Visualising Location-Based Information using Augmented Reality

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Abstract

The use of augmented reality extends navigation in location-based mobile applications. This thesis introduces the concept of *narrative navigation* and describes the design and testing of four mobile application prototypes that explore the proof-of-concept for narrative navigation.

We explored the work related to Augmented Reality and navigation and found that no scholars have focused on the use of Augmented Reality by navigating users in the context of location-based stories. This thesis aims to answer the research question of how Augmented Reality visualisations can reflect location-based data to tell a story on mobile devices. While typical navigation only involves guidance to a single point, narrative navigation requires navigation that focuses on the linearity of the story. The goal of our research is to investigate how augmented reality can be used to visualize location-based information for navigation in a storytelling environment.

We carried out the design, development, and testing of the Initial Digital Prototype, exploring the use of Augmented Reality technology to display the Point of Interest (POI) position, direction, distance, and story chapter order, and guide users to the next location in the story. In the subsequent Paper Prototype, we explored four navigation visualisations, showing the next story element through stylized flags of varying heights. We found that showing the next story location nearer to the bottom of the screen was the most successful way to guide users, but also found that many participants preferred to show location order by distance. In the Narrative Navigation Prototype, further POI design options are explored. We improved details such as size, quantity, description and the spacing of POIs, the camera tilt display, and the use of indicator arrows. In the Final Prototype, the concept of narrative navigation was confirmed by the positive evaluation of participants and confirmation of user interactions provided by our behavioural tracking maps that were used to observe participant movements and prototype interactions.

The thesis contributions include four insights into the concept of narrative navigation. The first is the use of augmented reality to visualise location-based stories on mobile phones; the second is to highlight the importance of showing the next location in the story sequence, which has been almost absent in related work. Removing visited story chapters will facilitate navigation and narrative ordering; and finally, the use of directional indicators that guide the small phone screen to connect to the real world.

We have shown that narrative navigation is a promising concept that can expand application scenarios based on location information.

Dedicated to my grandfather (Dawei Zhang), whose 103 years of life experience encouraged my continuous pursuit of change.

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Chapter 1 Introduction

Augmented Reality uses visual objects (for example, photos, 3D models, animations, and video) to link the virtual world and the real world. Unlike Virtual Reality, Augmented Reality (AR) does not require specialist equipment. The user can explore their surroundings through their mobile phone’s camera, with the live view shown on their screen overlaid with AR objects. AR has been increasingly explored in the context of information visualisation, most notably in augmenting information presented in books (e.g., Pasaréti et al., 2011). By augmenting story narratives, illustrations, and interactive content, authors, publishers and designers aim to immerse the reader in the content of the story through use of AR. Augmented reality technology may provide users with additional spatial awareness, and further contextual information that goes beyond the offerings of storytelling traditionally presented in books and other print media (MacIntyre et al., 2001).

Augmented Reality has also been used in other contexts, including location-based information, such as architecture and guided tours (Fritsch et al., 2001; Höllerer et al., 1999; Morrison et al., 2009). Mobile AR (MAR) applications combined with geographic location are becoming more popular because users can easily access various geographic location services and other information according to their geographic location (Aurelia et al., 2014). Augmented reality can be used also as an information visualisation tool by connecting visual information and the physical address to meet the user's requirements for real-time and convenience of information acquisition (Bhorkar, 2017). For example, with augmented reality technology, the user who is travelling somewhere can obtain information surrounding their location through the mobile application, using various types of location-based services, such as ‘Live View’ function in the Google Maps application, virtual information such as nearby restaurants, car rentals, and local attractions are superimposed on the real scene displayed on the mobile device screen.

Location-based services (LBS) use location-based data and present information to mobile devices. Currently, location-based service is offered for the fields of games, retail, and tour guides (Hinze & Bainbridge, 2012; Kolodziej & Hjelm, 2006). When a participant arrives in a location, they are provided with the relevant information.

1.1 Research Focus

In this thesis, we are interested in using Augmented Reality (AR) in both the context of story presentation and location-based services, to focus on visualising location-based story narration. We will discuss each aspect of the research focus here.

Many apps have been developed that include narration and location-based Points of Interest (POI), typically without AR. Hinze and Bainbridge (2012) developed a system called "Tipple" that provides audio instructions and navigation directions to visitors in specific geographic locations. The system combines audio and GPS as a trigger to introduce information about relevant points of interest. However, some participants had difficulty interacting with the system because they expected it to more clearly show significant locations and provide routing directions. Motivated to provide such navigation support, we research options to add interactivity to a location-based story.

Augmented Reality has only recently begun to be used to enhance location-based media. We hypothesise that AR and location-based technology could be used to create new storytelling experiences. Navigation has two meanings in this context, one being the navigation of the story content, and the other being the navigation of the user to the right place. One aspect of this study investigation involves connecting AR navigation to location-based storytelling. Navigation guides users to go to their destination step-by-step. Typical navigation involves guidance to a single point only – *narrative navigation* requires navigation that respects the linearity of the story.

Traditionally, narrative navigation belongs to the category of narratology, which refers to the navigation of narrative consumption under various cross-media (Feiereisen et al., 2019; Feiereisen et al., 2020). In our research, we define *narrative navigation* as navigating users to geo-locations along a (linear) storyline using augmented reality visualisation. Narrative navigation focuses on both narrative content order and location-based story chapter navigation.

In this thesis, we argue that narrative navigation can be created by combining AR technology in conjunction with GPS information to guide users to visit points of interest (POI) based on the story content. The goal of my PhD investigation is to research *how to use Augmented Reality to visualise location-based information for navigation in a storytelling context*.

1.2 Background

In this section, we define the most important terms used in our research (location-based service, storytelling, and AR), along with exploring the general background of the area of study that PhD investigation engages with.

1.2.1 Location-Based Service

Location is a representation of the abstraction of a physical location. It is primarily concerned with spatial relationships on the surface of the Earth. From the perspective of the relationship between positions, location can be divided into absolute position and relative position. Location-based data comprise a set of specific and unique data sets that describe this relationship, including latitude and longitude, direction, time to record the location, usage of the device, and user's personal information.

A location-based service (LBS) is a service based on location-based data that meets users' geographic location requirements. Location-based services often provide location-based information, such as tourism information (Hinze & Voisard, 2003; Kolodziej & Hjelm, 2006) or stories (Paay et al., 2008) to their users.

LBS information acquisition can be divided into *triggered* push and *user-requested* acquisition (D'Roza & Bilchev, 2003). In the trigger mode, such as advertising push, when a user reaches a specific location, the relevant advertisement is automatically pushed based on the location. By contrast, in the user-requested mode, such as a navigation map, information is requested by the user depending on their location.

Some of the same vital terms exist in the field of location-based service, GIS and geo-informatics research (Jiang & Yao, 2006). Location-based services are mainly used by users to obtain or push the required geographic information service from mobile devices via the Internet or a mobile network. The primary user of the LBS application is a mobile user whose location changes frequently. Location-aware computing refers to real-time computing of physical user location, while context-aware services focus on location-based contextual information (Jiang & Yao, 2006).

Positioning technology plays an essential role in LBS. Depending on the indoor LBS and outdoor LBS applications, the services are divided between Global positioning system (GPS), A-GPS (Assisted GPS), GSM cellular location, RFID, iBeacon, Wi-Fi, NFC (Near Field Communication), UWB (Ultra-wideband) (Burigat & Chittaro, 2005).

POI refers to geographic objects that can be represented by points and includes the information of longitude and latitude. POI data is a fundamental concept of LBS applications (Zhu & Zhou, 2009). Many AR applications in LBS are using POI to deliver information to their users.

POI are sometimes accompanied by geographic information, such as posting a photo with a location on Instagram, sending a tweet or Facebook with a Google Map location (Hochmair et al., 2018). For example, the Hamilton Gardens Application links the history and design of LBS, POI and themed gardens. LBS connects the real-time location of the GPS and this map in the Application (see Figure 1.1 left). For example, when the user arrives at a POI (Indian Char Bagh Garden), the application will pop up information about the garden (see Figure 1.1 right).

