10 min
Compari's 0.9 mile / 18 min
Yama Sushi 1.3 mile / 26 min
Scroll down
Search
Restaurants (5)
Scroll up
Tumby's Pizza 1.4 mile / 28 min
Search
Restaurants (7)
Biwa 0.4 mile / 8 min
Kale 0.7 mile / 14 min
Aviary 0.9 mile / 18 min
Masu Sushi 0.9 mile / 18 min
Scroll down
Search
Restaurants (7)
Scroll up
Bogie's Place 0.9 mile / 18 min
Little Bird 1.2mile / 24 min
Andina 1.5 mile / 30 min
Search
Restaurants (12)
Roe 0.2 mile / 5 min
Screen Door 0.3 mile / 6 min
Le Pigeon 0.3 mile / 6 min
Toro Bravo 0.4 mile / 8 min
Scroll down
Search
Restaurants (12)
Scroll up
Cabezon 0.8 mile / 16 min
PaaDee 1 mile / 20 min
Iorio 1 mile / 20 min
Nostrana 1.2 mile / 24 min
Scroll down

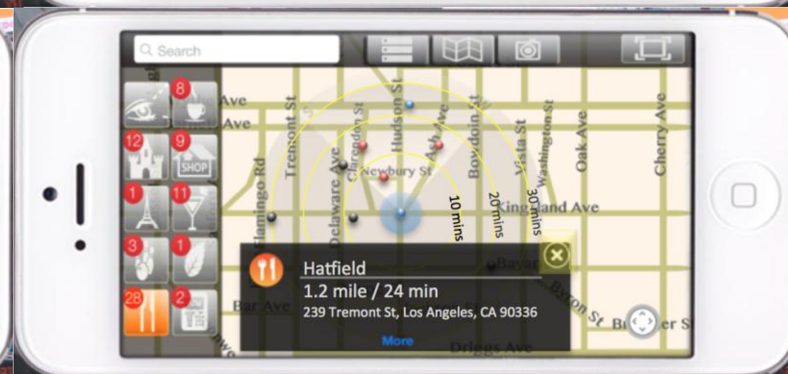
Map-Interface B

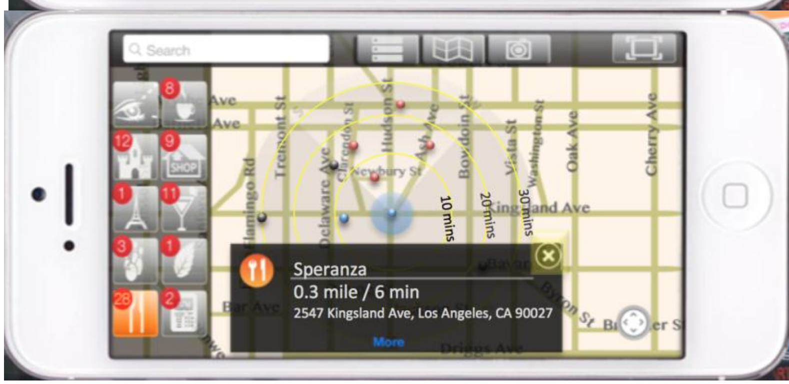
Map-Interface S

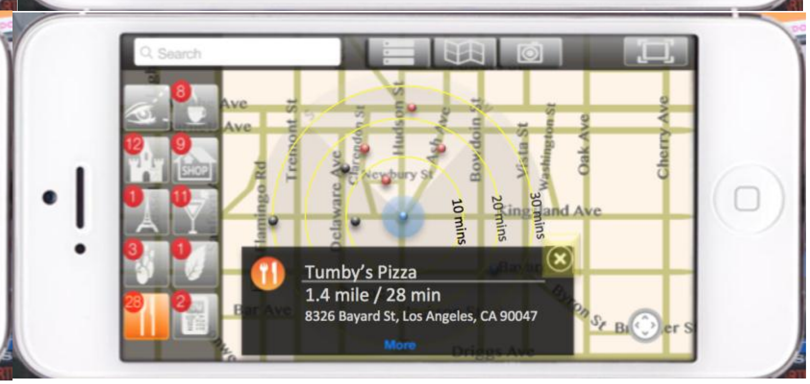

Bogie's Place
0.8 mile / 16 min
25 Clarendon St, Los Angeles, CA 90336
More

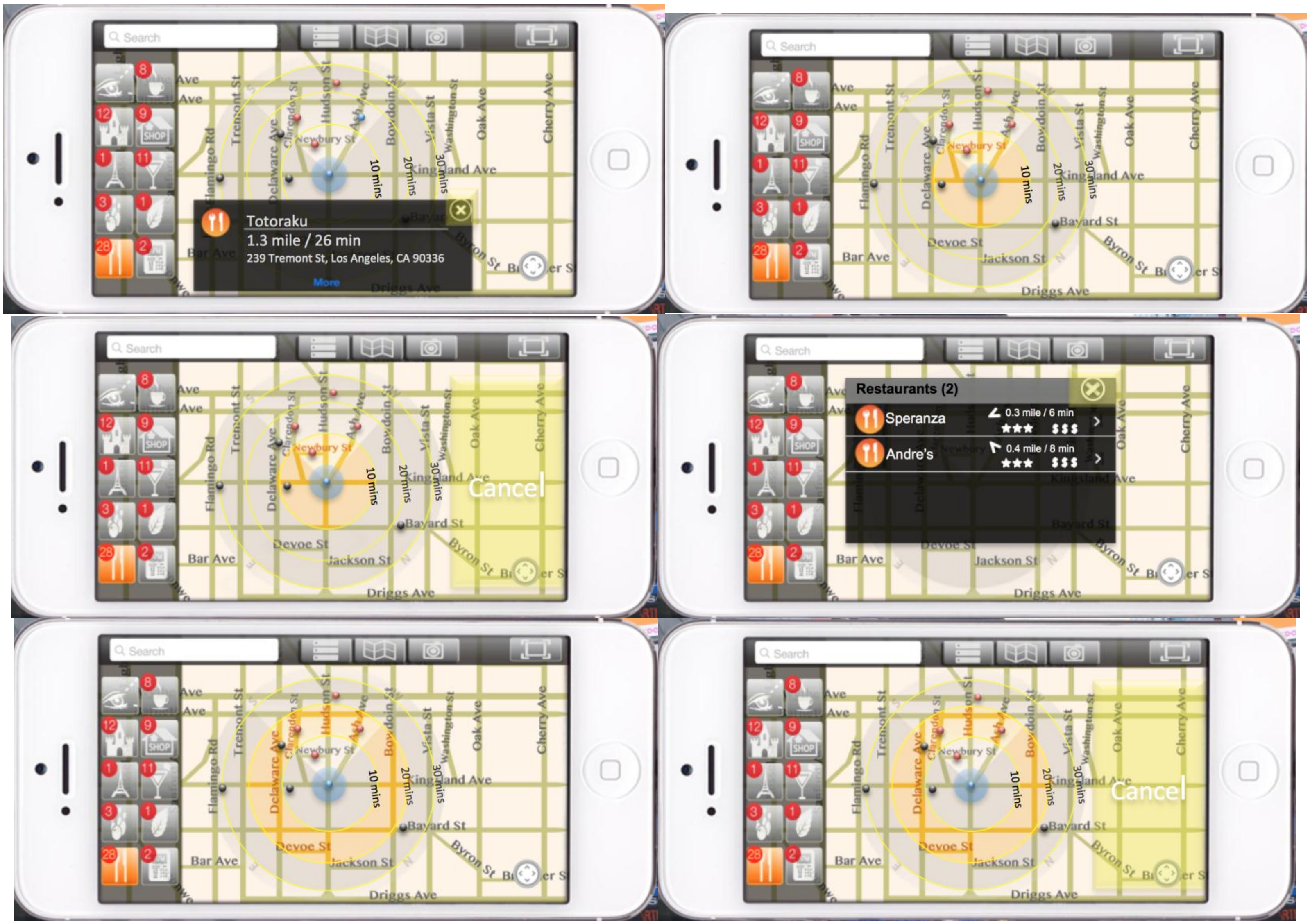

Gusto
0.9 mile / 18 min
8432 Delaware Ave, Los Angeles, CA 90048
More


Compari's
1.3 mile / 26 min
5490 Flamingo Rd, Los Angeles, CA 90045
More


Hatfield
1.2 mile / 24 min
239 Tremont St, Los Angeles, CA 90336
More


Speranza
0.3 mile / 6 min
2547 Kingsland Ave, Los Angeles, CA 90027
More


Tumby's Pizza
1.4 mile / 28 min
8326 Bayard St, Los Angeles, CA 90047
More


Search
Totoraku
1.3 mile / 26 min
239 Tremont St, Los Angeles, CA 90336
More
Restaurants (2)
Speranza
0.3 mile / 6 min
Andre's
0.4 mile / 8 min
Cancel
10 mins
20 mins
30 mins
Flamingo Rd
Tremont St
Delaware Ave
Clarendon St
Hudson St
Ash Ave
Bowdoin St
Vista St
Washington St
Oak Ave
Cherry Ave
Newbury St
Kingsland Ave
Bayard St
Devoe St
Jackson St
Byron St
Bar Ave
Driggs Ave


Search
Cancel
10 mins
20 mins
30 mins
Restaurants (8)
Speranza
0.3 mile / 6 min
Andre's
0.4 mile / 8 min
Bogie's Place
0.8 mile / 16 min
Hatfield
0.8 mile / 16 min
Scroll down
Scroll up
Gusto
0.9 mile / 18 min
Totoraku
1.3 mile / 26 min
Compari's
1.3 mile / 26 min
Tumby's Pizza
1.4 mile / 28 min

APPENDIX L AFTER-SCENARIO QUESTIONNAIRE

ASQ PARTICIPANT NO. ________ (AR MAP S B)

		Strongly disagree	1	2	3	4	5	6	7	Strongly agree	NA
1	Overall, I am satisfied with the ease of completing the tasks in this scenario										
2	Overall, I am satisfied with the amount of time it took to complete the tasks in this scenario										
3	Overall, I am satisfied with the support information (messages) when completing the tasks										

APPENDIX M SOFTWARE USABILITY SCALE

SUS PARTICIPANT NO. ________ (AR MAP S B)

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

APPENDIX N AR INTERFACE TASK SHEET

AR Interface Task Sheet Participant no. ___________________

		Interface B	Answer			Interface S	Answer
D	0	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.		D	0	Find the restaurants with less than 4 (<= 3) dollar signs and also within 20 minutes of walking. Enter the number of restaurants.	
A	1	Find the closest restaurant with 3 rating stars. Enter the time to it.		A	1	Find the closest restaurant with 4 rating stars. Enter the time to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.	
	3	Find the restaurants with less than 4 (<= 3) dollar signs and also within 20 minutes of walking. Enter the number of restaurants.			3	Find the restaurants with more than 3 (>= 4) stars and also within 10 minutes of walking. Enter the number of restaurants.	
B	1	Find the closest restaurant with 2 dollar signs. Enter the time to it.		B	1	Find the closest restaurant with 3 rating stars. Enter the time to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.	
	3	Find the restaurants with more than 3 (>= 4) rating stars and also within 10 minutes. Enter the number of restaurants.			3	Find the restaurants with less than 4 (<= 3) dollar signs and also within 20 minutes of walking. Enter the number of restaurants.	
C	1	Find the closest restaurant with 5 rating stars. Enter the distance to it.		C	1	Find the closest restaurant with 5 star ratings. Enter the distance to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having less than 4 (<=3) dollar signs, find the highest rating. Enter the rating.	
	3	find the restaurants with more than 2 (>=3) dollar signs and also within 24 minutes. Enter the number of restaurants.			3	Find the restaurants with less than 4 (<= 3) dollar signs and also within 18 minutes of walking. Enter the number of restaurants.	
D	1	find the closest restaurant with 5 rating stars. Enter the distance to it.		D	1	Find the closest restaurant with2 dollar signs. Enter the distance to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having more than 3 (>=4) rating stars, find the largest dollar signs. Enter the number of dollar signs.	
	3	Find the restaurants with more than 3 (>= 4) rating stars and also within 20 minutes. Enter the number of restaurants.			3	Find the restaurants with more than 3 (>= 4) stars and also within 16 minutes of walking. Enter the number of restaurants.	