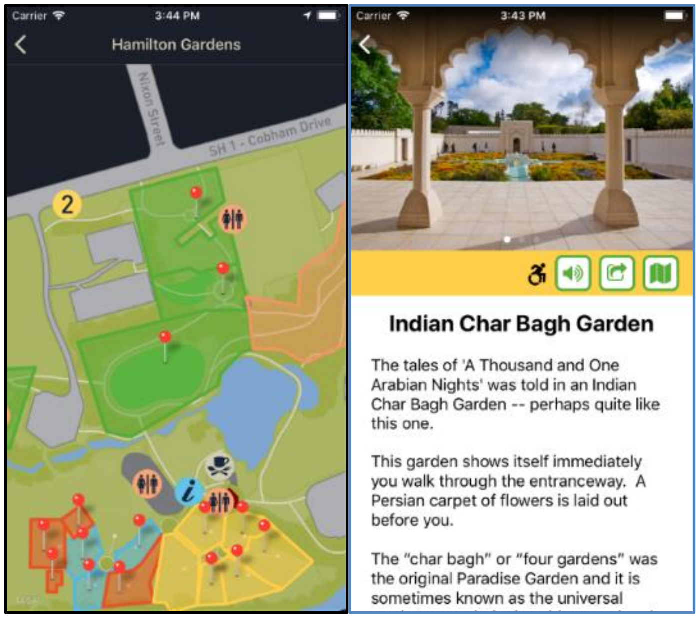


Figure 1. 1 Map and POI of Hamilton Garden Application (left) and the information of Indian Garden (right). From Hamilton Gardens App, by University of Waikato, n.d. (https://isdb.cms.waikato.ac.nz/research-projects/tipple-project/hamilton-gardens). Copyright n.d. by University of Waikato.

However, during the process of exploring location-based stories, we identified some key limitations: such as the lack of data to visualise location-based stories, the difficulty of connecting location-based data and user location, and the use of POI that have almost no interaction with story, etc.

Our thesis relates to LBS, to explore location-based data visualisation methods. One of our research focuses is also LBS when they refer to tools that determine and guide the user when realizing AR visualisations.

1.2.2 Storytelling

The concept of "storytelling" has long existed and is widely used in different fields and people's daily lives. Oxford dictionaries define storytelling as an activity of telling or writing stories (Simpson & Weiner, 1989). Storytelling can make abstract and complex knowledge simple and easy to understand. It is one of the oldest methods of information communication and learning to provide a way to express a narrative to an audience (Mello, 2001). The inheritance of many ancient cultures is realised through storytelling. Storytelling has communication characteristics and is also a method of teaching and learning (Meyer & Bogdan, 2001).

Storytelling is an effective communication technique in that it offers a certain order and logical relationship, and often includes visual information such as text, images, sounds, and videos in the storytelling process. Soleymani et al. (2017) identifies storytelling as including live readings of poetry or prose stories, and being presented to audiences in the form of dramas and operas. Baldwin and Ching (2017) argued that storytelling has three features: dynamic presentation, data visualisation and multi-sensory aspects. The purpose of the dynamic presentation is to attract the attention of the audience and present them with visual pleasure. Data visualisation uses statistical graphics and information graphics to help people understand complex data and abstract concepts, while multiple senses provide visual, auditory, motion, and tactile perception of corresponding information.

Different target users need to use different ways of storytelling. For instance, the use of storytelling techniques in theme parks and museums is the most direct way to engage children and students in educational content such as scientific knowledge and to provide a pleasant and interactive experience. (Garzotto et al., 2010). A narrative approach may provide more understanding, interest and participation, and it can lead the typical participants to get the most scientific information through the multimedia content (Dahlstrom, 2014).

Storytelling not only has a place in face-to-face encounters but also in digital media. Location-based services can be tools for conveying stories to their users (Hinze & Bainbridge, 2012; Hinze & Voisard, 2003). Kosara and Mackinlay (2013) argue that data visualization can also serve as a communication tool for storytelling when the stories told contain large amounts of data.

The thesis engages the significance of LBS when exploring AR data visualisation for location-based stories. The inspiration for our research came from popup story books that tell a location-based story. We discuss the case use of a pop-up book called POP-UP China (Lau, 2010). The book tells the stories about geolocation landmarks including the Great Wall, Terracotta Warriors, Armillary Sphere, Dunhuang Grottoes, the Forbidden City, and Bird’s Nest National Stadium.

Figure 1. 2 POP-UP CHINA and 3D Paper artworks from the book. Photograph by Qimo Zhang.

The pop-up book includes more than 450 small parts, and has a strong visual impact for the reader. The book combines storytelling and location-based data, and the reader can enjoy the information related to locations, even 3D paper art (3D paper sculpture).

The book produces miniature displays of the real scenes, delivering readers a sense of presence, such that readers can enjoy a three-dimensional paper scene without visiting the landmark. The pictures and texts of each chapter assist the reader in understanding the story related to the scene. However, despite the e-book being visually appealing and providing location information, it does not allow the reader to interact with the locations from which the story emerges. The book introduces a story that includes location information rather than a location-based story. In turn, the thesis examines how to present similar location information through a technology-based solution that is sensitive to the user's location.

1.2.3 Augmented Reality

Augmented reality was first defined by researchers in the fields of computer science by Milgram et al. (1994), who pioneered the definition of AR, describing the concept as "augmenting natural feedback to the operator with simulated cues" (p. 283), with a narrower definition "a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world". Klopfer (2008) extends the definition of AR to include any field that blends virtual information with real-world environments. In a subsequent paper, Klopfer and Squire (2008) defined AR as "a situation in which a real-world context is dynamically overlaid with coherent location or context-sensitive virtual information" (p.205). Moreover, in another subsequent article, Klopfer and Sheldon (2010) proposed that AR can offer a technology-mediated feature that combines real and virtual environment content.

Unlike virtual reality (VR), AR uses a partial virtual environment instead of a purely virtual environment with VR (Azuma, 1997). Milgram et al. (1994) proposed the concept of the Reality-Virtuality continuum and provide a framework for the four concepts that exist in the transition between a real environment and a virtual environment (see Figure 1.3).

In the concept of this continuum, mixed reality is a general term for four different situations. In addition to the well-known real environment and virtual environment, AR includes real-world and virtual worlds superimposed on the real world, while including more real environments than virtual environments. Augmented Virtuality also includes real and virtual environments, while including more virtuality environments than real environments (Wu et al., 2013).

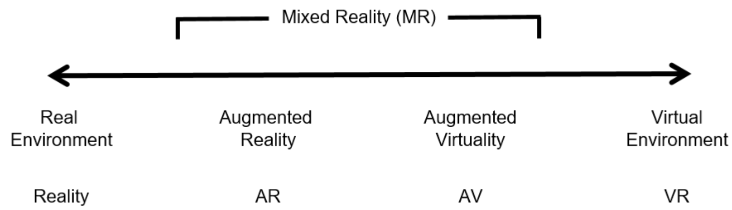


Figure 1. 3 Virtuality continuum. From "A taxonomy of mixed reality visual displays," by P. Milgram, and F. Kishino, 1994, IEICE TRANSACTIONS on Information and Systems, 77(12), p.1322. Copyright (c)1994 IEICE, Reprinted with permission.

Augmented Reality combines real and virtual objects. Figure 1.4 represents an augmented reality system: the camera captures the video of the real scene and merges the virtual objects in the augmented reality application to show the effect of augmented reality.

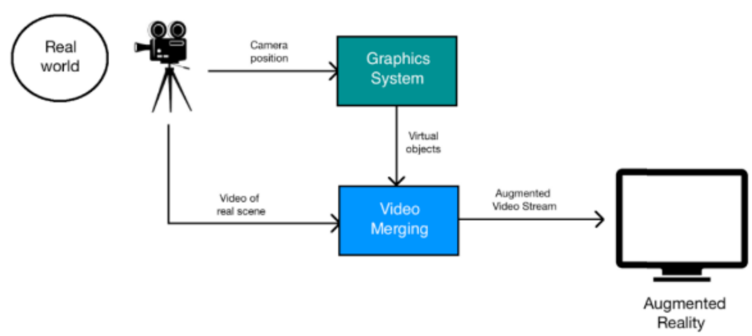


Figure 1. 4 Description of AR System. From "The Use of Augmented Reality Technology for Primary School Education in Perlis, Malaysia," by I.N.M. Bistaman, Journal of Physics: Conference Series, 1019(2018), p.4 https://doi.org/10.1088/1742-6596/1019/1/012064. CC BY 3.0 DEED.

Mobile augmented reality extends the location restrictions of augmented reality applications, combining mobile communication technologies, LBS and improves user visualisation and interaction based on AR (Swan et al., 2017).

1.2.3.1 Augmented Reality Mechanisms

Augmented reality tracking technology and display technology are important elements of AR implementation. Below we will introduce typical methods for augmented reality tracking and display.

Augmented Reality Tracking Methods

The tracking method is the most significant element of augmented reality. Markers used for AR recognition are elements that differentiate them from other objects present, such as natural texture pictures, QR codes. Therefore, computer vision methods are suitable for identifying markers. Marker-based and marker-less are the two main vision-based tracking methods suitable for augmented reality.