APPENDIX O AR INTERFACE TASK TIME RECORDING SHEET

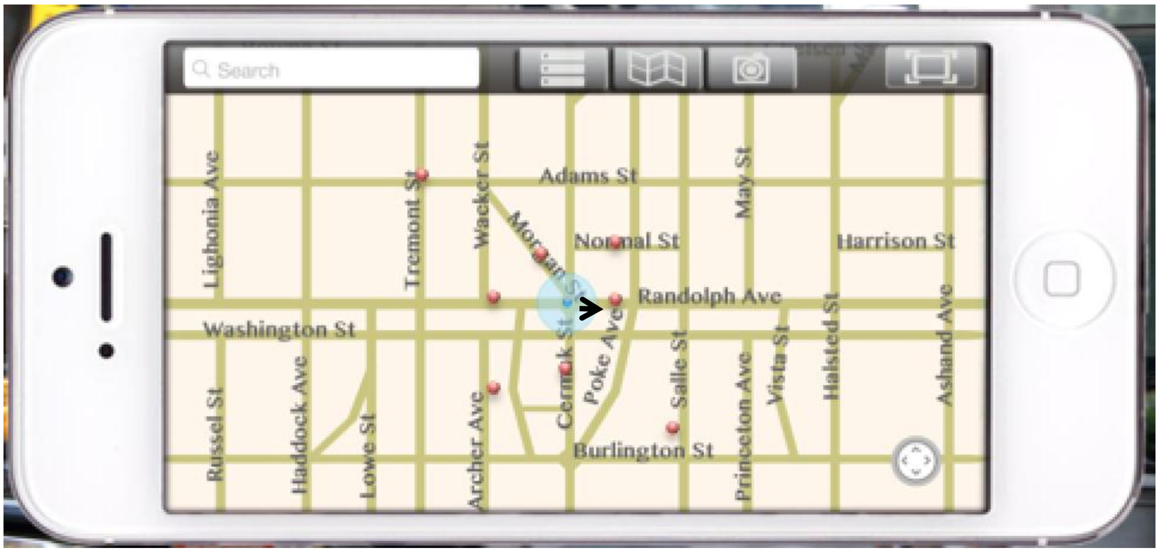
AR Interface Task Time Recording Sheet Participant no. ____________________

		Interface B	Time			Interface S	Time
D	0	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.		D	0	Find the restaurants with less than 4 (<= 3) dollar signs and also within 20 minutes of walking. Enter the number of restaurants.	
A	1	Find the closest restaurant with 3 rating stars. Enter the time to it.		A	1	Find the closest restaurant with 4 rating stars. Enter the time to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.	
	3	Find the restaurants with less than 4 (<= 3) dollar signs and also within 20 minutes of walking. Enter the number of restaurants.			3	Find the restaurants with more than 3 (>= 4) stars and also within 10 minutes of walking. Enter the number of restaurants.	
B	1	Find the closest restaurant with 2 dollar signs. Enter the time to it.		B	1	Find the closest restaurant with 3 rating stars. Enter the time to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.	
	3	Find the restaurants with more than 3 (>= 4) rating stars and also within 10 minutes. Enter the number of restaurants.			3	Find the restaurants with less than 4 (<= 3) dollar signs and also within 20 minutes of walking. Enter the number of restaurants.	
C	1	Find the closest restaurant with 5 rating stars. Enter the distance to it.		C	1	Find the closest restaurant with 5 star ratings. Enter the distance to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having less than 4 (<=3) dollar signs, find the highest rating. Enter the rating.	
	3	Find the restaurants with more than 2 (>=3) dollar signs and also within 24 minutes. Enter the number of restaurants.			3	Find the restaurants with less than 4 (<= 3) dollar signs and also within 18 minutes of walking. Enter the number of restaurants.	
D	1	Find the closest restaurant with 5 rating stars. Enter the distance to it.		D	1	Find the closest restaurant with2 dollar signs. Enter the distance to it.	
	2	Among restaurants having more than 3 (>=4) rating stars, find the fewest dollar signs. Enter the number of dollar signs.			2	Among restaurants having more than 3 (>=4) rating stars, find the largest dollar signs. Enter the number of dollar signs.	
	3	Find the restaurants with more than 3 (>= 4) rating stars and also within 20 minutes. Enter the number of restaurants.			3	Find the restaurants with more than 3 (>= 4) stars and also within 16 minutes of walking. Enter the number of restaurants.	

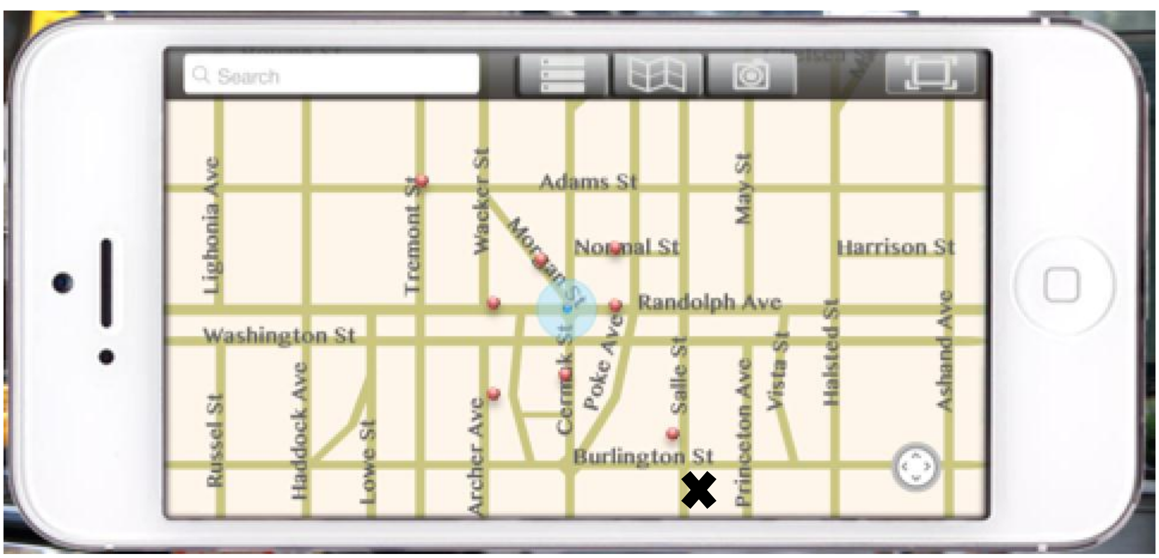
APPENDIX P MAP INTERFACE TASKS

For map interface B: Participant no. ___________________

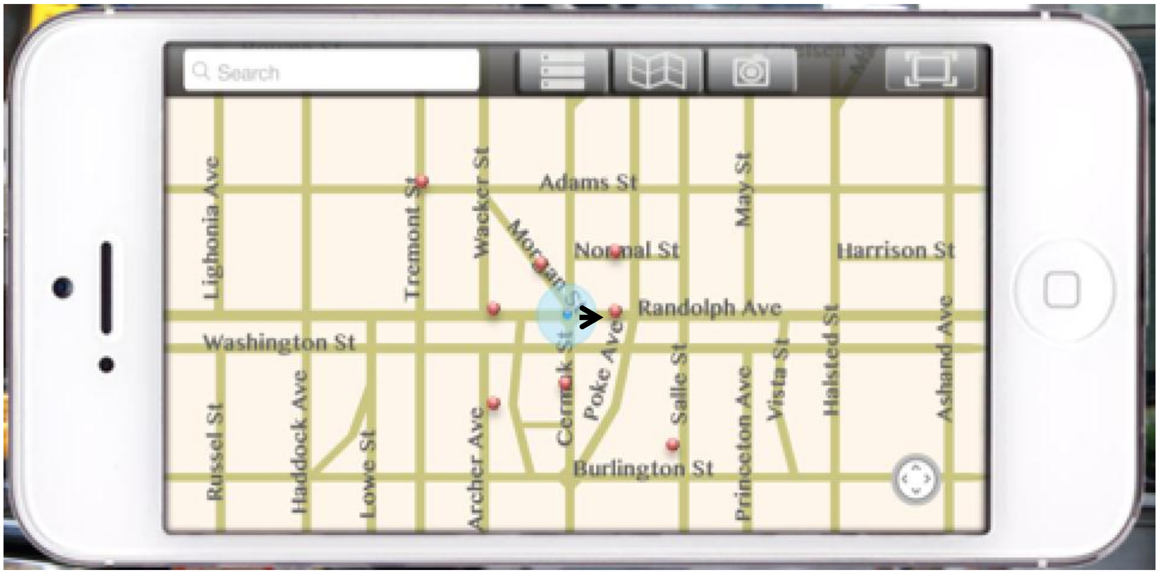
1. Enter the number of restaurants that can be reached within 10 minutes
2. Now supposed you are standing at the marker, and facing and walking to the direction as the arrow indicates (see figure below). Find the restaurants that can be reached within 20 minutes. Enter the number (You can turn at any subsequent intersections.)



3. You found a movie shown at 7:00PM at a location (see figure below). To save some of your time, find the restaurants that are on all optional paths to the show and within about 10 minutes of walking from where you are now. Enter the number of restaurants.



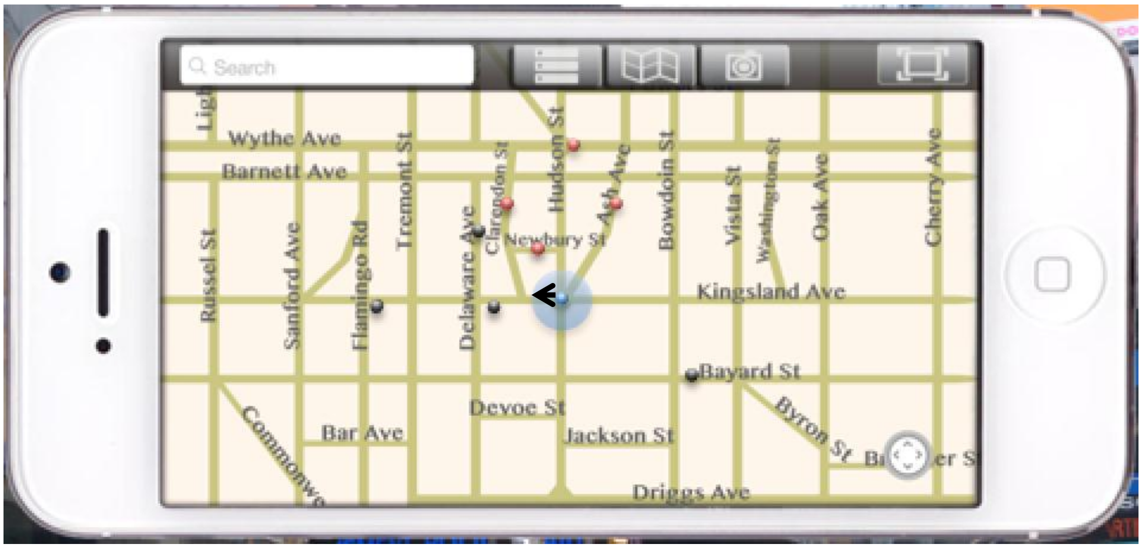
4. If you keep walking on this path, after about 20 minutes, where would you get? Mark the point at which you can reach (on the provided Figure below).



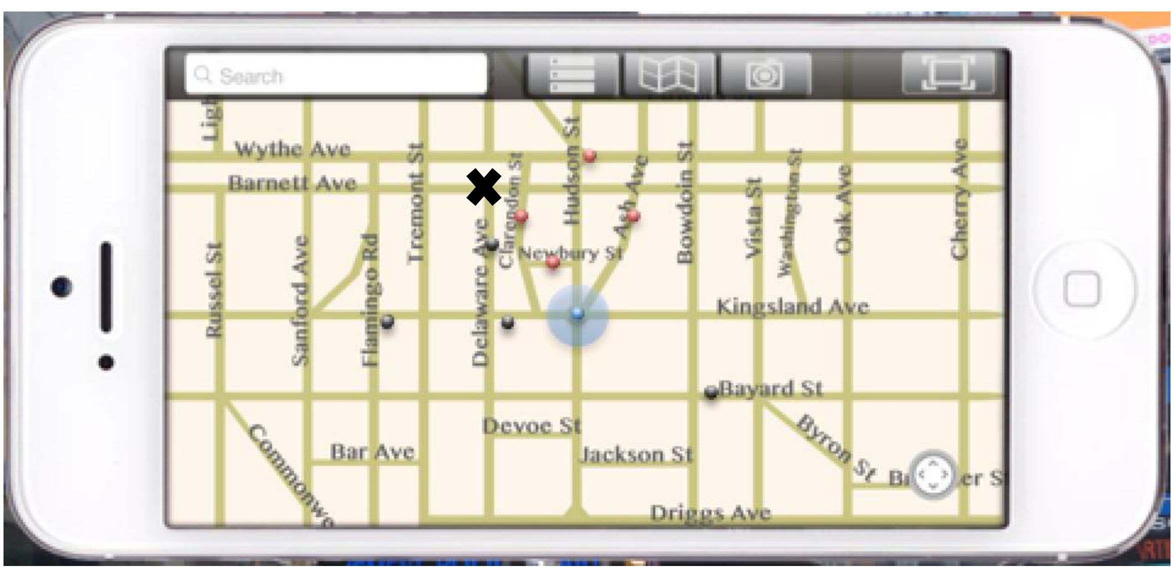
For map interface S: Participant no. ____________________

Task Queries:

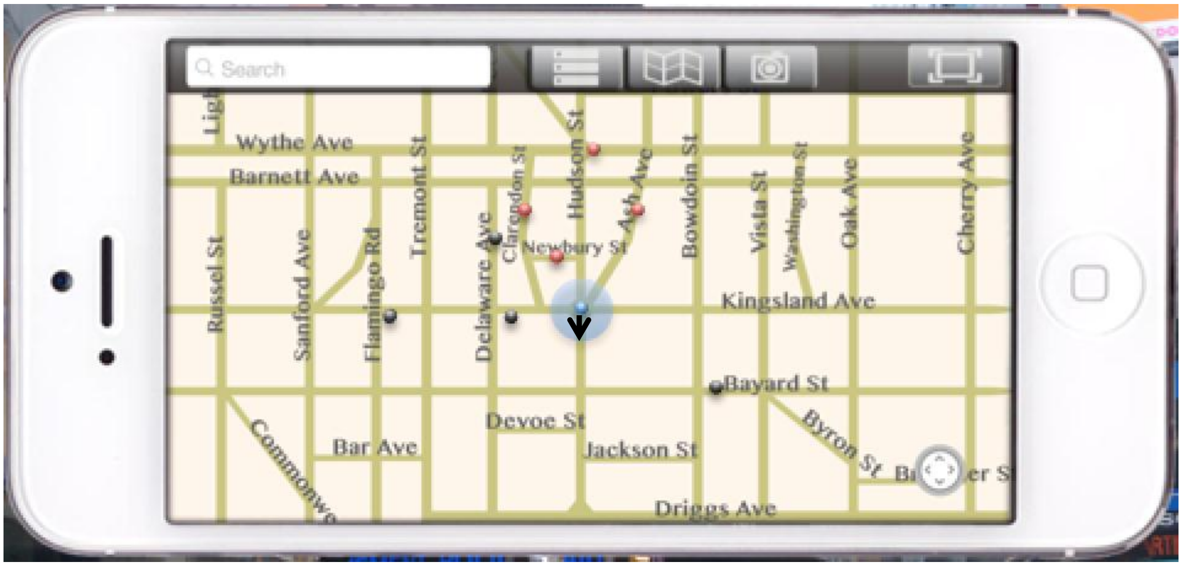
1. Enter the number of restaurants that can be reached within 20 minutes
2. Now suppose you are standing at the marker, and facing and walking the direction as the arrow indicates (see figure below). Find the restaurants that can be reached within 20 minutes. Enter the number of restaurants. . (You can turn at any subsequent intersections.)



3. You found a musical show shown at 7:00PM that a place (see figure below). To save some of your time, find the restaurants that are on all optional paths to the show and within about 20 minutes of walking from where you are now. Enter the number.



4. If you keep walking on this path, after about 20 minutes, where would you get? Mark the point at_which you can reach on the provided figure below.