Marker-based tracking is based on image descriptors such as QR code, enabling virtual objects to be superimposed on the marker's position when the marker is scanned by the camera of the AR software equipped device. Maker-less tracks natural images and solves the problem of visual interference of the QR code on original images.

Augmented Reality Display Method

The display method of AR involves a variety of display possibilities, including Head Mounted Display (HMD), such as AR glasses, Non-HMD., which includes Handheld Displays (HHD), such as a mobile phone, and spatial displays and PC displays (Lim & Park, 2011). An example of an HMD is the HoloLens system from Microsoft, which is a high-resolution display that includes support for gestures, gaze and voice recognition, and object control. Currently, HHD are gaining popularity when using AR displays.

In this investigation, the focus is predominantly on mobile AR using HHDs to support LBS.

Azuma (1997) mentions three characteristics of the AR system: the combination of the real environment and virtual objects, real-time content interactions, and virtual object and real object 3D overlay registration. When combining reality with virtual reality, the real environment and virtual objects (information or animation) can be seen simultaneously on the display device. Real-time interaction means that the reader can interact with the virtual objects displayed in the AR system. For example, a reader interacts with the 3D animation of the book and touches the virtual button to play the video or game interaction.

1.2.3.2 Visualisation using Augmented Reality

Data visualisation is one of the important applications of AR. Augmented Reality data visualisation can superimpose virtual data onto the real-world environment to enhance users' on-site experience.

Next, we introduce the use case of the Centennial of Changes of Victoria Harbour in Hong Kong, see Figure 1.5 (Lau, 2015). Victoria Harbour is a famous landmark in Hong Kong, and all locals and foreign tourists who come here want to access location-based information and the harbour's history. This book uses AR technology to visualise location-based stories (information).

Figure 1. 5 The book, Hong Kong: A Centennial of Change. Photography by Qimo Zhang.

This book included a large amount of location data (in difference to location-based or geo-located data), with its AR effects being available on ten double-pages; the book displaying the significant events at that time, such as Hong Kong's return to Chinese sovereignty in 1997 (see Figure 1.6).

Figure 1. 6 AR effect illustrating Hong Kong's return to Chinese Government in 1997. Photography by Qimo Zhang.

As shown in Figure 1.6, when the reader uses the camera of the mobile application to face the left page, the mobile phone screen will display the 3D model of the building, the animation of the national flag rising and fireworks.

There are two special scenarios introduced, one is the 1962 typhoon simulation, "Wanda" was one of the strongest and deadliest typhoons to hit Hong Kong after World War II, killing 183 people and injuring 388. Figure 1.7 shows the damage to Victoria Harbour by Typhoon Wanda in 1962.

Figure 1. 7 AR effect of the typhoon Wanda in 1962. Photography by Qimo Zhang.

Another scene is captured by an animation that simulates the reader standing on top of Victoria Peak, overlooking the skyscrapers around the Victoria Harbour coastline where they rise from the ground.

Figure 1. 8 The AR effect of the skyscrapers rise up from the ground. Photography by Qimo Zhang.

In summary, the book focuses on AR storytelling, using the "digital pop-up" concept, the 3D model and animation to tell a story. The book uses AR elements to reproduce the real scene of Victoria Harbour.

If GPS functionality were added to the App, it could provide readers with a more interactive experience when they are on location. The thesis is concerned with applications that provide such location-based information, with the underlying intention being to provide more interactive engagement with stories.

1.2.3.3 Augmented Reality Narrative Method

Augmented reality immersive narrative is different from their experience of other digital media. Viana and Nakamura (2014) argued that the digital narrative of augmented reality games is an immersive system based on the third-person perspective, which is different from the first-person perspective of most digital games. They further proposed introducing the concept of augmented space into augmented reality games to create a narrative that interacts with physical space and three-dimensional space. Haahr (2017) has mentioned that locative games such as Pokémon GO use a sandbox narrative method without any inherent plot, and are not suitable for such location-based AR games with a certain time length and specific chapter content.

We noticed that the augmented reality narrative method studied in this thesis is different from the standard narrative method. On the basis of using the third-person perspective to participate, our narrative method needs to adopt a method different from the sandbox narrative, and follow the order of the story chapter content to narrate.

1.3 Structure of the Thesis

The thesis is structured as follows: Chapter 2 presents the related work on AR picture books, AR map/atlas, location-based augmentation, AR supported data visualisation, AR navigation and POI shown in AR view. We will highlight the challenges related to this work and their relevance to my PhD.

Chapter 3 explores the design and development of an Initial Digital Prototype. The work in this chapter investigated the development of functions and settings for this prototype, and their design and development. The story order of two Initial Digital Prototype versions was designed and tested. Specifically, we explored the impact of presenting POIs from high to low on screen, and from low to high on screen respectively.

Chapter 4 introduces interviews with 15 participants using the Initial Digital Prototype, and analyses the user feedback (after having done a user study). The findings of the chapter were that many participants struggled with story order concepts, and led us to evaluate further the differences between POI presentation by distance or by story order.

Chapter 5 describes the design of a Paper Prototype. This Paper Prototype was then used in an interview study with 30 participants. Four options were explored for order by story flow and order by distance in AR.

Chapter 6 describes the design and development of the Narrative Navigation Prototype. This prototype was developed based on the findings of the analysis of the Paper Prototype. Following a walk-through of the Narrative Navigation Prototype, four questions were explored and redesigned. Next, we designed and visualised the participant's movement tracking map.

Chapter 7 proposes the evaluation of the Final Prototype. This prototype was tested with 30 participants using a user observation study. This chapter reports the analysis of the user study, as well as insights gained from participant's movement tracking data that was also captured during the user study.

Chapter 8 is a summary and conclusion of this thesis. We describe the contributions of the thesis and the scope for further research in this area.

1.4 Summary

We not only introduced the research focus and research question, but also investigated the research background related to LBS, storytelling and AR. We described here the basic, important and fundamental concepts of each aspect of our focus, using three examples, or use cases, to illustrate each aspect.

The pop-up book lacked the interactivity of location-based storytelling, despite all eight scenes containing geographic information. The book on the subject of "Hong Kong" uses AR to illustrate stories, providing readers to a large extent with an immersion experience, but this does not further connect the chapter of the book with the geographical coordinates. When the reader and the book are at Victoria Harbour, narrative navigation cannot be carried out, although the book has a storyline and geographic coordinates.

We also noticed that these use cases lacked comprehensive integration of the following elements: location-based data, narrative order between story chapters, connection of story chapters to the geo-physical world, and navigation to the corresponding location of the story chapter. We therefore identified the concept of narrative navigation as the key research focus of this thesis.

In conclusion, storytelling is a popular way of delivering information and strengthens the close connection between information, story, and location. This investigation combines a location-based service, and AR in storytelling to guide users to location-based information in a story. Next, we will analyse related work for the purpose of identifying the latest developments related to our research question.

Chapter 2 Related Work

The chapter will explore a series of related work that is relevant to our thesis questions. Our intention is to identify a gap between the progress being made in current research on the topic and the research question. The key areas relating to the research question are AR research and navigation research. Section 2.1 will explore four aspects of AR research, and identify and analyse the relationship between the features of existing knowledge on this topic and the research. Section 2.2 will focus on research navigation and POI display related to the work. Section 2.3 will provide a summary and conclusion to the chapter.

2.1 Augmented Reality Research to date

This section presents an overview of related work based on AR use in picture books, augmented maps, location-based augmentation and AR-supported data visualisation. We first introduce related projects (see Sections 2.1.1-2.1.4) and then discuss their means of visualising location-based data using AR in the discussion (see Section 2.1.5) to outline the gap in the literature which we seek to contribute to my PhD. Finally, we focus on how location-based information is visualised, such as how it interacts with the location and which type of visualisation.

For comparing related work, we defined five aspects to identify the relationship between the work and our research:

(1) intended indoor or outdoor use.
(2) a system is focused on locations versus reacts to current user locations.
(3) design for information visualisation versus user interaction.
(4) use of 2D, 2.5D or 3D visualisation (2.5D visualisations simulate true 3D behaviour by stacking 2D images in a 3D environment), and
(5) AR visualisation within the item or beyond an item (such as books or maps).

2.1.1 Augmented Reality Picture Books

Section 2.1.1 describes augmented reality picture development. Augmented reality picture books are a fast-growing field and accompanied by technological changes. In the early development of augmented reality technology, some researchers focused on the impact of augmented reality books on people, especially for children aged 5 to 18 years old (K-1~12) (Lim & Park, 2011). At this stage, the use of HMD devices and marker-based AR applications dominated the mainstream (Lim & Park, 2011). We searched Google Scholar using the keywords "augmented reality picture book" and tracked references by "snowballing backwards" and citations "snowballing forwards". Finally, 31 papers were selected, focusing on the subfield of augmented reality picture books.