APPENDIX Q MAP TASK RECORDING SHEET

Map Task Recording Sheet Participants No. ______________________

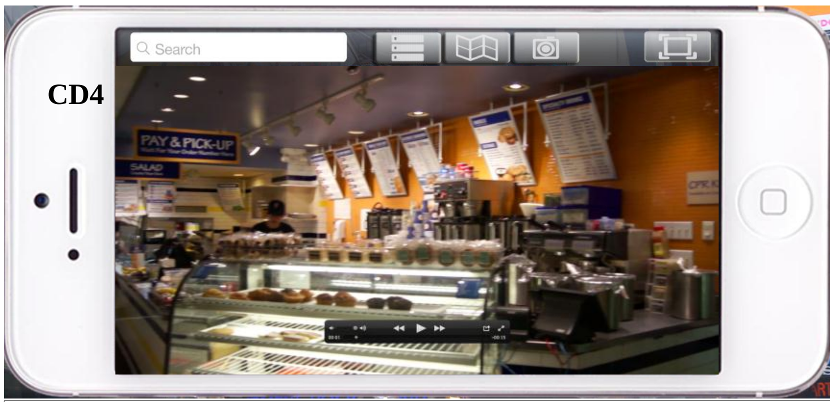
Tasks/Time	Interface S	Interface B
Task Order:		
1		
2		
3		
4		
Note		

APPENDIX R CONCEPT EVALUATION INTERFACES SCREENSHOT

CD4

CD4

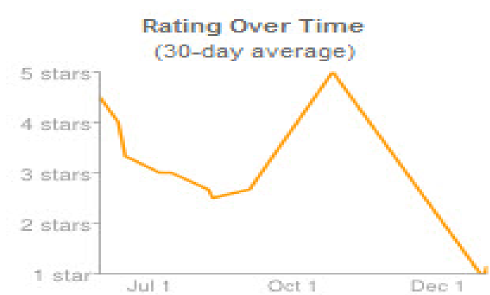
CD4



CD4

CD5

CD5



APPENDIX S CLAIMS ANALYSIS

No.	User Requirements	System Requirements	Proposed Information Design Feature	Hypothesized Pros (+) of the Feature	Hypothesized Cons (-) of the Feature	Proposed Interaction Design Feature	Hypothesized Pros (+) of the Feature	Hypothesized Cons (-) of the Feature	Design Note
1	For exploratory browsing and goal-directed exploration, users shall be supported with different layers or modules of information to select at as they wish (P2:68;P4:40;P1:224;P3:148;P5:235)	*For exploratory browsing and goal-directed exploration, system shall provide users with "layers" or "modules" of information representing various categories of activities.*	Having a "layer" concept	has a variety of layers corresponding to various types of POIs		viewing "layers" by selecting icons on tab bar	makes "layers" easily accessible all the time	but may confuse some inexperienced users	Having a variety of layers corresponding to different types of POIs; Layers serving as a filter mechanism;]
				serves as a filter mechanism			can be closed by tapping on the side tab bar to preserve screen real estate for AR view		
				can minimize the clusters of information					
					but users may be confused about the categorization of POIs				
2	For exploratory browsing and goal-directed exploration, users shall have personalization options to set up preferences and add personal or cultural related POIs (P1:191;P5:163;P2:81;P2:94).	*For exploratory browsing and goal-directed exploration, system shall provide personalization options for users to set up preferences and add personal or cultural related POIs.*	Having preference setup	encourages more engagement and involvement	but may try to include too much information	using "settings" to set up preference	reinforces the feeling of user control		
				builds up user's database					
3	For exploratory browsing and goal-directed exploration, users shall have an option to express and describe their needs to the system (P1:118;P2:33;P5:126).	*System shall provide an option for users to express and describe their needs directly at a particular moment.*	Having a "what I want now" concept	has a direct way to navigate users to POI categories based on their current needs		having a splash page when loading: "what I want now" and "explore nearby"			
						for "what I want now" showing a temporary view with radio button showing "I am hungry" "I am bored" "I am curious" "I am tired" "I am thirsty"; loading AR view with layer tab bar opened			

						for "explore nearby" loading AR view with layer tab bar opened			
4	For exploratory browsing and goal-directed exploration on mobile AR viewer, users shall be able to identify or recognize their own location and orientation, as well as obtain information about relevant POIs in their vicinity (P1:271;P4:243;PF2:44;P3:63;P3:75;P3:188;P4:78;P4:233;P5:249).	*For exploratory browsing and goal-directed exploration, on mobile AR viewer, system shall provide users with information about their own location and orientation, and relevant POIs in their vicinity.*	highlighting streets' information: the street's name, signs	facilitates user's perception of streets in vicinity	but may lead to considerable image processing time	viewing the layer of "streets" by selecting it on the tap bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
				provides information about streets in vicinity	but increases the visual detail and complexity of augmented reality view				
			highlighting POIs with building's name and its category(e.g., museums, shops, restaurants),	facilitates user's perception of POIs in vicinity	but may lead to considerable image processing time	viewing the layer of different types of POIs by selecting them on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
				provides information about POIs in vicinity	but increases the visual detail and complexity of augmented reality view				
			showing an interactive radar with the location of the building and one's own location	facilitates user's locating and orienting		when tilting the phone up to 90 degrees up, the radar changes from a round radar to a distorted elliptical radar distorted from the user's perspective	takes advantage of the change of the interface position	but may confuse some inexperienced users	
						By activating the radar in the map mode, the radar and map overlap.		but increases the visual detail and complexity	
5	For exploratory browsing and goal-directed exploration, users shall be supported the following specific ways (5a-c) to assist their recognition and identifying process (P1:246; P3:171;P4:224;P5:235;P5:238):	*For exploratory browsing and goal-directed exploration, system shall provide users with the following information:*							

5a	Prioritized and more detailed information, upon request, about POIs that are directly visible from the AR viewfinder, to assist user's "scan" activity; includes an option to reveal additional information;	*Prioritized and more detailed information, at request, about POIs (that is directly visible from the AR viewfinder) to assist user's "scan" activity; and an option to reveal further information;*	having a detailed description box for POIs that can be seen clearly in user's immediate vicinity	provides detailed information about POIs in one's immediate vicinity		viewing the description box by tapping on the highlighted tappable POI area on the AR viewer	provides a convenient way to see the recognized POI	but users may not realize these components exist	
5b	Less detailed information, upon request, about nearby POIs that are not directly or completely visible from the AR viewfinder; includes an option to reveal additional information;	*Less detailed nformation, at request, about nearby POIs (that is not directly or completely visible from the AR viewfinder); and an option to reveal more information;*	having a table view of clusters of POIs activated by a tappable area; those POIs are in one's visual field but cannot be inspected closely	provides easy-to-scan information about these POIs		viewing the table view by tapping on the highlighted tappable POI area	provides a convenient way to see the recognized POI area		
5c	Less detailed information, upon request, about distant POIs that are visible but vague from the AR viewfinder; includes an option to reveal additional information.	*Less detailed information, at request, about distant POIs (that is visible but vague from the AR viewfinder); and an option to reveal further information;*	having a table view of POIs; those POIs are not in one's visual field	provides easy-to-scan information about these POIs		OR viewing the table view by opening the AR viewer	provides a convenient way to see the clustered POIs	but users may not realize the difference between "eye" icons for image recognition, and this feature.	
				makes POIs spatial relations distinguishable					
			having all automatically loaded and displayed information within walking distance and having an option to view information regarding farther POIs;	reduces the amount of information shown on mobile AR viewer by encouraging users to filter by layers		activating the distance adjusting slider by touching and holding on any area of the radar (3 areas: near/middle/far)	gives users fine-grained control over selecting a specific value from a continuous range of values	but users may not realize these components exist	
							has a minimum and a maximum increment value		
							is also useful because users would benefit from instant feedback when they adjust to a distance value		
						manually adjusting the distance slider by sliding the bar up and down	leverages user's familiarity with the adjusting mechanism		
						viewing more POIs in one's vicinity (keeping the same 3 circles covering 3 areas) by adjusting the distance slider	provides an intuitive way to perceive POIs in terms of distance	but increases the visual detail and complexity	
							is also useful because users would benefit from instant feedback when they adjust to a distance value		

			information regarding less planned-in-advance POIs (e.g., restaurants) shall be less than 20 minutes walking;			viewing the distance to a POI in the description box	provides a spatial aspect of the POI		
			information regarding planned in-advance POIs (e.g., attraction places) shall be within a larger walking range;						
6	For exploratory browsing and goal-directed exploration, users shall be supported by an image recognition feature in order to identify and highlight the requested POIs that are directly visible to the user (P1:164;P2:232;P6:285; P2:242; P1:285;P5:28;P5:274;P5F:107;P5F:124).	*For exploratory browsing and goal-directed exploration, system shall provide image recognition feature to identify and highlight the requested POIs that are directly visible to the user.*	having image recognition feature enabled by filters to recognize POIs in one's vicinity	supports user's visual scan activity	but the accuracy may be constrained by image processing technology	viewing highlighted POI areas or bubbles enabled by image recognition feature and location-based services by selecting a particular layer on the tab bar	connects the radar area with the image recognized POI AR view	but users may not realize these components exist	
						viewing highlighted images by physically rotating to different directions	increases the user's involvement with the environment	but may embarrass the user if too many people surround	
7	For exploratory browsing and goal-directed exploration, users shall be supported by information on "attention-catching" POIs that stand out in the environment (P3F:37;P2:208); and/or those that are goal-related (P4:327;P3:265; P1:355;P3:267;P6:366).	*For exploratory browsing and goal-directed exploration, system shall provide users information on "eye-catching" POIs standing out in the environment, such as colorful and interesting-shaped buildings, and goal-related POIs.*	highlighting eye-catching POIs in one's immediate vicinity: colorful and interesting-shaped buildings (not necessarily for navigation)	supports user's visual scan activity		viewing highlighted images by selecting a layer of "explore nearby"	aids perception and comprehension of the POIs nearby		
		For exploratory browsing activity and goal-directed exploration, system shall increase <u>*the perceived visibility*</u> *of user's interested POI in one's vicinity and provide its attribute information.*				viewing highlighted images by physically rotating to different directions	takes advantage of the change of the interface position	but may lead to social awkwardness in crowds	
8	For exploration and navigation, users shall be able to keep track of the following environmental cues (8a-h):	*For exploration and navigation, system shall provide environmental cues that users may keep track of:*	For exploration and navigation activities,						

8a	street information (e.g., street numbers/street signs) (P1:83;P2:115;P3:57;P4:74; P3:57;P4:34;P4:59);	*street information (e.g., street numbers/street signs);*	highlighting street numbers and street signs	supports user's visual scan activity		viewing highlighted images by selecting a layer of "street"	simplifies the interaction to a simple tap		
						removing the corresponding layer by a second tap on the layer	makes the add and remove intuitive		
						displaying "layers" in a two column-buttons format		but increases the visual detail and complexity	
						making sure the size of layers icon is 44x44			
8b	store signs and company logos (P4:58;P4:74);	*store signs and company logos;*	highlighting store signs and company logos			viewing highlighted images by selecting a layer of "logo"	simplifies the interaction to a simple tap	but may try to include too much information about POI	
8c	location of oneself (P5:87);	*location of oneself;*	having a button for a semantic map for a quick location and direction access			viewing semantic map by tapping a button "location" on the tab bar	enables a quick location & orientation		
8d	direction to destination POIs (P1:94);	*direction to POIs;*	having a button for a regular map service for a more accurate location and direction information			viewing a full map by tapping a button "map" on the segmented tab bar	makes a full map accessible all the time		
			having a button for a quick refocus on one's own location on semantic map and regular map			bringing back the user to where he/she is by clicking on a "re-focus" button on the semantic map and regular map			
8e	distance to destination POIs (P1:94;P4:127;P5:94; P5:87);	*distance to POIs;*	having distance information in the POI's description box			viewing distance to the POI in the description box	provides spatial information of the POI		
			having distance information on both semantic map and regular map			viewing (a description box for the POI) distance to the POI by tapping on the POI pin on the semantic map and regular map			
			having the layer tab bar accessible anytime (including on semantic map and regular map)			viewing the layer tab bar by tapping on the rounded tab bar if it is close	saves screen real estate for AR objects		
						closing the layer tab bar by a second tapping on the rounded tab bar			
8f	estimated time needed to reach a POI by taking into account various environmental factors (P1:94;P2:115;P5:94;P2F:7 8; P4:230);	*estimated time that takes to reach a potential POI taking into account of dynamic traffic and weather information;*	having estimated time to the POI along with distance information	makes distance more interpretable		showing estimated time to the POI along with distance	simplifies the estimation of the time taken to the POI		

8g	dynamic pedestrian traffic (P1:133;P2:115;P5:94);	*dynamic traffic;*	having a button for real-time traffic information for events or very crowded areas	enables users to view current traffic information to POIs		viewing real-time traffic information by tapping on "traffic" button on the tab bar	provides real-time pedestrian moving information to assist SA of the surrounding POIs	but may try to include too much information about POI	
	good or bad sections (regarding safety) in town.	*good or bad sections in town.*	having a safety layer incorporated with crime report information alone with POI layers	supports user's requirement regarding safety in exploring an unfamiliar place		viewing safety information by tapping on "safety" button on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action	but may try to include too much information about POI	
9	For exploratory browsing and goal-directed exploration, users' need to obtain more information about visual landmarks shall be supported on/from mobile AR viewer (P2F:36;P2F:42;P3:57;P3:225; P4:252; P4:255; P4:256).	*For exploratory browsing and goal-directed exploration, system shall provide users with information on visual landmarks on/from mobile AR viewer.*	highlighting visually distinctive landmarks	supports user's visual scan activity		viewing highlighted images by selecting a layer of "landmark"	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
10	For exploratory browsing and goal-directed exploration, users' need to obtain more information about cognitive landmarks shall be supported on/from mobile AR viewer (P1:69;P2:134;P4F:127;P6:85).	*For exploratory browsing and goal-directed exploration, system shall provide users with information on cognitive landmarks on/from mobile AR view.*	highlighting culturally distinctive landmarks	personalizes and provides a richer user experience		viewing highlighted images by selecting a layer of "landmark"			
11	For exploratory and navigation, users shall have a consistent and interlinked interface among insight view and overview (P2:89;P5F:176).	*For exploratory and navigation, system shall provide a consistent and interlinked interface among insight view and overview.*	having consistent and interlinked interfaces between mobile AR viewer, maps, and list view.	enhances consistency		making functions accessible and consistent across views			
12	For exploratory browsing and goal-directed exploration, users shall be able to perform varying types of searches within the mobile AR viewer with returned searching results (P3:58;P2F:69;P6:265;P4F:56;P5F:107;).	*For exploratory browsing and goal-directed exploration, users shall be able to perform varying types of search within the mobile AR viewer with returned searching results.*	having a search function that can perform image search and query search	simplifies user's search activity		having a search toolbar with image searching icon	supports user's search activity		
13	For exploration and navigation, users shall be able to quickly scan information on mobile AR viewer to minimize the time spent on screen (P2:73;P5:150;P2F:75;P2F:114;P3F:83;P4F:132;P5F:59;P6F:50).	*For exploration and navigation, system shall provide users a quick and easy way to scan information on mobile AR viewer to minimize the time spent on screen.*	having a minimum interface design style	reduces visual complexity and simplifies interaction in the mobile context		having a minimum interface design for button design, font design; AR label design; AR description; AR radar;	reduces visual complexity		
				only provides task-important information					