Billinghurst, Kato and Pouyrev's report on AR in three journal articles. The first prototype of their journal articles, Billinghurst et al. (2001a) describe the user-experience of using an HMD device to understand how physical books transition from real objects to virtual models. The authors describe the principles of AR generation and the workings of handheld AR display hardware, and demonstrate how an educational picture book application follows step-by-step animation teaching of making chairs. User-surveys and interviews with 54 participants provided very positive feedback. In a second journal article, Billinghurst et al. (2001b) describe how the AR book can be used to view spatial datasets. Although this application is an early prototype, the AR book supports multiple levels of collaboration. In the third journal article, Billinghurst et al. (2001c) report that users not only see the AR scene, but can also interact with other virtual avatars using the VR perspective to build a Reality-Virtuality continuum.

Other researchers proposed a concept of a picture book as a metaphor (Billinghurst, 2002; Saso et al., 2003). Saso et al. (2003) described the experience of reading the book "Little Red" using an HMD as a new means of storytelling, using the reader's hands to both change the storyline and expand the boundary of the story.

Singh et al. (2004) developed an AR comic book application for children using standard mobile phones enabling children to use the camera in their mobile phone to capture the book page, which then appears with the following characteristics: full 3D display, tangibility and multiple characters.

Ucelli et al. (2005) report that they have observed changes in primary school students' (9-year-olds) cognitive capacities and interaction levels when using AR colour books (Chameleons) and found that AR can be an effective, innovative and engaging learning tool for children.

In 2007, with the development of AR technology and improvements in reader convenience, more and more AR applications used both web cameras and PC monitors to demonstrate AR effects. Dünser and Hornecker described in two conference papers in 2007 how two AR books ("Big Feet and Little Feet" and "Looking for the Sun") explore children's interactive experiences and collaborative learning, mainly through using observations and a semi-structured interview with 2 groups, one with six couples (parents) and one with six individuals (6.5- to 7-year-olds). The applications for these two books use a computer camera capturing the books' pages and display the AR effects on a PC screen. The authors found that both the AR story and the interaction sequences are both appropriate and engaging for young children (Dünser & Hornecker, 2007a; Dünser & Hornecker, 2007b).

Taketa et al. (2007) introduced a virtual pop-up book using AR technology. The book application registers 3D virtual objects with a marker-less tracking method of natural feature points. The author presents scenes to design and informally demonstrate a fracture of this book. The users mentioned their interesting and enjoyable reading experience.

Nischelwitzer et al. (2007) described the book "My Inside the body" (MIBB) as a children's interactive augmented reality application that can improve the potential of AR in the field of learning. They made the first preliminary test involving 18 participants between 7 and 13 years old. All participants were required to complete the same questionnaire which involved the need to respond to eight questions, before and after playing with the MIBB application with HDM and reading the related page.

An AR book with significant interactive effects for individuals and groups has been studied by Grasset et al. (2007). These researchers describe this prototype as including tangible interaction devices (cubes, paddles, etc.) that can trigger animations and move them off the page. Even the user’s avatar can appear on some pages in the book. The researchers concluded that the use of AR with the multi-sensory content of physics books could bring new media and technologies seamlessly together.

Chen et al. (2007) describe an AR prototype used for learning the Chinese phonetic alphabet. Thirty children were divided into two groups, whose capabilities were evaluated by comparing their writing, reading, and relational memory skills. The study found that the members of the AR group were better than those of the book group (control group) who used static images (see Figure 2.1).

Figure 2. 1 The AR picture book. From “Augmented interface for children Chinese learning,” by C. H. Chen, C, C. Su, P. Y. Lee and F. G. Wu, 2007, 7th IEEE International Conference on Advanced Learning Technologies (ICALT 2007), p. 269 (https://doi.org/10.1109/ICALT.2007.76). Copyright 2007 by IEEE.

Scherrer et al. (2008) explain that a book called Haunted uses an AR Toolkit software of computer vision techniques, resulting in the effects of the AR book to allow paper and computer screen meetings to be extracted from the reality from what the reader' eyes can see, where even the readers can feel the image of their hands (see Figure 3.2).

Figure 2. 2 AR interaction effects between real books and virtual creatures. From "The haunted book," by C. Scherrer, J. Pilet, P. Fua, and V. Lepetit, 2008, 7th IEEE/ACM international Symposium on Mixed and Augmented Reality, p.164(https://doi.org/10.1109/ISMAR.2008.4637347). Copyright 2008 by IEEE.

In 2009, several AR books were produced for mobile phone applications. Dias (2009) proposed the miBook (Multimedia Interactive Books) which comprised a combination of printed books (or books in their digital format) and corresponding audiobooks and their 3D models (and/or using 2D graphics), through augmented reality technology, helping users acquire knowledge of multimedia content faster. Dias (2009) used the satisfaction survey method to conduct a preliminary usability assessment of miBook for five adults and found that AR provided clearer understanding, knowledge acquisition and an enhanced learning experience. Dias concludes that miBook's visual enhancements transform standard textbooks into new educational tools.

Hsieh and Lin (2010) developed the Augmented Reality English Vocabulary Learning System (AREVLS), which is an interactive function that includes an English Vocabulary AR Book and an English Vocabulary Card Matching System. These authors utilise two ways to evaluate the system: a Heuristic evaluation using five experts to identify problems of system-use and the use of a system's usability scale for evaluating the system usability. The findings show that this system has availability and interactive enjoyment. The evaluation results were positive, and users enjoyed interacting with the system.

Martín-Gutiérrez et al. (2010) introduced an AR book they developed with the AR-Dehaes tool, which assists students improve their spatial abilities. Through comparing the data of the mental rotation test (MRT) and differential ability test, these researchers tested the spatial relationship

(DAT: SR) of three groups (an AR group of 24 people, a control group of 25 people and a total population of 445 people). The authors found that analysis of the variance of these data, using the validation study, shows that students' spatial abilities can be strengthened.

Zainuddin et al. (2010) reported using qualitative methods to study the effects of three deaf students using six AR books. They found that AR books are useful for deaf students who are visual learners, but, in this context, some requirements must be followed, such as requiring more colours or highlighted words and using sign language symbols. Another AR book study done by Sin and Zaman (2010) refers to an AR book called “Live Solar System” (LSS) that helped 40 secondary school students to learn astronomy. Tests of three aspects of usability of LSS – ease of use, learning ability, and effectiveness – found that this educational tool was easy to learn how to use and easy to use in practice (see Figure 2.3).

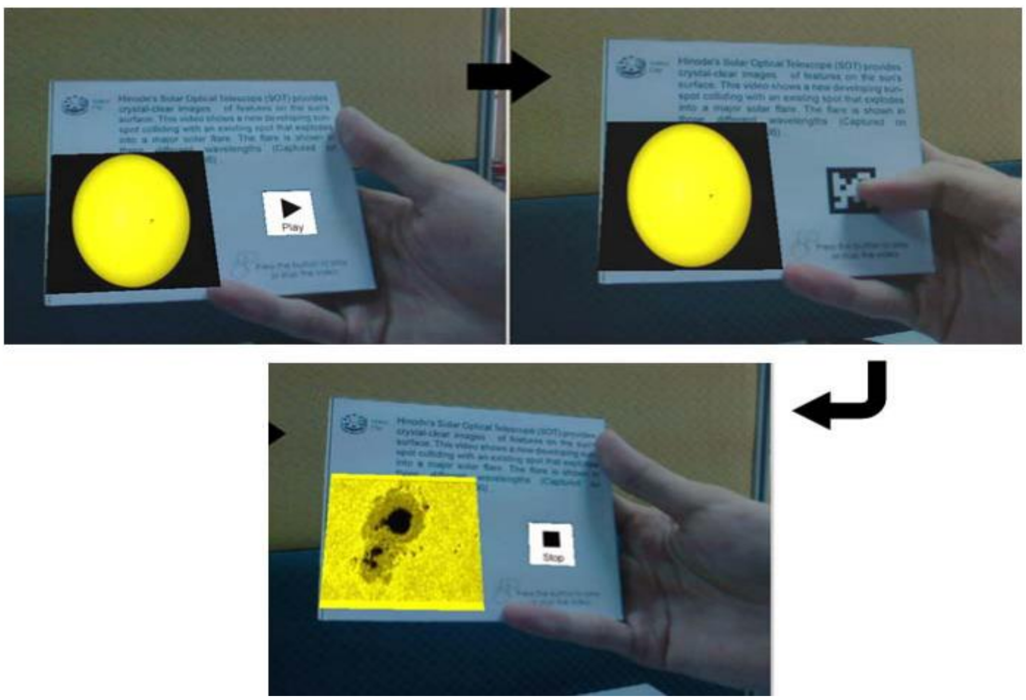


Figure 2. 3 Interactions of play and stop movie in Live Solar System. From “Live Solar System (LSS): Evaluation of an Augmented Reality book-based educational tool,” by A. K. Sin, and H. B. Zaman, 2010, 2010 International Symposium on Information Technology, p. 3 (https://doi.org/10.1109/ITSIM.2010.5561320). Copyright 2010 by IEEE.

In a similar study by Vate-U-Lan (2011) on AR 3D pop up children's books, the author introduced an application called "Seed Shooting Game" which designed and developed 11 pages of a story created using the "Zooburst" AR tool. The findings show a strong support for combining AR technology with educational theory.

Abas and Zaman (2011) focused on the development of AR Baca-Pulih storybooks and flashcards. When designing and developing AR flashcards, these researchers discussed how to apply cognitive theory, and to achieve the visualisation and reading level using storybooks and flashcards. They found that visualisation can help remedial students with their reading.

Ha et al. (2011) introduced the features of the Digilog Book tool and showed how this tool makes the AR-based temple bell experience book. These researchers developed a prototype of this interactive concept, allowing the reader to hit the virtual temple bell with a pen-shaped manipulation tool and use the finger to trigger the virtual button, in order to rotate and release the control bell. The findings showed that the Digilog Book has interactive characteristics, mainly includes enhanced multisensory feedback and a bare-hand input method of computer vision-based.

Vate-U-Lan (2012) explored an AR 3D pop-up book (Seed Shooting Game) for English language teaching. The game uses the reading method of ‘always on-screen orientation’ and gesture recognition. The researcher used individual, small group and real class trials, and found that most participants observed that AR books stimulated their desire to learn and were very attractive as educational resources.

Another AR book study done by Tomi and Rambli (2013), growing maturity of markerless tracking technology with AR described a case study of an interactive edutainment book using AR markless (The Thirsty Crow) using a mobile augmented reality application for preschool children. Through the researchers’ informal observations and gathering of user feedback from visitors during an exhibition, most of the parents and young children were excited by the value of the AR technology concept – this concept is good for attracting parents’ and childrens’ attention (see Figure 2.4)

Figure 2. 4 Prototype concept of the edutainment book. From “An interactive mobile augmented reality magical playbook: Learning number with the thirsty crow,” by A. B. Tomi, and D. R. A. Rambli, 2013, Procedia Computer Science, 25, p. 125 (https://doi.org/10.1016/j.procs.2012.11.015). Reprinted with permission.

The related work on augmented reality picture books discussed above indicates that the focus of the research has changed from exploring the characteristics of the AR user's reading behaviour to exploring the user's interactive experience. Cheng and Tsai (2014) proposed to focus on children and parents reading AR picture books in the field of science education, and its impact on behavioural patterns, spatial cognition and situational cognition. In subsequent studies in 2014, these researchers explored and analysed how children and parents share behaviour patterns and cognitive achievements while reading books, and used their interview method to investigate their feedback for 33 child-parent pairs. They found that two out of four behavioural patterns of AR picture book reading – "child as dominator" and the "communicative child-parent pair" – can improve children's cognitive achievement. Cheng and Tsai (2016) reported that when analysing previous research data, they found that children should dominate AR reading and operation when carrying out children-parents sharing.

Chen et al. (2016) demonstrated that augmented reality video modelling storybooks (ARVMS) for ASD (Autism Spectrum Disorder) children, this AR book developed by Vuforia platform development tool integrate with 20-freeze-frames videos, through three-phase experiments (the baseline, intervention and maintenance phase) to train children with ASD to understand basic human emotions includes happiness, anger, fear, disgust, sadness and surprise and to help them improve their social and emotional awareness.

Yilmaz et al. (2017) describe the relevance of preschool children's cognitive, listening skills, attitudes, and story comprehension performance (SCP) in Augmented Reality Picture Book (ARPB) reading activities. Through interviews and data collection of 92 children aged 5- to 6-years-old, the researchers found that the presence of animation and 3D characters increased children's enjoyment, but the potential risks of physical, social, health and ethical issues need to be considered, teachers and parents should not be allowed children to spend too much time with ARPB.

Vanderschantz et al. (2018) reported that they used the "at the zoo" page of an AR book called *Hannah's Favourite Place* to analyse three levels of interactions (simple and fun interactions, simple educational interactions and learning-interactions). These three experts then conducted two walkthrough evaluations respectively. These researchers found that the interactive function of AR books should be suitable for children's development depending on their age and ability.

Kasinathan et al. (2021) did an AR project based on the book *"The Ocean's Secrets"*, in which animated 3D models of marine animals and educational videos appear. Augmented Reality has been a great educational and entertainment learning tool for students during the Covid-19 pandemic. Figure 2.5 shows an octopus video playback from one page of this book.

Figure 2. 5 The AR video of the book. From "Augmented reality in ocean's secrets: educational application with attached book for students" by V. Kasinathan, A. T. A. Al-Sharafi, A. Zamnah, N. K. Appadurai, V. Thiruchelvam, and A. Mustapha, 2021, Linguistics and Culture Review, 5(S1), p. 1126(https://doi.org/10.37028/lingcure.v5nS1.1498), CC BY-NC-ND 4.0 DEED.

Table 2.1 provides a summary of the related work of augmented reality picture books.

Table 2. 1 Summary of AR prototypes of picture books.