14	For exploratory browsing and goal-directed exploration, users shall be supported with an adaptive interface that is constantly adapting to the user's behavior and buildup profile (P1:187;P2:55;P4F:89;P6:54;).	*For exploratory browsing and goal-directed exploration, system shall provide users with an adaptive interface.*	having an adaptive information system that learns to the user's behavior (e.g., based on the time that the user has visited this place previously)	enables less redundancy and provides information that builds up on the previous experience		implementing an interfaceadaptive mechanism	reduces information redundancy		
15	For exploratory browsing and goal-directed exploration, users shall be able to receive spatial information that is automatically adjusted based on environmental factors (P1:188;P4:327).	*For exploratory browsing and goal-directed exploration, system shall provide users information spatial information that is automatically adjusted based on environmental factors.*	having system automatically adjusted the density of POIs on AR viewer by, for example, adjusting the range area	reduces clusters of information	but users who do not find out how to adjust distance range may not find information about other POIs	implementing a mechanism to adjust the density of POIs on AR viewer automatically			
16	For exploratory browsing and goal-directed exploration, users shall be able to have and adjust the information range at will on a mobile AR viewer (P4:327; P5:133).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to adjust the information range at their will on mobile AR viewer.*	having an information range adjust bar	enables user's control on the information range		activating the distance adjusting slider by touching and holding on any area of the radar (3 areas: near/middle/far)		but may not be realized by some inexperienced users	
				provides additional information under user's request		closing the distance adjusting slider by a touching and holding			
17	For exploration and navigation, users shall be supported by a concept of "search & identify," enabled by an image recognition and identification feature in order to help users identify POIs at request, thereby assisting the natural human visual inspection activity (P1:164;P2:232;P6:285; P2:242; P1:285;P5:28;P5:274; P5F:107;P5F:124).	*For exploration and navigation, system shall provide users with a concept of "search & identify", enabled by image recognition and identification feature in order to help users identify POIs at request, assisting the natural human visual inspection activity.*	having a "search & identify" concept for goal-directed navigation	simplifies user's search and identify activities		hinting the search toolbar with "search & identify" underneath	aids perception and comprehension of the searched POI		
				reduces user's workload on					

				searching and identifying					
18	For exploration and navigation, users shall have an option to access the POI's visualization information, if applicable (e.g., real-time view, or photorealistic pictures) (P4:269; P5:276).	*For exploration and navigation, system shall provide an option for users to access the POI's visualization information, if applicable (e.g., real time view, or photorealistic pictures).*	having photorealistic street views of the POI (e.g., the storefronts and the sides of a merchant)	enables visualization of the outside environment of the POI		showing photorealistic street views of the POI by tapping on one of the views on the description box	builds on common experience		
			OR having real time live stream of the street of the POI if applicable	enables visualization of the outside environment of the POI	but may have technical constraints and other issues at this point	showing real time live stream of the street where the POI locates by tapping on a hyperlink button "start live stream" then "outside" on a temporary view on the description box	provides real-time camera view of the POI		
				may aid comprehension and projection of the POI and future user experience					
19	For exploratory browsing and goal-directed exploration, users shall have an option to access specific POI attributes that cannot be easily described textually, if applicable (P3F:112;P2F:67;P4:193).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to be aware of the POI's attributes that cannot be easily described textually, if applicable.*	having photorealistic inside views of a POI if applicable	enables visualization of the inside environment of the POI		showing inside views together with street views	builds on common experience		
			OR having real time live stream inside the POI	enables visualization of the inside environment of the POI	but may have technical constraints and other issues at this point	showing real time live stream inside POI by tapping on a hyperlink button "start live stream" then "inside" on a temporary view on the description box	provides real-time camera view of the POI		
				may aid comprehension and projection of the POI and future user experience					
20	For exploration and navigation, users shall be supported by an interface to quickly check one's current location/orientation and a desired destination's location/orientation, if applicable (P2:154;P4:247;P5:145).	*For exploration and navigation, system shall provide an interface to allow users quickly* one's current location/orientation and destination's location/orientation, if applicable.	having a schematic map that automatically distorts a full map into a simplified one	offers a quick access to the location/orientation feature	but lack spatial accuracy and more detailed spatial information about the place	viewing semantic map with destination POIs by tapping a button "location" on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action	but users may not realize these components exist	

				makes POIs more apparent on the semantic map		highlighting emphasized areas of interest with dimmed background on the semantic map	Increases contrast; aids perception of the POIs on the simplified version of map			
			OR having a concept of radar-map overlap; but distorted to accommodate environmental factors, e.g., geographic factor, traffic factor.	provides accurate information	but may not be visually pleasing, e.g., irregular shaped boundaries	Activating the overlap by tapping a tab bar from bottom of the screen, regardless the mode (landscape or portrait); disabling it by swiping it off to the bottom of the screen.				
					but increases visual details and complexity					
			Having a concept of radar-map overlap without distortion i.e., having concentric circles to provide an approximate distance/time judgment	Provides an approximate distance/time judgment	but may not be as spatially accurate as the differently-shaped boundaries (in distorted radar-map overlap)					
			having a direction indicator	makes the heading direction clear enough; aids orientation;	but may increase visual complexity					
			color coding on destinations	makes destinations distinguishable from other POIs	but may increase visual complexity					
21	For exploration and navigation, users shall have an option to be aware of the ongoing status of events or activities in their vicinity (P3:186;P4:234;P5:101).	*For exploration and navigation, system shall have an option to provide users with information about the ongoing status of events or activities in user's vicinity.*	having a layer of "events and activities"	makes it easy to view events and activities in one's vicinity		viewing the layer of events and activities by tapping on "events and activities" button on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action			
			having ongoing status information regarding ongoing events and activities in the description box	enables users to view current events/activities progress		showing real time textual update about ongoing events and activities by tapping on "real time update" in the description box	provides a convenient way to see the real time updates			
				aids decision making process on future visit					events/activities: special exhibits, club performance, theater shows,	

22	For exploration and navigation, users shall be supported with multimodal input and output to alleviate having to engage both hands in the mobile context (P1F:109;P1F:119;P2F:183;P6F:120;P4F:130).	*For exploration and navigation, system shall provide users with multimodal input and output.*	having voice control feature	frees up one or two hands if external hardware is wearable	but may be constrained by the mobile context (e.g., noise, wind)	integrating into OS voice control technology			
					but may be constrained by social factors				
			having gesture control feature	frees up one or two hands if external hardware is wearable	but may be constrained by the mobile context (e.g., noise, wind)	integrating into OS gesture control technology			
					but may be constrained by social factors				
23	For exploration and navigation, users shall have a mobile AR interface with a glare-free screen, operating properly under varying light conditions (P3F:56).	*For exploration and navigation, system shall provide users a mobile AR interface with a glare-free screen, operating properly in varying light.*							
24	Users shall have accurately tracked, registered and displayed augmentation on mobile AR viewer (P2F:75;P2F:114P3F:83;P4F:132;P5F:59).	*System shall provide users with accurately tracked, registered and displayed augmentation on mobile AR viewer.*							
25	For exploratory browsing and goal-directed exploration, on mobile AR viewer, users shall be supported by an overview of spatial patterns and relationships of POIs in one's vicinity regarding some aspects of attributes (P3:196;P4:243;P4:248;P5:260;P5:47;P5F:44;P4:28;P5F:50;P4F:85;P4:243;P5:260;P6:272).	*For exploratory browsing and goal-directed exploration, system shall provide users an overview of spatial patterns and relationships of POIs in one's vicinity regarding some aspects of attributes.*	having an interactive radar feature	simplifies POI representations	but the size may be too large or too small for mobile interaction	viewing objects highlighted within a certain distance on the AR viewer by tapping on an area of radar	provides distance range information	but it may not be realized by some inexperienced users	
						viewing all POIs in the radar as a default setting by tapping anywhere on the non-active space (dead space)		but it may not be realized by some inexperienced users	
				provides a convenient spatial overview of POIs		not tappable dots	avoids tapping errors which may lead to user frustration		

			having a semantic map	simplifies POI representations	but lacks spatial accuracy	viewing semantic map by tapping a button "location" on the tab bar	enables a quick location & orientation		
				provides a convenient spatial overview of POIs					
			having a full map	provides more accurate geo-information than the radar and semantic map	but too much visual details may slow down user's process spatial information	viewing a full map by tapping a button "map" on the upper tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
26	For exploratory browsing and goal-directed exploration, users shall have an option to perceive an overview on a mobile AR viewer (P2F:89;P2F:165;P2F:86).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to perceive an overview on mobile AR viewer.*	having a concept of spread out view	provides an overview on mobile AR viewer	but increases visual complexity		provides a convenient way to see the clustered POIs	but users may not realize the difference between image recognition represented by the "eye" icons and this feature (showing general direction information).	
					but may lead to difficulties of interacting with a large number of POIs				
			OR having a table view with all information listed	provides easy-to-scan information about these POIs	But may lack the intuitive feeling of “AR” (only direction is augmented in this design; although this is true for representing distant objects on AR)	activating the table view by opening the AR viewer at user’s will	Is easily accessible	But user may feel lack of control	
				reduces visual clusters					
				enables information sorting and ranking function on the table view; makes POIs default rank based on distance to the user’s location		Activating sorting and ranking by tapping on a sort & rank button			
			on table view, having a pivot control for ranking by different parameters	enables comparison and facilitates decision making among alternatives	but the size of the table maybe too large	OR showing a pivot control view for POIs sorted or ranked by different parameters	provides a convenient way to show similar POIs		
						viewing pivot items by swiping between similar items		but it may not be realized by some inexperienced users	

27	For exploratory browsing and goal-directed exploration, users shall have a way to know the amount of POIs sharing one or more attributes under query in one's vicinity (P2F:44;P2F:52;P4F:49;P4F:54;P4F:57;P6F:65).	*For exploratory browsing and goal-directed exploration, system shall provide the amount of POIs sharing one or more attributes under query in one's vicinity.*	indicating the number of POIs sharing one or more attributes	provides users a general idea of how big the cluster is and how far is the cluster of items from users		showing the number of POIs as a badge on the "layer" icon	shows the quantity information without requiring any interaction	but may confuse some inexperienced users	
			indicating the number of POIs in a group, which can be categorized based on attributes (e.g., distance/time, ratings, prices) at user's will; then revealing more detailed information about the POIs in this group, upon request.				preserves screen real estate when presenting a long list of POI elements from which the user is expected to choose	but may increase the visual detail and complexity	
			(as a default mode) showing the "amount" information about a group of POIs that are in a certain distance/time; then revealing more detailed information about the POIs in this group, upon request.			Showing information about a group of POIs within a spatial boundary; can be combined with the map-radar overlap concept;	helps users grasp the "gistification" of the information (e.g., encoding only relative values of information)	but may confuse some inexperienced users	
						originating and showing the spatial boundaries from the position of the user	Helps individual's locate and orient	but increases the visual detail and complexity	
28	For exploratory browsing and goal-directed exploration, users shall be supported with a progressively disclosed interface to gradually receive information upon request (P1:66;P1:75;P4:90;P6:139).	*For exploratory browsing and goal-directed exploration, system shall provide users a progressively disclosed interface to reveal more detailed information at user's request.*	having an interface with a cluster of items with the number indicating the number of items in that cluster	reduces visual complexity and aids comprehension of the information		showing the number of POIs on the triggered table view	shows the quantity information without requiring any interaction	but increases the visual detail and complexity	
			having a progressively disclosed user interface with the POI label including name of the place, ratings, type of restaurant, price range, and the type of business of the POI (if applicable), then progresses into additional information(e.g., menus).	aids comprehension of the POI and avoids information overload		showing the name of the place, ratings, type of restaurant, price range, and the type of business of the POI (if applicable) on the description box		but increases the visual detail and complexity	
						having a "more" button on the description box	shows more information as requested		

29	For exploratory browsing and goal-directed exploration, users shall be able to have a way to know the <u>spatial relationships</u> of the POIs sharing one or more attributes under query (P2F:103;P3F:70;P4F:145).	*For exploratory browsing and goal-directed exploration, system shall provide users the <u>spatial relationships</u> of the POIs sharing one or more attributes under query.*	having the map and radar features accessible	enables seamless switch between interfaces		making the AR, map and radar buttons in a fixed segmented view on the upper screen	has essential functions easily accessible all the time	but it takes up screen real estate	
			Having the map-radar overlap accessible			see no. 20 and 27 for more details			
30	For exploratory browsing and goal-directed exploration, users shall be supported with information that locally-based individuals uniquely possess (P1:52;P5:61).	*For exploratory browsing and goal-directed exploration, system shall provide users with information that locally-based individuals uniquely possess.*	having an area that locals can contribute their knowledge about POIs, paths, or areas that locals in terms of the best places to visit, the fun thing to do, the places to eat, the good or bad sessions of the town, and the certain sections of the town to specialize in.	encourages social interaction with locals who can provide more insights about the place		showing local's opinions about a particular POI in "what locals say" area in POI's description box			
						showing local's advise/recommendations in a page called "insight"			
31	For exploratory browsing and goal-directed exploration, users shall be supported with a ranking mechanism that can rank POIs based on one or more attributes at request (P2F:70;P5:163;P6;94;P3:211;P1:305).	*For exploratory browsing and goal-directed exploration, system shall a ranking mechanism that can rank POIs based on one or more attributes at request.*	having POIs a default setting from close to distant in table view	reduces mental workload to rank items by the user		viewing POIs in a table view as a default setting from close to distant order	builds on common experience		
				builds on common experience					
32	For exploratory browsing and goal-directed exploration, users shall be able to have an option to compare alternative POIs under query in a quick and easy way (P2F:70;P2F:180;P3F:64).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to compare alternative POIs under query in a quick and easy way.*	having a "compare" page button to compare 2 POIs on the tab bar	reduces short-term memory errors and mental workload		viewing compared 2 POIs side by side by selecting the "compare" button on the tab bar		but users may not realize these components exist	
			having a "compare" button along with each POI	makes the compare function accessible		adding a POI into "compare" page by checking a "compare" button in a description box or in a table view			