Author(s)	Title	Indoor/ Outdoor	Location -based data	Reacts to user location	No location	Visuali sation	Inter- action	Visualisation type			Visualisation placement		Tracking	Display method	Relevant features / Learning affordances
								2D	2.5D	3D	within the book	extends beyond the book			
Lau (2015)	Hong Kong: A Centential of Change (see use case study)	N/A	Y		Y	Y				Y	Y		Markerless	Tablet PC (iPads) Mobile Phone	Full of fun educational elements
Billinghurst et al., (2001a)	The magicbook-moving seamlessly between reality and virtuality	N/A			Y	Y	Y			Y	Y		Fiducial Markers	HHD	Collaboration / user experience
Billinghurst et al., (2001b)	MagicBook: transitioning between reality and virtuality	N/A			Y	Y				Y	Y		Fiducial Markers	HHD	AR user see the avatar of VR user
Billinghurst et al., (2001c)	The MagicBook: a transitional AR interface	N/A			Y	Y	Y			Y	Y		Fiducial Markers	HMD	User gave very positive feedback
Billinghurst (2002)	Augmented reality in education	N/A			Y	Y	Y			Y	Y		Not mentioned	HMD	Enhance collaborative tasks AR can become a means to move students to animated interactive virtual environments.
Saso et al., (2003)	Little red: storytelling in mixed reality	N/A			Y	Y	Y			Y	Y		Fiducial Markers	HMD	The reader's hands to interferes with and expand the boundary of the story
Singh et al., (2004)	3D augmented reality comic book and notes for children using mobile phones	N/A			Y	Y				Y	Y		Fiducial Markers	Mobile Phone (HHD)	Mobile phone interface / recognize multiple markers at the same time
Ucelli et al., (2005)	Learning using augmented reality technology: multiple means of interaction for teaching children the theory of colours	N/A			Y	Y	Y			Y	Y		Fiducial Markers	HMD / PC Camera	AR can be as an effective innovative and engaging learning tool for children
Dünser and Hornecker (2007)	Lessons from an AR book study	N/A			Y	Y	Y			Y	Y		Fiducial Markers	PC Camera	AR story and interaction sequences can be appropriate and demanding enough for young children
Dünser and Hornecker (2007)	An observational study of children interacting with an augmented story book	N/A			Y	Y	Y			Y	Y		Fiducial Markers	PC Camera	AR story and interaction sequences can be appropriate and demanding enough for young children
Taketa et al., (2007)	Virtual pop-up book based on augmented reality	N/A			Y	Y			Y	Y	Y		Markerless	HMD / PC Camera	The users mentioned their interesting and enjoyable reading experience.
Nischelwitzer et al., (2007)	Some aspects of the development of low-cost augmented reality learning environments as examples for future interfaces in technology enhanced learning	N/A			Y	Y	Y			Y	Y		Fiducial Markers	PC Camera	Interactive / improve their the potential of AR in education
Grasset et al., (2007)	The mixed reality book: a new multimedia reading experience	N/A			Y	Y	Y		Y	Y		Y	Fiducial Markers	HHD + PC Screen	Books could bring new media and technology together seamlessly
Chen et al., (2007)	Augmented interface for children Chinese learning	N/A			Y	Y	Y			Y	Y		Fiducial Markers	PC Camera	AR learning environment is the better choice than static photo learning for children
Scherrer et al., (2008)	The haunted book	N/A			Y	Y				Y	Y	Y	Markerless	PC Camera	AR's animation effects extend to beyond the book
Dias (2009)	Technology enhanced learning and augmented reality: an application on multimedia interactive books	N/A			Y	Y	Y			Y	Y		Markerless	PC Camera	miBook's visual enhancements bring standard textbooks to new educational tools
Hsieh and Lin (2010)	Interaction design based on augmented reality technologies for English vocabulary learning	N/A			Y	Y	Y			Y	Y		Fiducial Markers	PC Camera	Availability and interactive enjoyment
Martín-Gutiérrez et al., (2010)	Design and validation of an augmented book for spatial abilities development in engineering students	N/A			Y	Y				Y	Y		Fiducial Markers	PC Camera / AR-Dehaes	Students' spatial ability can be strengthened
Zainuddin et al., (2010)	A participatory design in developing prototype an augmented reality book for deaf students	N/A			Y	Y				Y	Y		Fiducial Markers	PC Camera	AR books are useful for deaf students to visualise abstract concepts
Sin and Zaman (2010)	Live Solar System (LSS): Evaluation of an Augmented Reality book-based educational tool	N/A			Y	Y	Y			Y	Y		Fiducial Markers	HMD	It is an educational tool which was easy to learn and easy to use
Vate-U-Lan (2011)	Augmented Reality 3D pop-up children book: Instructional design for hybrid learning	N/A			Y	Y	Y			Y	Y		Fiducial Markers	PC Camera	The experience was seen as a guideline
Abas and Zaman (2011)	Visual learning through augmented reality storybook for remedial student	N/A			Y	Y				Y		Y	Fiducial Markers	PC Camera	visualisation can help the reading of remedial students
Ha et al., (2011)	Digilog book for temple bell tolling experience based on interactive augmented reality	N/A			Y	Y	Y			Y	Y		Markerless+bluetooth	PC Camera	Enhance multisensory feedback and a bare-hand input method of computer vision-based
Vate-U-Lan (2012)	An augmented reality 3D pop-up book: the development of a multimedia project for English language teaching	N/A			Y	Y	Y			Y		Y	Markerless	Web Camera	The quasi-experimental study based on 484 third-year students achieved high results
Tomi and Rambli (2013)	An interactive mobile augmented reality magical playbook: Learning number with the thirsty crow	N/A			Y	Y	Y			Y	Y	Y	Markerless	Android device	The AR concept is good for attracting their attention
Cheng and Tsai (2014)	Children and parents' reading of an augmented reality picture book: Analyses of behavioral patterns and cognitive attainment	N/A			Y	Y				Y	Y		Markerless	Tablet PC (iPads)	Improve children's high cognitive attainment
Cheng and Tsai (2016)	The interaction of child-parent shared reading with an augmented reality (AR) picture book and parents' conceptions of AR learning	N/A			Y	Y				Y	Y		Markerless	Tablet PC (iPads)	Children should dominate AR reading and operation in the framework of carrying out children-parents sharing
Chen et al., (2016)	Augmented reality-based video-modeling storybook of nonverbal facial cues for children with autism spectrum disorder to improve their perceptions and judgments of facial expressions and emotions	N/A			Y	Y			Video		Y		Markerless	Tablet PC (iPads)	Improving their awareness of social and emotional
Yilmaz et al., (2017)	Are augmented reality picture books magic or real for preschool children aged five to six?	N/A			Y	Y	Y			Y	Y		Markerless	PC Camera	The presence of animation and 3D characters increased their enjoyment
Vanderschantz et al., (2018)	Using augmented reality to enhance children's books	N/A			Y	Y	Y			Y	Y		Markerless	Mobile Phone	The interactive function of AR books should be suitable for the development of children's age and ability.
Kasinathan et al., (2021)	Augmented reality in ocean's secrets: educational application with attached book for students	N/A			Y	Y	Y		Video		Y		Markerless	Mobile Phone	improving students' reading skills

Augmented Reality Picture Books Summary

In summary, the positive impact of AR picture books is concentrated in the following areas: positive user experience (Billinghurst, 2002; Tomi & Rambli, 2013); engaging children to interact and learn (Dünser & Hornecker, 2007; Nischelwitzer et al., 2007; Ucelli et al., 2005); understanding visually abstract concepts for learning and use (Sin & Zaman, 2010; Vate-U-Lan, 2011; Zainuddin et al., 2010); enhance spatial cognition, situated cognition attainment (Cheng & Tsai, 2013, 2014, 2016).

The current challenges are divided into two issues. The first relates to a combination of technical issues (identification sensitivity triggering, availability, holistic models and design principles). is the second related to emerging technologies (AR glasses), multi-sensory experience concerning AR applications and the long-term effects of an uncontrolled novelty effect (Akçayır & Akçayır, 2017).

From this review of the literature, we have identified only one example of location-based data in all 31 AR picture books that have been analysed, while none of the books analysed reacted to user location. None of the books surveyed included the use of Location-based Services and AR. Some included only LBS, while others included only AR, but never both. Furthermore, there is a lack of a link between visualising location-based content and the AR experience of readers of picture books. These gaps in the literature inspired me to consider these augmented picture books as having design potential for our research on visualising location-based AR.

2.1.2 Augmented Maps/Atlas

With the development of augmented reality technology, augmented paper maps have emerged. The map is a visual representation of our physical space, related to the earliest process of civilisation change (Werner, 2018). Geographic information content in augmented reality maps is extended as additional information by description, graphics or 3D object (Moloney & Dave 2011).

Augmented Reality will extend the visual performance of paper maps and combine many features of geographic information and paper maps to break the static representation of traditional paper map visualisation. Augmented paper maps provide a rich human-computer interaction approach that uses an augmented switch and an augmented pointer to interact with the virtual object of the augmented map, therefore enhancing the description of real-world maps (Bobrich & Otto, 2002).

We identified 13 relevant articles on “Augmented Maps/ Augmented Atlas” by using Google Scholar.

Thomas et al. (1998) report that they have extended the use of AR technology from indoor to outdoor environment surveys, using a wearable computer with GPS and HMD to build AR-based navigation software packages ('map-in-the-hat') for visual navigation. After three trial phases, long-distance, large dataset and urban setting, the findings show that the visual navigation hints provided by the application for the outdoor standard orienteering task.

Augmented Reality research for paper maps explores a wide range of output modes. Bobrich and Otto developed one of the earliest augmented reality paper map systems in 2002 (Paelke & Sester, 2010). Bobrich and Otto (2002) describe a 3D overlay that presents a digital model on a real map using a head-mounted display. This prototype is an archaeological map of a castle that can be used to display additional information to the HMD through an augmented switch. This finding demonstrates the application of pattern recognition technology and data visualisation to traditional maps.

Schöning et al. (2006) describe a method of accessing a map by moving a camera device (such as a mobile phone) to increase the digital geo-referenced content on the map. The high-resolution maps and large-scale physical maps can augment personalised content and dynamic content with augmented reality without modifying anything.

An example of augmentation of physical maps with real-time information was proposed by Morrison et al. (2009). They observed two groups of testers using the AR map and google maps on the Nokia S60. These researchers conducted three trials involving an AR group (26 participants) and a digimap group (11 participants). The researchers gathered data using a three-page questionnaire form, the interview experiences of each participant and observations of interactions and collaborative use of the augmentation of physical maps. Their findings indicate that AR maps can be used as a collaborative tool (see Figure 2.6 for the MapLens example).

Figure 2. 6 MapLens map enhancements. From "Like bees around the hive: a comparative study of a mobile augmented reality map," by A. Morrison, A. Oulasvirta, P. Peltonen, S. Lemmela, G. Jacucci, G. Reitmayr, A. Juustila, 2009, SIGCHI Conference on Human Factors in Computing Systems, p. 1889(https://doi.org/10.1145/1518701.1518991), Copyright 2009 by ACM.

Schöning et al. (2009) describe the concept known as "Map Torch Light", connecting the AIPTEK V10 mobile projector to the Nokia N95 via an AV cable, which will augment information (POI, street, and area) project to a paper map to interact with it.

Paelke and Sester (2010) suggest that the concept of augmented paper map (APM) concerns the design of a system that integrates electronic devices and APMs to combine other information and functions. These researchers integrated GPS positioning, location-specific updates and interactive electronic maps with paper navigation maps. Augmented paper maps have two modes of use. In the MR perspective mode, APM devices can be used to easily enter and modify waypoints in combination with paper maps. In the purely virtual mode, APM displays do not need to be combined with a paper map to display past locations and receive visual information from other navigation devices (see Figure 2.7).