33	For exploratory browsing and goal-directed exploration, users shall be provided with an interactive AR view with augmentations enabling direct manipulation (P1F:18;P2:94;P2:273).	*For exploratory browsing and goal-directed exploration, system shall provide an interactive AR view with augmentations enabling direct manipulation.*	having a feature to remove POIs directly on mobile AR view	leverages user's familiarity with touchscreen based interaction		removing a POI on mobile AR view by touching and holding the POI and tapping on appeared close button	leverages user's familiarity with deleting apps from smartphone		
						removing a POI on table view by swipe it out from left to right	leverages user's familiarity with deleting items from list		
34	For exploratory browsing and goal-directed exploration, users shall be supported with a view by which users can browse information semantically in a categorical way (P1F:75;P3F:75;P4F:85).	*For exploratory browsing and goal-directed exploration, system shall provide users a view where users can browse information semantically in a categorical way.*	having a table view for POIs in one's vicinity accessible all the time at user's will	See more details regarding the table view on no. 26		viewing a table view by tapping on "List" on the upper segmented control button along with "AR" and "Map"	having essential functions easily accessible all the time		
			Having a table view for POIs on mobile AR view for the corresponding direction as the user turns	See more details regarding the table view on no. 26					
35	For exploratory browsing and goal-directed exploration, users shall be provided with a filter mechanism (P5F:124;P1F:18;P2:273).	*For exploratory browsing and goal-directed exploration, system shall provide users with a filter mechanism.*	having layers accessible on the side bar	encourages direct manipulation to select targeted layers		viewing a temporary view of range pickers by touching and holding the corresponding layer to set up filter criterion	simplifies the interaction by using pickers		
36	For exploration and navigation, users shall have an option to access alternative paths along with corresponding POI information to the destination (P3:211;P1:305).	*For exploration and navigation, system shall provide users an option to access information about alternative paths along with corresponding POI information to the destination.*	showing different path alternatives on the semantic map with POIs	provides alternative paths for users to choose from		viewing different path alternatives by tapping on a "path" button on the semantic map	offers more options for a richer experience	but increases the visual detail and complexity	
37	For exploration and navigation, users shall be made aware of POIs of potential interest based on a pre-established user profile, which could serve as alternative paths to the destination (P5:163;P2;94;P3:211;P1:305).	*For exploration and navigation, system shall provide users personalized information about their potentially interested POIs that are on their path to the pre-selected POIs.*	showing potentially interested POIs (based on the prior behavior and preference setup) along with different path alternatives on the semantic map	encourages more browsing activity		showing potentially interested POIs that are along the path on the semantic map by tapping on a "POI" button	provides a convenient view of POIs in vicinity	but increases the visual detail and complexity	
						viewing individual POI description (with a "reminder" buttons) by tabbing on POI bubble	simplifies the interaction to a simple tap to provide the user a way to trigger an action		

38	For exploratory browsing and goal-directed exploration, users shall have an option to set up and receive location-based (spatial) reminders of POIs of potential interest on their way to the destination (P5:163;P2;94).	*For exploratory browsing and goal-directed exploration, system shall provide an option for users to set up and receive location-based (spatial) reminders of their potentially interested POIs on their way to the destination.*	having a reminder button with each POI	makes the user be aware of the POI when approaching to it	but it may be annoying if the reminded POIs are too dense in an area	toggling on a "reminder" to the POI by tapping the option for each individual POI in the description box or the table view	provides a convenient way to set up reminder		
39	For exploratory browsing, goal-directed exploration and goal-directed navigation, users shall be provided at will with information about POIs sharing one or more attributes *or* alternatives (if applicable) (P1:231;P1:368;P2:333; P3:320; P4:389;P4:295;P3F:71; P4:295;P5:289;P6:401).	*For exploratory browsing, goal-directed exploration and goal-directed navigation, system shall provide users with information about POIs sharing one or more attributes or alternatives (if applicable) at will.*	having a pivot control for POI "similar"	enables comparison and facilitates decision making among alternatives	but the size of the table maybe too large	showing a pivot control view for "similar" for each individual POI description box (pivot header: similar; pivot items are in the list)	provides a convenient way to show similar POIs		
						viewing pivot items by swiping between similar items	is used to split a single data set, to make it easier for the user to locate the information they're interested in		
						are "same type" (the finest category) of POI in one's vicinity			
40	For exploration and navigation, users shall be able to (perceive and) interpret POIs' spatial relations on mobile AR viewer (P4F:132; P6:334).	*For exploration and navigation, system shall provide users a way to make POIs' spatial relationships (perceivable and) interprable.*	having different design representations for POIs that are close and farther away, such as using in size, color, situation variations.	makes POIs that are close and farther away distinguishable on the mobile AR view	but it may confuse some inexperienced users about the difference	having description boxes and table views on a transparent temporary view	makes users feel that they are still in the context of the AR view		
							hints at the background view		
41	For exploratory browsing and goal-directed exploration, users shall have an option to be aware of information about POIs in their current vicinity and in the vicinity of their destination(s). (P6F:101;P4F:123;P4F:165; P6F:101).	*For exploratory browsing and goal-directed exploration, system shall provide users an option to be aware of information about POIs in their current vicinity and in the vicinity of their destination(s).*	showing POIs around current locations and destinations on the semantic map	facilitates comprehension of spatial relationships and comparisons		showing POIs that are around current locations and destinations on the semantic map		but increases the visual detail and complexity	
42	For exploratory browsing and goal-directed exploration, users shall have information with uniformed layout, *varied* for different types of POIs (P5:105).	*For exploratory browsing and goal-directed exploration, system shall provide users information with uniformed layout, varied for different types of POIs.*	having different uniform information pages for different types of POIs	leverages user's expectations to different types of POIs		having different uniform pages for description box for different types of POIs			A uniform page is a page where one has pages of info to present where each page looks exactly the same, but

									the data differs on each.
43	Users shall be able to interact with mobile AR viewer analogous to interactions with a touch-screen based camera (P8:89;P5F:107;P5F:124).	*System shall enable users' interaction with mobile AR viewer analogous to interactions with a touch-screen based camera.*	enabling zoom in/out feature	leverages user's familiarity with the touchscreen based camera		using pinch-to-zoom gesture to zoom in/out the AR view	leverages user's familiarity with pinch-to zoom interaction		
			having a screen-freeze button available on mobile AR viewer	overcomes the physical interaction awkwardness in the mobile context		freezing the current screen by tapping on screen freeze button	leverages user's familiarity with screen print feature on smartphone		
						unfreezing the screen by a second tapping on screen freeze button			
			having interaction properties on the frozen screen		it may confuse some inexperienced users	using pinch-to-zoom gesture to zoom in/out the frozen AR view	leverages user's familiarity with image interaction on smartphone		
44	Users shall be able to save POIs for later access at will (P2F:70; P2F:180; P3F:64).	*System shall provide users a feature to save POIs for later access at will.*	having a bookmark button along with each POI	reduces short-term memory errors and mental workload		adding a POI to the "bookmark" page saved for later decisions by tapping on the "bookmark" button in the description box or table views	leverages user's familiarity with bookmark on webpage		
			having a bookmark page button on the side bar	encourages more engagement		viewing all bookmarked POIs by tapping on "bookmark" in tab bar		but users may not realize these components exist	
				leverages user's familiarity with bookmark function					
45	Users shall be supported with a personal context in their vicinity (P1:221;P3:164;P4:208; P2:176; P5:219).	*System shall provide users with a personal context in their vicinity.*	having language translation feature on the side bar	overcomes language barrier		activating "language translation" service by tapping on "language" button on the layer tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		

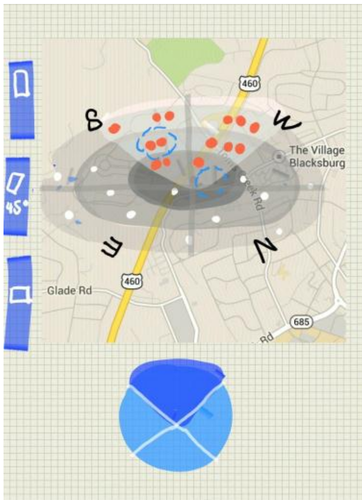
46	Users shall be able to make changes and adjustment quickly on path and destination selection (P2:94;P3:74).	*System shall enable users to make changes and adjustment quickly on path and destination selection.*	having a function of "add to path" for each POI	simplifies destination and path selection		adding a POI to a path by tapping the "add" button in the POI description box or table view	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
			having a function of "remove from path" for each selected POI	simplifies change on destination and path selection		removing a POI from a path by toggling the "remove" button in the POI description box or table view	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
			having a function of "add more" on the "path" page	simplifies change on destination and path selection		adding more POIs to a path and directing to the list view by tapping on the "add more" button on the "path" page	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
			having a function of "remove from path" on the "path" page	simplifies destination and path selection		remove a POI from a path by touching and holding the POI and tapping on the close option	leverages user's familiarity with delete interaction on smartphone		
			having a button in tab bar for "path" page (with alternative paths)	facilitates access to the alternative paths		viewing all alternative paths by tapping on a "path" button on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
			showing automatically generated alternative paths for added POIs on a "path" page	encourages path exploration in one's surrounding area		viewing automatically generated alternative paths by tapping on the "path" page	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
47	For exploratory browsing and goal-directed exploration, users shall have an option to be informed of real time crowds/pedestrian flow in events (P1:133;P2:115;P3:57;P3:225).	*For exploratory browsing and goal-directed exploration, system shall provide an option to inform users the crowds/pedestrian flow to stimulate an exploration or to provide cues of where a busy area is.*	having a "traffic" button on the side bar for dynamic pedestrian traffic information of the surrounding area in one's vicinity	enables users to view current trendy POIs to visit		viewing real-time traffic information by tapping on "traffic" button on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
48	For exploratory browsing and goal-directed exploration, users shall be supported with trends-revealing or establishing information, at request, which can be used to establish a trend of experiences in one POI to assist make projections on their (near) future visit (P1:140;P4:376;;P4F:130P5F:110;P5F:75; P5F:114;P5F:119;	*System shall provide users with an option to have trends-revealing or establishing information, at request, which can be used to establish a trend of experiences in one POI to assist make projections on their (near) future visit.*	having a "trend" figure for aggregated ratings over time	enables users to view the trendy of POI's attributes		viewing aggregated review keywords for aggregated rewards over time in POI description box	simplifies the interaction to a simple tap to provide the user a way to trigger an action	but increases the visual detail and complexity	

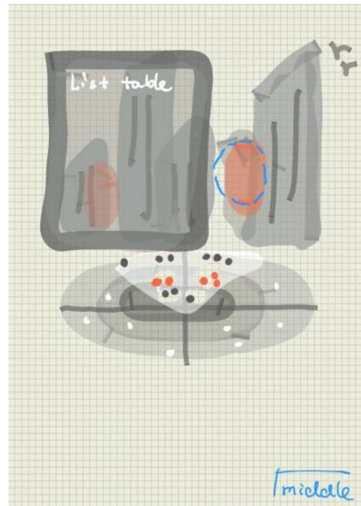
	P5F:120;P5:330;P5:339).								
			OR having an aggregated review keywords	enables projections by building up a well rounded "picture" of the POI		viewing aggregated review keywords for aggregated rewards over time by tapping on "more" from a POI description box	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
			OR having computerized processed "foresight" information for what the place is going to be like at a later time	make computerized projections for the user	but may lead to less feeling of control				
					but may lead to trust issue about the accuracy of the computer generated information				
49	For exploratory browsing and goal-directed exploration, users shall be made aware of the real time information of POI, at request, regarding dynamic and interactive aspects of the POI, enabling user's projections of its future state. (P1:100;P1:363;P1:370;P2:44;P3:225;P2:337P3:320;P4:322;P4:391;P5:339;P5:326;P6:144;P6:392;P6:380;P6:407;P1F:72;P1F:82;P2F:169;P4F:145;P4F:152;P5F:112;P5F:114;P5F:115).	*For exploratory browsing and goal-directed exploration, system shall provide users the real time information of POI, at request, regarding dynamic and interactive aspects of the POI, enabling user's projections of its future state.*	*System shall provide users with real time information regarding:*	having real time live stream of the POI if applicable	enables visualization of the outside environment of the POI	showing real time live stream of the street of POI by tapping on a hyperlink button "start live stream outside" on the description box	simplifies the interaction to a simple tap to provide the user a way to trigger an action		
					may aid comprehension and projection of the POI and future user experience				
					but may have technical constraints and other issues at this point				