Figure 2. 7 A physical concept of the APM. From "Augmented paper maps: Exploring the design space of a mixed reality system," by V. Paelke, and M. Sester, 2010, ISPRS Journal of Photogrammetry and Remote Sensing, 65(3), p. 261(https://10.1016/j.isprsjprs.2009.05.006), Reprinted with permission.

Stroila et al. (2011) introduced a prototype of augmented reality maps that can help users to interact with transit maps on a Nokia N900 mobile phone based on the user's geolocation. Through the use of a coded transport map database, the vision engine' Franken camera API and the OpenCV (computer vision) library of the graphics engine, the application can be used to recognise and track plane objects, superimposed real-time navigation information. (See Figure 2.8).

Figure 2. 8 A prototype of augmented reality map. From "Augmented transit maps," by M. Stroila, J. Mays, B. Gale, and J. Bach, 2011, IEEE Workshop on Applications of Computer Vision (WACV), p. 486, Copyright 2010 by IEEE.

Besharat et al. (2016) report that an augmented reality application has been developed that allows visitors to access social network information through AR on printed maps that correlate these maps with POI information. Based their laboratory research, the AR on printed map achieves the same effect as the Google maps' navigation system functions in the preliminary field trial.

Bednarczyk (2017) introduced AR technology research on Geomatics. This researcher's first experiment used the computer vision technology of AR to enhance information from traditional maps. Bednarczyk's second experiment examines the approximate location of the geodetic control point which is superimposed on the user's location with AR technology. This finding shows the possibility of using augmented reality technology in geomatics.

De Almeida Pereira et al. (2017) did qualitative research on the acceptance, motivation, and improvement of printed maps and AR maps. This prototype used an AR mapping system for the New Zealand landscape and census data. The researchers invited 60 people to participate in this experiment to assess the use of the system and improve access to knowledge. Their survey results show that most users prefer to use AR maps rather than printed maps (see Figure 2.9).

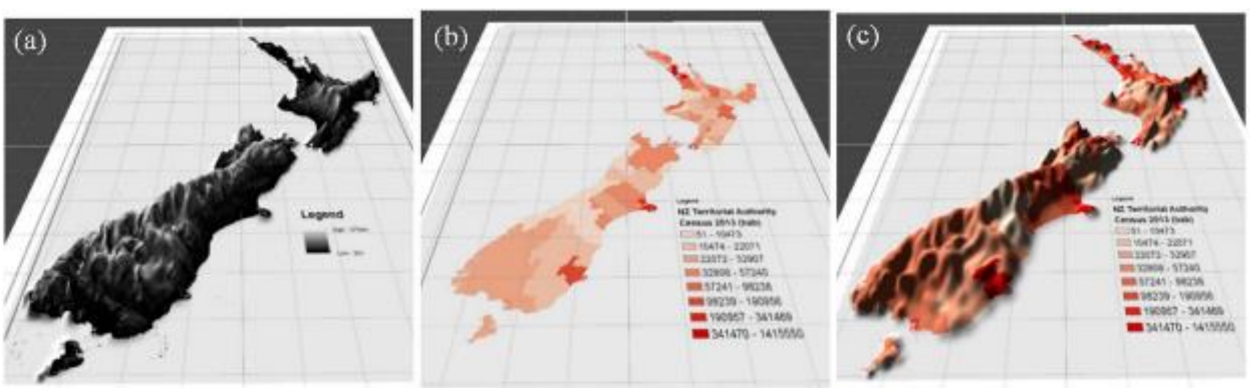


Figure 2. 9 Virtual information presented by the AR system. From "Augmented Reality and Maps: New Possibilities for Engaging with Geographic Data," by G. H. De Almeida Pereira, K. Stock, L. Stamato Delazari, and J. A. S. Centeno, 2017, The Cartographic Journal, 54(4), p. 316(https://doi.org/10.1080/00087041.2017.1411417). Copyright 2017 by Taylor & Francis.

Matsumoto et al. (2021) introduced an application that uses AR to see additional relevant information on a shopping district map for the purpose of revitalizing local shopping malls. The Figure 2.10 shows the AR effect of the shopping district map leaflet.

Figure 2. 10 AR effect of the shopping district map leaflet. From "Development of a smartphone application for promoting shopping district using paper maps and Augmented Reality" by S. Matsumoto, S. Yamagishi, T. Kashima, and T. Hasuike, 2021, 2021 10th International Congress on Advanced Applied Informatics (IIAI-AAI), P. 623(https://doi.org/10.1109/IIAI-AAI53430.2021.00111). Copyright 2021 by IEEE.

Maulana et al. (2022) did a study that uses spatial AR to visualize suitability maps for soil, climate, and terrain data, by accurately projecting 3D terrain onto paper maps, and allowing it to visualize the real-world terrain. Figure 2.11(a) is the original land suitability map, while Figure 2.11(b) shows the projected land suitability map.

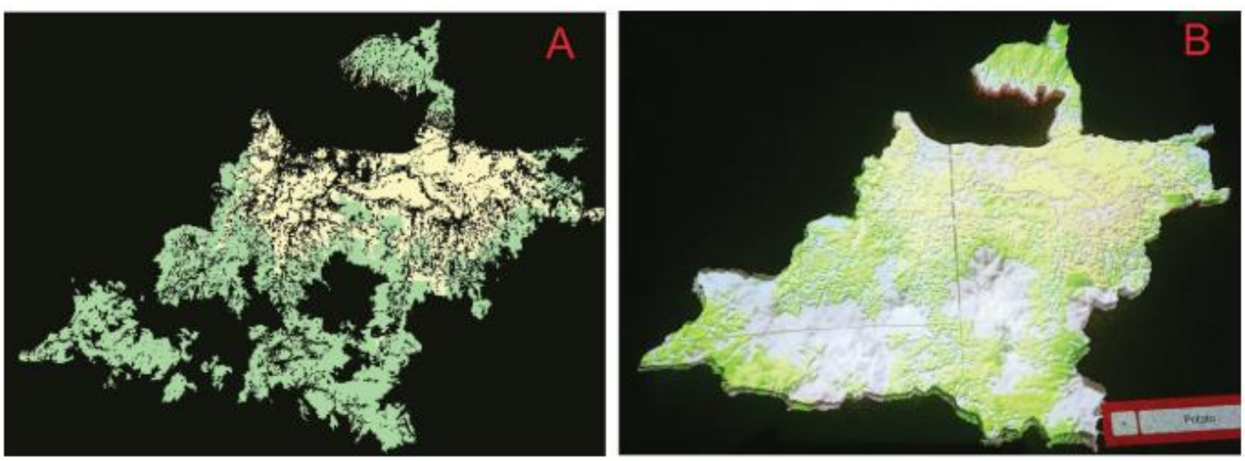


Figure 2. 11 (a) Original 3D model of map with visual data (left) (b) the projected land suitability maps (right). From "Spatial Augmented Reality (SAR) System for Agriculture Land Suitability Maps Visualization," by H. Maulana, T. Sato, and H. Kanai, 2022, International Conference on Human-Computer Interaction, p. 323(https://doi.org/10.1007/978-3-031-06015-1_22). Reprinted with permission.

Xie et al. (2022) introduced an interactive system based on AR maps which they used in remote sighted assistance (RSA) research. The AR map can display the user's real-time location, POI information and map detail zoom in real time. The AR map is used to enhance the RSA system for indoor navigation. Figure 2.12(a) is the real-time location of the AR map and provides the distance to the destination. Figure 2.12(b) is the POI information, while Figure 2.12(provides is a detailed zoomed-in view of the AR map, and Figure 2.12(d) illustrates the POI and directional 2D map.

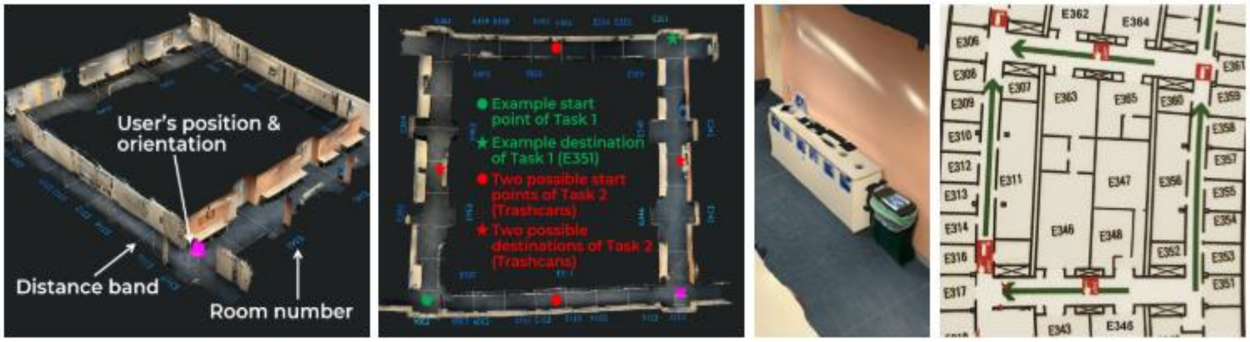


Figure 2. 12 (a) AR map (left) (b) POI information (centre-left) (c) zoom-in detail of the trashcans (centre-right) (d) 2D map (right). From "Helping Helpers: Supporting Volunteers in Remote Sighted Assistance with Augmented Reality Maps," by J. Xie, R. Yu, S. Lee, Y. Lyu, S. M. Billah, and J.M. Carroll, 2022, Designing Interactive Systems Conference, 886. Copyright 2022 by ACM.