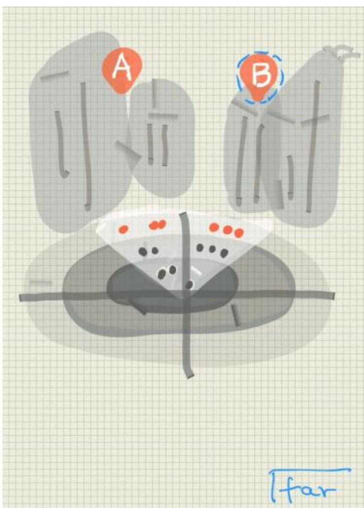
			For restaurants, the real time view of the restaurant before they go to regarding the current availability of the POI, crowd situation, seat availability and line situation.						
			For shops, regarding the current availability of the POI, crowd situation, and line situation.						
			For tourist attractions, regarding the current availability of the POI, crowd situation, ticket selling situation, line situation, and weather information.						
			For activities and events, regarding the current availability of the POI, crowd situation, ticket-selling situation, line situation, current playing information, and weather information.						
			For traffic information, regarding the timetable and upcoming transport information.						
50	For exploratory browsing and goal-directed exploration, users shall have an option to interact with locally based individuals or other users for serendipitous or acquaintanceship-based social interactions (P1:334;P2:66;P5:110).	*For exploratory browsing and goal-directed exploration, system shall provide users a feature that enables social interaction with locals.*	having a feature on the local page that locals can communicate with visitors	enables social interaction		having a reply area and question asking area for visitors asking questions in the section of "what locals say" in POI's description box.	facilitates the local-user interaction	but may try to include too much information about POI	
						having a reply area and question asking area for visitors asking questions in a page called "locals"		but may try to include too much information about POI	
						having a name list of locals that could be conected for user's questions on "locals" page			
						using a light to indicate the local's current availability "on mobile" (green) or "off mobile" (gray) on "locals" page			

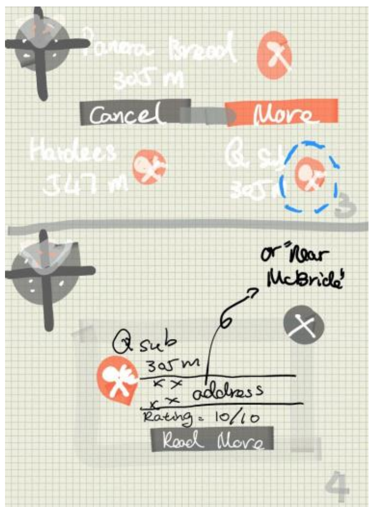
51	For exploration and navigation, users shall have an option to set up and receive temporally-relevant information reminders at will (P3:81;P5:116).	*For exploration and navigation, system shall provide an option for users to set up and receive temporally-relevant information reminders at will.*	having a time period setting feature for each POI as an option	reminds users the time frame if they have any		setting a reminder for visiting a POI in a specific time frame by tapping on "reminder" on the POI description box on the "path" page			
						having 2 options in a temporary view: "setting a visiting time window" and "sending a reminder when approaching"		but may be annoying if too many POIs are set to reminders	
						showing time pickers after tapping on "setting a visiting time window" in a temporary view	simplifies the interaction by using pickers		
52	Users shall be provided with safety information about sections of an unfamiliar place under query (P5:87;P6:101;).	*System shall provide users with safety information about sections of an unfamiliar place under query.*	having a safety layer incorporated with crime report information alone with POI layers	supports user's requirement regarding safety in exploring an unfamiliar place		viewing safety information by tapping on "safety" button on the tab bar	simplifies the interaction to a simple tap to provide the user a way to trigger an action		

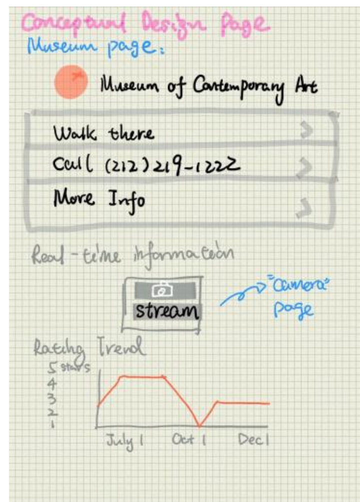
APPENDIX T INTERFACE DESIGN SKETCHES & STORYBOARD SAMPLES

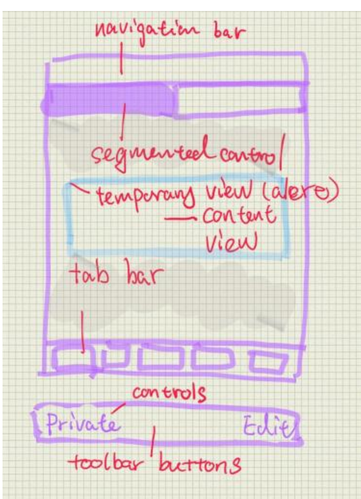


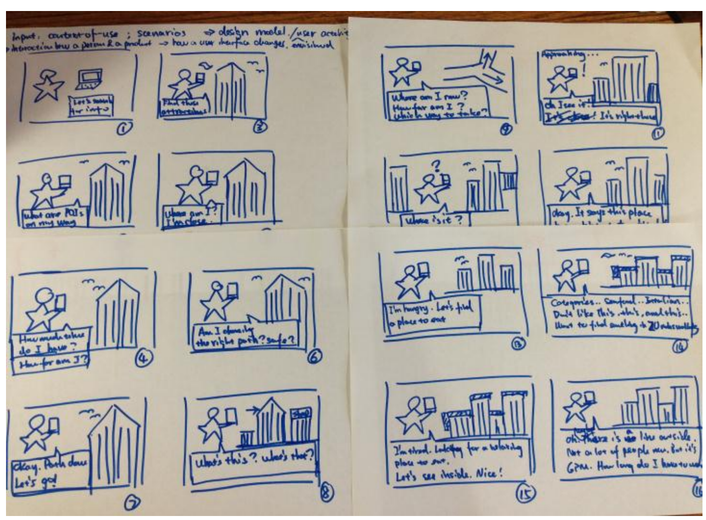












APPENDIX U SAMPLE OF ACTIVITY NOTES FROM STUDY 1

SA1 Perception

code: perc_environmental cues that users keep track of:

Street/street numbers/street signs (P1:83;P2:115;P3:57;P4:74;P3:57;P4:34;P4:59), store signs/company signs (like Starbucks) (P4:58;P4:74), direction (P1:94), distance (P1:94;P4:127;P5:94), approximate time that may take (P1:94;P2:115;P5:94)(especially when one is in a hurry), traffic (P1:133;P2:115;P5:94), pedestrian (P1:133;P2:115;P3:57;P3:225), landmarks (P3:57), where oneself is (P5:87), where the major attractions that one wants to see are (P5:87), good or bad sections in town (P5:87).

Direction is considered important to be tracked of because the participant doesn't want to start walking in a certain direction and then realizes it's miles away (P4:127).

Support users' perception

System shall provide environmental cues that users keep track in exploring a place

Users shall be able to keep track of street/street numbers/street signs (P1:83;P2:115;P3:57;P4:74;P3:57;P4:34;P4:59);

Users shall be able to keep track of store signs and company signs (P4:58;P4:74);

Users shall be able to keep track of direction (P1:94);

Users shall be able to keep track of distance (P1:94;P4:127;P5:94);

Users shall be able to keep track of approximate time that may take to reach a place considering traffic and weather(especially when one is in a hurry) (P1:94;P2:115;P5:94;P2F:78; P4:230);

Users shall be able to keep track of traffic (P1:133;P2:115;P5:94);

Users shall be able to keep track of landmarks (P3:57;P3:225; P4:252; P4:255; P4:256);

Users shall be able to keep track of where oneself is (P5:87);

Users shall be able to keep track of where the major attractions that one wants to see are (P5:87);

Users shall be able to keep track of good or bad sections in town (P5:87);

Seeing crowds go to that way will help the participant understand and reinforce his assumption that this is a busy area, such as a transportation station or a live concert here (P3:225;P2F:35). This stimulates the participants want to go to the same area (P2F:35;P2F:47). Seeing crowds heading down to a street also can stimulate the participant to make a decision, because the participant believes that there are going to be something that look at, comparing to only a few small number of people there (P4:109).

In addition, one participant said he would go to talk to some of these people and ask them about places to go (P2F:47).

Support users' perception

System shall provide crowds/pedestrian flow to stimulate an exploration or to provide cues of where a busy area is.

Users shall be able to be informed of crowds/pedestrian flow (P1:133;P2:115;P3:57;P3:225);

The participant worry about walking on something or hitting something and then fall down, so they need to keep track of pavement, sidewalk, bolder surfaces, something to walk, as long as there is a place that you could walk. There are awful places that you're not allowed to walk(P2:73).

In addition, the participant would also need to stay aware of what's going on around the phone with concerns of running into people while holding a phone in front of him (P5:150).

If he walks, he wouldn't hold up the phone all the time, because he doesn't want to get the tunnel vision and miss things like Cannoli man or the guy who wants money for pod. Although he also wants the information from the phone, he doesn't want to sit there and look at his phone constantly. He desires a quick scan on phone and quickly gets an idea of what's around (P5:150).

Support users' perception *System shall provide users a clear and easy way to scan information on mobile AR screen to minimize the time that they spend on the screen, not on the actual view* Users shall be able to quickly identify and scan information on mobile AR screen (P2:73;P5:150;P2F:75; P2F:114P3F:83;P4F:132;P5F:59;P6F:50).

In a digitized augmented reality context, if there is some place that he can't easily see, he would like to use maps; if the place is only a few blocks away, he would like to be guided by big arrows on mobile AR (P5:143).

On mobile AR, it's hard to tell if the place is close or further away(P4F:132). Participants would like to see what's close and what's further away, especially when something is right there like 10 feet away (P4F:132).

Support users' perception *System shall provide users a way to make objects that are close and further away distinguishable on mobile AR view.* Users shall be able to perceive and interpret objects' spatial relations on mobile AR screen (P4F:132).

code: perc_attend to environment objects

Interestingly shaped, or old, or tall architecture/building could also draw people's attention, because they're assumed to be located in the heart of the town (P2F:36;P2F:42).

Support users' perception *System shall provide users with information on visual landmarks (objects that are visually distinctive) appeared in the user's natural field of view on mobile AR view.* Users' need to know more information about visual landmarks shall be supported on mobile AR screen (P2F:36;P2F:42). Note: this requirement is important because users' attention are drawn by such visual landmarks (e.g., visually unique-shaped, old, or tall architectures).

If there is a famous place, like the Broadway, people tend to just be at that place to experience it (P4F:127).

One participant happened to see the Matt the upper house on his way to the main historical spots, he recognized it from a TV show and went to see it (P4F:127).

For a familiar place, people tend to remember what the "important things" look like on a road to help recognize the place without looking for signs (P6:85). One participant recalled that he cannot recognize his own place when the road has been widened and trees have been removed. He had to find street numbers to find his own place where he stays years (P6:85).

Support users' perception *System shall provide users with information on cognitive landmarks (landmarks having unique meaning that stand out; they could be personally, culturally, or historically important).* Users' need to know more about cognitive landmarks shall be supported on mobile AR screen (P4F:127;P6:85).

If people cannot really see much from the environment, they tend to think the environment is flat and not interesting, not much going on, they then tend to choose other routes or go to other places(P2F:44;P2F:52;P4F:49;P4F:54).

By contrary, if people are in a busy area, they assume there are a lot of “stuff” going on, and they don’t have to walk for long time (P4F:54). Even in a busy area, sometimes, the places looks further apart, so in that case people think they can’t really walk that much to go to these places (P4F:57).

Support users’ perception *System shall provide users with an overview of the surrounding area.* Users shall have an overview of the surrounding area with which they can have a better awareness of what is around (P2F:44;P2F:52;P4F:49;P4F:54;P4F:57).

code:perc_attend to screen

With using mobile AR, users tend to attend only on screen without paying much visual inspection on the surroundings (P2F:75;P3F:83;P4F:132). This has two implications. First, the information received from mobile AR has to be very accurate (e.g., the distance to the place), otherwise the user might be misperceived or misdirected by it (P5F:59), resulting in distrust of the tool. Second, people’s concerns of running into others limit the usage of the handheld mobile AR to sporadic usage. All participants do not want to constantly hold the phone in front of them all the time.

For example, it has been observed when Macados (a restaurant) is inside a mall, one participant found the restaurant was 30 meters away on mobile AR, then he entered into the mall and found the restaurant eventually. He entered into the building without noticing the sign of the restaurant right on the entrance outside the mall, where he passed (P2F:114).

When time pressure is a factor, one participant would scan around without using the app to see if there is any restaurants around. If there is not one that he is interested in, he would use the app to search for restaurants nearby (P6F:50).

Support users’ perception *System shall provide users search function within the mobile AR viewer* Users shall be able to search within the mobile AR viewer (P13:58). Rationale: To provide search activity

code: perc_position to other environmental objects

One participant raised the question that it’s difficult to tell that whether the 142-meter-away place is on the back of a Chinese store or not on the current mobile AR app (P5F:54).

code: perc_locate and orient oneself

The task of orientation can be problematic especially in a crowded and busy city scene where the participants are easily disoriented without strong orientation cues, such as landmarks and street signs available to them at the time, from either natural scenery or mobile navigation service support.

For location, participants use Google maps to see what places close by to tell what the streets are and where they run, with relation to whatever points that they’re trying to get to (P3:196;P4:243; P4:248;P5:260).

For orientation, the participant will look at Google Maps to find which road he is looking at (P5:269;P6:277). For example, the map shows the building next way, the participant has to pick one place to see if it shows to his left or right. In that direction, he would be able to orient himself (P6:277).

People make sense of the map by looking at the street layout, finding a good orientation point (such as an intersection, cross streets, shops), finding street signs (P4:243;P5:260), or finding “you’re here” marker on the map (P6:272).One would use map to pick a unique place nearby as a starting point. If he got lost, he would come back here and start again (P6:269).

In a digitized augmented reality context, the participant would like the tool to give him a broad sense of where he is in the city overall besides views from the local level (P5:263); one would use the map to get a sense in terms of locating himself (P6:272).

Support users' perception
System shall provide users a map view or map-like feature supplementing mobile AR view to provided an overview of what's around and other spatial information
Users shall be supported by a map (or map-like) feature (P3:196;P4:243; P4:248;P5:260;P5:47;P5F:44;P4:28;P5F:50;P4F:85).
Note: This requirement is important because location and orientation are important to exploring a place.
Extrapolation: Users shall be supported by a map interface that has good usability (P4:243;P5:260;P6:272).
Note: A map should have features like automatic locating and orienting, dropping pins, etc.

Some directly look at the signs (P1:271) or street names (P4:243) close by to tell what street they're on, buildings have numbers on them (P1:271).

Support users' perception
System shall provide users with a location and orientation option to show markup information about close by street information (signs, street names, building numbers), and landmarks on mobile AR view
Users shall be able to view signs, street names, building numbers close by if they are looking for location and orientation information (P1:271;P4:243).
Note: This requirement is important, because signs and street names help people locate and orient themselves.

Locating oneself could be tedious because one has to do that from time to time during an exploration (P4:247).

The more complex the area is, such as interception of three departures, the more difficult for someone to locate him/herself (P4:247).

Support users' perception
System shall provide users with a way to quickly check one's location and orientation on a simple interface(e.g., not a full map).
Users shall be able to have a way to quickly check location and orientation (P4:247).
Note: This requirement is important, because users have to check such information frequently during an exploration; and this may be intensified when the area is complex.

code: perc_sense of direction

According to the participant, direction refers to what the participant needs to go and the street he walks on (P3:225). When using mobile AR, many participants referred a restaurant to a direction, such as statement like Macodos is in this direction which pointed to that corresponding direction (P3F:53).

The participant relies on icons, landmarks, like the big building with huge neon letters, different colors (P4:252). The participant will refer to himself by the ABC mart, because it is a landmark to him (P4:255).

GPS to get the sense of direction (P2:226), sunlight and compass on the smartphone (P1:280) could be another option for one to identify direction.

In a digitized augmented reality context, the participant would like to have things like street signs pop-up to know where he is; or provide north east south west like walking in north on 77 street (P4:256).

code: perc_identify

If the participant can see the building with naked eyes and find it interesting, he will just walk to the place by taking a narrow street attracted to him and walk around to look at things. That would be a part of fun looking at it and exploring and figuring out what it is and see what's going on (P2:249;P6:285). If he is in doubt or cannot recognize the place, he will look for the sign or the name of the place and see if it's there (P2:232;P6:285). Even it's hidden inside a building, the participant will find the little tablet outside the building (P2:242).

Google maps gets one close to the place. Once close to the place, one uses the sign of the building (P1:285), or the name of the building (P5:28;P5:274) to identify the place. Specifically, people would use visual inspection to identify signage, such as company logo, and then connect the sign on mobile tool and the one in real life to realize where he is (P4:259;P5:276). Language would be very important in this case (P4:274;P5:277).

In a digitized augmented reality context, when approaching the place, like a block or two away, the participant would like to have a function to search within mobile AR to find the name of the pre-determined destination (P5:28;P5:283;P3F:58) or can be told to look to his left or right to find it (P5:283). In addition, they would like to scan for where the app shows the arrow to identify the place by its name or the direction to the place (P6:283;P5:283), so the place marker can pop up on the screen for people to follow (P1:289;291:298;P5:286).

Support users' perception

System shall provide users with image recognition feature to identify and show signs and names of the place that they are approaching to.

System shall provide users automatic image recognition feature to identify and show searched signs/place/object.

Users shall be supported by image recognition feature to identify and show signs, and names of the place that they are approaching to (P1:164;P2:232;P6:285; P2:242; P1:285; P5:28;P5:274;P5F:107;P5F:124).

The participant also wanted to have a way to have the ability to see storefronts, pictures, what it looks like from front door, or from one of the sides, both sides, something like Google Street View (P4:269). If you've seen storefront before or the sign or the company logo, when you're approaching it, you should recognize and match what you've seen before in real life (P4:269).

Another participant also commented that Google Street View could be helpful if they're more accurate and nicely marked (P5:276).

Support users' perception

System shall provide users with photorealistic street views or real time live stream of the place that they are interested in.

Users' need to see storefronts and what the store looks like from sides shall be supported by being provided with photorealistic street views or real time live stream of the place (P4:269; P5:276).

When one can see interesting buildings from far away, they want to go to see the buildings by choosing a decent path (P2:94) and avoid bad place to walk (P2:94).

Support users' perception

System shall provide users with a concept of adding places from mobile AR view directly with which they can add interested places from mobile AR view

Users shall be able to add a destination from mobile AR view directly when they find one or more are interesting (P2:94).

code: perc_noticing things in exploration

Some personal and cultural related places, such as Russian restaurants to an Russian, because people who are not aware of Russian language would not recognize it (P2:81); entrance to the subway station (P4:78), sign boards (P3:63), tourist instruction (P3:63). For example, in finding an entrance of a subway station, the participant helped his friend standing across streets looking for the entrance find the entrance at the end of the building, not downstairs (P4:78).

Support users' perception

System shall provide users with customizable interface with which users can customize and add personal and cultural related objects/places in exploring a place.

System shall provide markups of sign boards, tourists instruction marked for tourists places on mobile AR view.

Users' shall be able to customize and add personal and cultural related objects/places in exploring a place (P2:81).

Rationale: To provide personal experience

Extrapolation: users shall be able to have sign boards, tourists instruction marked on mobile AR view (P4:78;P3:63; P4:78).

code: perc_noticing ongoing events

The participant relies on newsletters or things like that for those kind of things to notify him beforehand (P4:81).

There are some random things that the participant has never expected. The participant might pick up something that others might not, because he said he tends to look around the stores and storefront for, for example, sales that he passes, unlike others who just focus on where they're going on the sidewalk (P5:101). For example, while the participant was walking, he saw a guy dressed up in giant cannoli advertising some local bakery. He thought it was interesting and completely out of no where, and his whole family enjoyed looking at it (P5:97). He said he always keeps an eye out while he was walking (P5:97). In times square, he also saw a homeless guy with a sign said need money for beer, pizza, and pod, who was thought a funny guy (P5:101). Another participant heard the sound of a small concert going on the other street right next to the one that they were walking on (P5:105).

Support users' perception

System shall provide users with information about the existing interesting events under going on street.

Users shall be made aware of the existing interesting events under going on street (P5:101).

code: perc_things standing out from the environment

mobile AR creates a feeling of places being densely packed than they're actually looked in the physical environment (P2:153).

The participant wouldn't want to sit down on a computer and go to Wikipedia to look up stuff, especially for the things that you think you've already known. However, mobile AR provides him a serendipitous experience of looking at these things (P5:193).

When one is on foot, not missing street is important, because he/she might have to walk a lot or not be able to find the place in the end (P6:197).

SA2: Comprehension

code: comp_acquire patterns

In making a decision, people compare places. They look for clusters first (P1:66; P1:75; P2F:58; P2F:104). For example, if they have two clusters, they would examine one cluster first, and then the second (P2F:58).

On mobile AR, one participant looked at the radar, which is a radar-like dot graph showing where are Points of Interest are, and found two clusters nearby. He would first walk his way to explore the first cluster by seeing the restaurant's appearance, insides of what's going on, and then decide. If he doesn't like anything from here, he would just walk to the second cluster and see what he's going to like there (P2F:104).

The reason why they want to look at the places himself, according the participant, there is too much overlays on mobile AR view (P2F:105). Once he's getting close to the cluster, he expected more spread out view of these places. Once he's inside the cluster, he would like to look around to see it's interesting or not by looking inside of the place. Things he's looking for include the place's looking, what kind of people there are, reviews, and what kind of music it's playing, etc.(P2F:105).

One participant looked at the Google map first before he went to the civil and national museum of history. On streets, he can see these places from far away, it's a cluster of museums. Although the participant couldn't identify which building is which, he can still go to the general direction and navigate to the cluster and then see the big signs for these tourists places once get close to that district (P1:66; P1:75).

In a familiar place, people have already built a mental model for that place, so they know where to go or where to find things (P1:66).

Support users' comprehension

System shall provide users with a cluster of items with number indicating the amount of items in that cluster as a whole at first to give users a general idea of how big the cluster is, and how far is the cluster of items for the user. After zooming into the cluster, smaller cluster should appear until the finest granular level of individual item shows up.

Users shall be supported with progressive disclosure on clusters of items (P1:66; P1:75).

Rationale: Progressive disclosure is useful when a great number of information should be presented to users.

Notes: users are struggling with recognizing places around him, so it should be good to mark each category with a number, such as 2 sites (P6F:65). In addition, users expressed that they are afraid of missing sites on the mobile AR view, since there are so many (P6F:65).

code: comp_acquire overview

When people need to find restaurants close by, they tend to use mobile tool to look at all restaurants, and then filter out the good restaurants from bad ones (P1F:59).

Participants looked at same type of restaurants on the mobile AR view (e.g., Italian restaurants) and wanted to see how close they are, before making a decision on where to go (P5F:130).

One participant zoomed out on the mobile AR view in an effort to see more "things" around from the "camera viewer" (P2F:89). He also would like a more spread-out view rather than clustered view to see "everything" with labels of the place's name, rating, the dollar sign, and how classy it is (P2F:165).

Support users' comprehension

System shall provide users spread out view of places.

Users shall have a way to view a spread out view of places on mobile AR view (P2F:89;P2F:165;P2F:86).

Note: Many user are willing to see the spread out view, rather than the stack view, because that saves their efforts to unfold the items one by one. Also, if one turns mobile AR slightly out of the current direction, when one returns, spread out view becomes stacked view again. It has been observed that frustrated the users.

System shall provide users with accurately tracked, registered and displayed augmented information

Extrapolation: Users shall be supported by accurately registered and tracked augmented markers on mobile AR screen (P2F:75; P2F:114P3F:83;P4F:132;P5F:59).

Rationale: To provide people a feel of “live feed view” as a more real-time experience to match their mental model of mobile AR

Extrapolation: categories shall also be provided

Rationale: To facilitate filtering and selecting processes

Support users’ comprehension

System shall provide users with direct manipulated interactive mobile AR interface (e.g., zooming, panning, and saving), similar to the interface of touch-screen based camera on smartphone, enabling users to interact with objects on the mobile AR viewer.

Users shall be able to interact with mobile AR interface as they do on touch-screen based camera on smartphone (P8:89;P5F:107;P5F:124).

Note: Users tend to have a connection between camera and mobile AR because the way they see it on the smartphone. Thereby, it’s important to utilize the analogy to design mobile AR in a manner in which assembles the interaction on the camera view, such as zooming, panning, and saving.

code: comp_quantify/estimate amount

One participant mentioned that finding the center of the downtown by looking at clusters is also desirable (P2F:103). He also needed to look at the places with his eyes, not entirely relying on the mobile AR tool (P2F:103).

Support users’ comprehension

System shall provide users with the number of objects/places that are of their interests

Users shall be able to have a way to know the amount of objects/places that are of their interests (P2F:103).

Rationale: To provide quantities and amounts for users to choose from

code: comp_discover order

From observation, most participants did not pick the top ratings, but set a criteria of ratings being higher than 4 stars. Then they compared 2 or 3 such places either in one category or in all categories, remembered them in their heart, and read more information (e.g., distance, reviews, menus) for further decision. When they read reviews, they only read 1 or 2 random or most recent reviews, disregarding most of the following reviews.

For example, one participant claimed he would pick the top 5 nearest places, and then look at their ratings, chose one with the highest rating, and then navigated to this particular place (P2F:70).

Support users’ comprehension

System shall provide users automatically ranked places in terms of distance from the user in ascending order.

Users shall be able to have automatically ranked places in terms of distance from the user in ascending order (P2F:70).

code: comp_acquire relations and comparisons

If the participant has multiple choices, to make a decision, distance to these places is the first criterion that he is looking for (P2F:180). Participants make decisions by comparing different distances of restaurants, such as one is closer to another one (P3F:64).

When the participant is not satisfied with the one he just found after knowing more information about it, or one simply cannot find the one that is in his mind, he tends to find some of the similar restaurants close by (P1F:109).

Support users' comprehension

System shall provide users with a concept of places comparing with which they can have a comparison page for easy compare 2 or 3 places

Users shall be able to have a way to quickly compare their interested places (P2F:70; P2F:180; P3F:64)

Rationale: To provide a mechanism to reduce users' short-term memory load when comparing

Extrapolation: Users shall be able to store/mark the places that are of their interests (P2F:70; P2F:180; P3F:64).

Participant wanted to quickly identify the type of the place (e.g., seafood, fast food restaurant)(P3F:75).

Support users' comprehension

System shall provide users with the type (category) of the place on mobile AR view

Users shall be able to quickly identify the type (category) of the place on mobile AR view (P3F:75).

Note: This is important because it provides users with the most essential information about objects on mobile AR view without making users click on each of them.

If people want to know a place's atmosphere, they tend to read through couple of reviews or just go to the place to see it (P3F:112).

Support users' comprehension

System shall provide users a way to peep into the atmosphere of the place (e.g., photorealistic inside views or real time live stream of the place) that they are interested in.

Users' need to see the atmosphere or inside view of places by being provided with photorealistic inside views or real time live stream of the place (P3F:112;P2F:67;P4:193).

APPENDIX V COGNITIVE WALKTHROUGH ON WIKITUDE INTERFACE

Target group user characteristics:

It is envisaged that the mobile AR will be used by users aged 18-49 having the following user characteristics:

1) have owned and used a Smartphone for at least six months;
2) conduct leisure activities (e.g., searching for attractions, restaurants, etc.) when they are in an unfamiliar place;
3) consider technology as necessary in their daily lives.
4) Have light to medium previous experience on mobile AR smartphone application;

Average:

5) Spatial ability;
6) Personality;
7) Memory;
8) Verbal ability.

Initial goals of the user:

To explore the surrounding area in an unfamiliar place;

To make decisions on which places to go *or* what things to do on site;

To explore and make decisions in a timely manner;

Tasks to be analyzed

The user has to use the mobile AR app provided to 1) free explore the surrounding area and check out the information about one particular place; 2) find some souvenirs for his or her friend; 3) find out if it's worth coming back to an area to discover the night life nearby at night; and 4) decide if he/she should go to a place to eat.

Tasks action sequence

1. Looking for tourists attractions

1.1.1. View on mobile AR: View all places and look for details for interested places in the mobile AR view

1.1.1.1.1. (Tap Travel)
1.1.1.1.2. Tap Sights
1.1.1.1.3. Rotate the phone around to reveal details
1.1.1.1.4. Tap on a stack of objects on mobile AR viewer
1.1.1.1.5. Tap on More
1.1.1.1.6. Tap on one of the objects on mobile AR viewer
1.1.1.1.7. Browse the information box about the place
1.1.1.1.8. Tap on read more
1.1.1.1.9. Visit the website
1.1.1.1.10. Tap on Back

1.1.2. Adjust the distance: Adjust the distance of surrounding area

1.1.2.1.1. Tap on the radar
1.1.2.1.2. Adjust the slide bar to a smaller distance
1.1.2.1.3. Tapping anywhere outside the information box or the close button to escape

1.1.3. View on map: View all places on the map view and look for details for interested places in the map view
1.1.3.1.1. Tap on Map view button
1.1.3.1.2. Zoom in on the map view
1.1.3.1.3. Tap on one of the objects on map view

1.1.4. View on list view: View all places on the list view and find one is interested and opened on the mobile AR viewer before
1.1.4.1.1. Tap on List view button
1.1.4.1.2. Scroll down the list
1.1.4.1.3. Tap on the one that is opened on the mobile AR viewer before

1.1.5. Navigation to the place: Find one place is of particular interest in the mobile AR viewer and find its particular location
1.1.5.1.1. Tap on the Camera view
1.1.5.1.2. Tap on one of the objects on the mobile AR viewer
1.1.5.1.3. Tap on Map view
1.1.5.1.4. Tap on the one of the objects on the map view
1.1.5.1.5. Tap on the information box
1.1.5.1.6. Tap on the Route button
1.1.5.1.7. Tap on Open
1.1.5.1.8. <Goes to the third party Maps>
1.1.5.1.9. (or Tap on the List view
1.1.5.1.10. Tap on the one of the objects on the list view)

2. *Looking for restaurants*

2.1.1. View on mobile AR: View all places and look for details for interested places in the mobile AR view
2.1.1.1.1. Find restaurants
2.1.1.1.2. Tap restaurants
2.1.1.1.3. Rotate the phone around to reveal details
2.1.1.1.4. Tap on a stack of objects on mobile AR viewer
2.1.1.1.5. Tap on More
2.1.1.1.6. Tap on one of the objects on mobile AR viewer
2.1.1.1.7. Browse the information box about the place
2.1.1.1.8. Tap on read more
2.1.1.1.9. Visit the website
2.1.1.1.10. Tap on Back

2.1.2. Adjust the distance: Adjust the distance of surrounding area
2.1.2.1.1. Tap on the radar
2.1.2.1.2. Adjust the slide bar to a smaller distance
2.1.2.1.3. Tapping anywhere outside the information box or the close button to escape

2.1.3. View on map: View all places on the map view and look for details for interested places in the map view
2.1.3.1.1. Tap on Map view button
2.1.3.1.2. Zoom in on the map view
2.1.3.1.3. Tap on one of the objects on map view

2.1.4. View on list view: View all places on the list view and find one is interested and opened on the mobile AR viewer before
 2.1.4.1.1. Tap on List view button
 2.1.4.1.2. Scroll down the list
 2.1.4.1.3. Tap on the one that is opened on the mobile AR viewer before

2.1.5. Navigation to the place: Find one place is of particular interest in the mobile AR viewer and find its particular location
 2.1.5.1.1. Tap on the Camera view
 2.1.5.1.2. Rotate the phone around to reveal details
 2.1.5.1.3. Tap on a stack of objects on mobile AR viewer
 2.1.5.1.4. Tap on More
 2.1.5.1.5. Tap on address
 2.1.5.1.6. Tap on Open

3. *Looking for events*

3.1.1. View on mobile AR: View all places and look for details for interested places in the mobile AR view
 3.1.1.1.1. Find events
 3.1.1.1.2. Tap events
 3.1.1.1.3. Rotate the phone around to reveal details
 3.1.1.1.4. Tap on a stack of objects on mobile AR viewer
 3.1.1.1.5. Tap on More
 3.1.1.1.6. Tap on one of the objects on mobile AR viewer
 3.1.1.1.7. Browse the information box about the place
 3.1.1.1.8. Tap on read more
 3.1.1.1.9. Visit the website
 3.1.1.1.10. Tap on Back

3.1.2. Adjust the distance: Adjust the distance of surrounding area
 3.1.2.1.1. Tap on the radar
 3.1.2.1.2. Adjust the slide bar to a smaller distance
 3.1.2.1.3. Tapping anywhere outside the information box or the close button to escape

3.1.3. View on map: View all places on the map view and look for details for interested places in the map view
 3.1.3.1.1. Tap on Map view button
 3.1.3.1.2. Zoom in on the map view
 3.1.3.1.3. Tap on one of the objects on map view

3.1.4. View on list view: View all places on the list view and find one is interested and opened on the mobile AR viewer before
 3.1.4.1.1. Tap on List view button
 3.1.4.1.2. Scroll down the list
 3.1.4.1.3. Tap on the one that is opened on the mobile AR viewer before

3.1.5. Navigation to the place: Find one place is of particular interest in the mobile AR viewer and find its particular location
 3.1.5.1.1. Tap on the Camera view
 3.1.5.1.2. Rotate the phone around to reveal details
 3.1.5.1.3. Tap on a stack of objects on mobile AR viewer

3.1.5.1.4. Tap on More
3.1.5.1.5. Tap on address
3.1.5.1.6. Tap on Open

Basic scenario provided to participants

Now imagine this is your first time traveling abroad and it's your first time coming to Tokyo. You stay at a place in a central business district, one of the busiest and crowded blocks where most foreigners go for attractions, museums, parks, entertainment, shops, or simply hanging out experiencing the exotic culture. Now you just came out of Shinjuku station by yourself and you have 3 hours to spend before you meet up with one of your friends. Since you came here right after your semester finished, you've only been able to do a little research before you're on the spot. You know Shinjuku is large entertainment, business and shopping district around Shinjuku Station. Since that you don't know too much on where to go or what to do, you are excited to explore this place. At this moment, ….

Scenario 1

You don't have anything planed out yet, but you know this is a busy area so you can find something to do after you come here. You decided to explore it and discover some popular places nearby, like sights, museums, parks, arts, shops, and bars. You have to decide where you want to go and what you want to do now.

Scenario 2

Along with your walk, you want to find some souvenirs for your friends.

Scenario 3

Now you need some information to help you decide whether it's worth coming back to this district to discover the nightlife nearby, like clubs, shows, theaters, etc.

Scenario 4

Now let's imagine it's 6:30PM. It's the last night before you're leaving Tokyo. You and your friend want to go to a very popular local restaurant selling authentic local food, called Tai, that you heard before you came here. Then you plan to go to watch a local show after meal. So it seems you only have 1 hour to eat. It's not far away from this station. But you're afraid of not be able to catch the show if you take too long in eating, so you're deciding whether you should go to this place to eat or maybe just find some other places.

COGNITIVE WALKTHOUGH FOR A STEP

Task: Action:

1. Goal structure for this step.
   1.1. **Correct goals.** What are the appropriate goals for this point in the interaction?

   1.2. **Mismatch with likely goals.** Will the user have this goal?
   If not, what percentage of users might have trouble? (%0 25 50 75 100)
2. Choosing and executing the action.
   2.1. **Availability.** Is it obvious that the correct action is a possible choice here?
   If not, what percentage of users might have trouble? (%0 25 50 75 100)

   2.2. **Label.** What label or description is associated with the correct action?

   2.3. **Link of label to action.** If there is a label or description associated with the correct action, is it obvious, and is it clearly linked with this action? If not, what percentage of users might have trouble? (%0 25 50 75 100)

   2.4. **Link of label to goal.** If there is a label or description associated with the correct action, is it obviously connected with one of the current goals for this step? How? If not, what percentage of users might have trouble? (%0 25 50 75 100)

   2.5. **No label.** If there is no label associated with the correct action, how will users relate this action to a current goal? If not, what percentage of users might have trouble? (%0 25 50 75 100)

   2.6. **Wrong choices.** Are there other actions that might seem appropriate to some current goal? If so, what are they, and what percentage of users might choose one of these? (%0 25 50 75 100)

   2.7. **Time-out.** If there a time-out in the interface at this step does it allow time for the user to select the appropriate action? If not, what percentage of users might have trouble? (%0 25 50 75 100)

   2.8. **Hard to do.** Is there anything physically tricky about executing the action? If so, what percentage of users might have trouble? (%0 25 50 75 100)

3. Modification of goal structure.
   3.1. **Quit or backup.** Will users see that they have made progress toward some current goal? What will indicate this to them? What percentage of users will not see progress and try to quit or backup? (%0 25 50 75 100)

   3.2. **Accomplished goals.** List all current goals that have been accomplished. Is it obvious from the system response that each has been accomplished? If not, indicate for each how many users will not realize it is complete.

   3.3. **Incomplete goals that look accomplished.** Are there any current goals that have not been accomplished, but might appear to have been based on the system response? What might indicate this? List any such goals and the percentage of users will think that they have actually been accomplished. (%0 25 50 75 100)

   3.4. **"And-then" structures.** Is there an "and-then" structure, and does one of its subgoals appear to be complete? If the subgoal is similar to the supergoal, estimate how may users may prematurely terminate the "and-then" structure.

3.5. **New goals in response to prompts.** Does the system response contain a prompt cue that suggests any new goals or goals? If so, describe the goals. If the prompt is unclear, indicate the percentage of users who will not form these goals. (%0 25 50 75 100)

3.6. **Other new goals.** Are there any other new goals that users will from given their current goals, the state of the interface, and their background knowledge? Why? If so, describe the goals, and indicate how many users will form them. NOTE that these goals may or may not be appropriate, so forming them may be bad or good.

COGNITIVE WALKTHROUGH - PROBLEM DESCRIPTION

Problem no.: Kind of problem:

Brief description of the problem:

How did you find this problem?

What **percentage** of users might have trouble?

0 100%

How did you estimate this percentage?

How **frequently** will users encounter this problem?

rarely constantly

How did you estimate frequency?

What is the problems **severity**?

trivial moderate serious critical

How did you estimate severity?

Other comment s (design suggestion, improvement of the method for multimedia…):

APPENDIX W SA QUERIES AND QUERY VARIANTS

Information Process	User Req no.	Query	Query Variant 1	Query Variant 2	Revised query (based on designed interface)	Query Variant
Perception	4	Enter your location at this point (on the provided map).	Use an arrow to indicate the direction that you are facing to (on the provided map).		Enter the location of yourself at this point (on the provided map).	
	5	Enter the number of POIs <in this category> in your visual field at this point of time.		Choose the category of <this building> (restaurant, attraction, event) (pointed by the researcher)		
		Enter the number of POIs <in this category> that you can reach taking this street.			Enter the number of POIs <in the category of restaurants> that you can reach taking <this street> Hudson St.	
		Enter the number of POIs that are within 10 mins of walking.	Enter the number of POIs that are within 5 mins of walking.	Enter the number of POIs in the category of <xx> within 5 mins walking		
	8	Enter the name of the street(s) that you are on at this point of time (A, B, C).			Enter the name of the street(s) that you are on at this point of time (A, B, C).	
		Enter the name of the **store** (or company) in the direction that you're facing to (A, B, C)			Enter the name of the store (or company) in the direction that you're facing to (A, B, C)	

	Enter the name of the landmark in the direction that you're facing to (A, B, C)			Enter the name of the landmark in the direction that you're facing to (A, B, C)
	Enter the location of yourself (on the provided map)			
	What is the direction of destination at this point of time?	Which direction is your destination at at this point of time?	Indicate the direction of the destination (on the provided map) at this point of time.	Indicate the direction of the destination (on the provided map) at this point of time.
	What is the distance to destination at this point of time?	Enter the POI distance (1 mile, 2 miles, 5 miles)		Enter the POI distance (1 mile, 2 miles, 5 miles)
	What is the estimated time to destination from here?	Enter the time to get to the POI (0-10 mins, 10-20 mins, 20-30 mins)		Enter the time to get to the POI (0-10 mins, 10-20 mins, 20-30 mins)
	Where is(are) the destination(s) located?	Enter the location of destination(s)(on the provided map)		Enter the location of destination(s)(on the provided map)
9	Enter the position of this visual landmark (on the provided map) to you after you walk about 5 mins down to this street.	Enter the name of <this visual landmark>.		
10	Enter the position of this cognitive landmark (on the provided map) to you after you walk 10 mins on this street.	Enter the name of <this cognitive landmark>.		

Comprehension	27	Enter the number of POIs in your vicinity.	Enter the number of POIs in your vicinity and in this direction.	Enter the number of POIs <in the category of restaurants> that are within 10 mins of walking.	Enter the number of Restaurants within 10 mins walking distance in the direction that you're facing.
	29	Enter the number of POIs <in this category> in your vicinity.	Enter the number of POIs <in this category> in your vicinity and in this direction.		
	31	Find the POI <in this category> with the second shortest distance to you. Enter the distance (within 1 mile, 2 miles, 5 miles)	Find the POI <in this category> with the highest rating. Enter the rating (3 starts, 4 starts, 5 stars)	Find the restaurant with the second shortest distance to you. Enter the distance (within 1 mile, 2 miles, 5 miles)	Find the restaurant with the highest rating. Enter the rating (3 starts, 4 starts, 5 stars
	32	Find one <XX in this category> with music performance. Enter its distance to you.		Find the Italian restaurant with music performance. Enter its distance to you.	
	39	Enter the number of POIs that have the same rating with <this one> <in the same category>.		Enter the number of restaurants that have the same rating with <this one> <in the same category>.	
		Enter the number of paths available to the destination.	Find the shortest path. Enter the number of POIs on the shortest path.	Enter the number of paths available to the destination.	Find the shortest path. Enter the number of POIs on the shortest path.
	40	Enter the distance to the destination that are within the same <property>.	Enter the number of POIs that are <in this type> within <10 min>s walking from here.	Find the restaurant with the same rating with the one you find. Enter the distance from you.	

	41	To what extent do you think you are aware of the current location?	To what extent do you think you are aware of the destination?		To what extent do you think you are aware of the current location?	To what extent do you think you are aware of the property of the destination?
Projection	8	Enter the approximate location of where you will get after you walk 5 mins in this direction (on the provided map).	Enter the approximate location of where you will get after you walk 5 mins to the destination on this path (on the provided map).		Enter the approximate location of where you will get after you walk 5 mins in this direction (on the provided map).	Enter the approximate location of where you will get after you walk 5 mins to the destination on this path (on the provided map).
	47	To what extent do you think you are aware of what's going on in the event right now?	To what extent do you think you are aware of what's going on (such as line/waiting situation, availability) in the destination right now?		To what extent do you think you are aware of what's going on in your surroundings right now?	To what extent do you think you are aware of what's going on (such as line/waiting situation, availability) in the destination right now?

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