2.1.2.1 Augmented Maps/Atlas Summary

While paper maps have the advantage of being able to be produced in a larger size, higher resolution, and with a better visual presentation than digital maps, augmented maps have the advanced features of dynamic and real-time updates between physical and virtual worlds. The following table (Table 2.2) shows ten articles that were implemented in combination using mobile phones or HMD and paper maps as a proof-of-concept.

Table 2. 2 Summary of AR prototypes of augmented maps.

Author(s)	Title	Indoor	Outdoor	Location -based data	Reacts to user location	No location	Visualisation	Interaction	Visualisation type			Visualisation placement		AR see through diaplay	Overlay information	Relevant features
									2D	2.5D	3D	within the maps	extends beyond the maps			
Thomas et al., (1998)	A wearable computer system with augmented reality to support terrestrial navigation		Y	Y	Y		Y		Y				Y	GPS+HMD Navigation	Latitude+Longitude Distances of waypoints	The visual navigation hints provided by the application for the outdoor standard orienteering task
Bobrich and Otto (2002)	Augmented maps	Y		Y			Y	Y		Y		Y		HMD	3D digital landscape model	The application of pattern recognition technology and data visualisation to traditional maps
Schöning et al., (2006)	Interaction of Mobile Camera Devices with physical maps	Y		Y			Y	Y		Y		Y		Mobile PDA	Geofeatures Map annotations Calculating distances	The high-resolution maps and large-scale physical maps can augment personalised content and dynamic content with augmented reality without modifying anything
Morrison et al., (2009)	Like Bees Around the Hive: A Comparative Study of a Mobile Augmented Reality Map		Y	Y	Y		Y	Y	Y			Y		Nokia S60 mobile phone	Location based media (photos and their metadata)	AR maps can be as a collaborative tool
Schöning et al., (2009)	Map torchlight: a mobile augmented reality camera projector unit	Y		Y			Y	Y	Y			Y		Mobile camera projector unit	Information highlighting and annotation	Augment information (POI, street and area) project to a paper map to interact with it
Paelke and Sester (2010)	Augmented paper maps: Exploring the design space of a mixed reality system	Y		Y			Y	Y	Y			Y		PDA with Bluetooth connection	Augmentation information interaction options	The use of APM mixed reality and purely virtual mode
Stroila et al., (2011)	Augmented transit maps	Y		Y	Y		Y	Y	Y			Y		Nokia N900 mobile phone	Real-time navigation information	To recognise and track plane objects, superimposed real-time navigation information
Besharat et al., (2016)	Augmented paper maps: Design of POI markers and effects on group navigation		Y	Y	Y		Y	Y			Y	Y		Mobile phone	POI information	AR map achieves the expected results of the same function as the attractive navigation system
Bednarczyk (2017)	The Use of Augmented Reality in Geomatics		Y	Y			Y		Y				Y	1.Computer screen 2.Android OS mobile phone	1.Image 2.approximate location of geodetic control points	the possibility of using augmented reality technology in the geomatics
De Almeida Pereira et al., (2017)	Augmented Reality and Maps: New Possibilities for Engaging with Geographic Data	Y		Y			Y	Y			Y	Y		Mobile phone	Virtual information (3D landscape, the number of inhabitants in 2D and 3D)	Most users prefer to use AR maps
Matsumoto et al., (2021)	Development of a smartphone application for promoting shopping district using paper maps and Augmented Reality		Y	Y	Y		Y	Y	Y			Y		Mobile phone	Image	Improving people interesting of the shopping mall
Maulana et al., (2022)	Spatial Augmented Reality (SAR) System for Agriculture Land Suitability Maps Visualization	Y		Y			Y				Y	Y		Projector	Virtual topography	assist farmers in understanding the resulting land suitability map
Xie et al. (2022)	Helping Helpers: Supporting Volunteers in Remote Sighted Assistance with Augmented Reality Maps	Y		Y	Y		Y	Y			Y	Y		iPad	3D model, POI information, real-time tracking, distance	AR maps are favored by most of the participants

Paper maps can improve the reader's spatial imagination. Augmented reality maps can provide 3D rendering and social interaction information. Han et al. (2013) and Werner (2018) identified the following challenges:

- Real-time rendering and updating of map information.
- Reuse of suggestions and comments on social networks (including attractions and destinations) in augmented reality applications.
- User interface design and easy navigation.

However, we analysed ten examples of augmented maps/atlas, and currently, we think the challenge should focus on:

- Visual data and map interaction issues.
- Augmented map' functional requirements of specialisation fields (on-site measurement, military, geometrics) and technical bottlenecks.
- The accuracy of generating an AR scenario needs to be further improved.

We observed that all 10 analysed maps use location-based data, but only 4 of the 10 maps reacted to user location. We also consider these augmented maps as design inspiration for our research on visualising location-based AR.

2.1.3 Location-Based Augmentation

A service that uses a handheld device or a head-mounted device dynamically and in real-time locates a person or an object moving on a mobile network is called the Location-based service. (Virrantaus et al., 2001).

Location-aware augmentation is the means by which users add different kinds of virtual information to a physical location, provide similar travel information, the yellow pages, and navigation services. For example, the City Guide Service is an information service for digital maps that specifically locates POI such as tourist attractions, a mobile yellow page service that refers to a specific digital map service that searches for addresses and contacts, and a navigation service that searches for a specified address on a digital map while providing a planning service for the route (Virrantaus et al., 2001).

One of first outdoor location-aware mobile systems was the Metronaut application developed by Smailagic and Martin (1997), at the visitor's location on the Carnegie Mellon University (CMU) campus, which is identified by the barcode from information signs around the campus, and involve negotiation with the campus control centre using the two-way pager. Abowd et al. (1997) describe this cyber guide project, in which they built a prototype of a mobile environment-aware tour guide that uses a context-aware application on a handheld device to obtain a tour guide service. Feiner et al. (1997) described that this system is one of the first AR prototypes to combine geolocation and mobile technology (Papagiannakis et al., 2008). It is designed to provide an immersive user experience for exploring the campus. The system uses a variety of equipment used to demonstrate the feasibility of the AR concept, including a head-mounted see-through display that displays travel information by placing virtual text on a real building, and a portable computer is placed in the backpack to calculate graphics and transmissions. The direction trackers and GPS trackers can track and collect geographic information.

An accurate location and positioning accuracy determine the effectiveness of user perception and interact with the real environment. Augmented reality can utilize visual and non-visual techniques for position tracking and orientation (Smit & Barnett, 2010). In visual technology systems, cameras are primarily used to determine direction and position. However, non-visual systems mainly include various combinations of sensors, such as gyroscope sensor, accelerometer sensor, Wi-Fi, Bluetooth sensor, infrared sensor, compass sensor and RFID (Smit & Barnett, 2010). Initially, location-based applications were designed for outdoor use because they primarily use GPS and cellular tracking technology (Chen & Kotz, 2000).

Data visualisation typically presents 2D and 3D visualisation in location-based enhancements, while some applications use 2.5D visualisation.

When exploring the related work for Location-Based Augmentation, we identified 19 relevant articles (ranging from 1997 to 2022).

2.1.3.1 Indoor/Outdoor LBS Augmentation

Thomas et al. (1998) proposed an augmented reality first-person game based on-location service. The ARQuake game uses a wearable computer with HMD to shoot monsters indoors and outdoors. This application can choose the matching tracking method (GPS or AR mark) according to the user's location (outdoors away from building, outdoors near buildings and indoors). The findings show that the authors have found a way to implement AR technology using inexpensive off-the-shelf software easily (see Figure 2.13).

Figure 2. 13 The AR effect of user HMD. From "A wearable computer system with augmented reality to support terrestrial navigation" by B. Thomas, V. Demczuk, W. Piekarski, D. Hepworth, and B. Gunther, 1998, Digest of Papers. Second International Symposium on Wearable Computers (Cat. No. 98EX215), p. 174(https://doi.org/10.1109/ISWC.1998.729549). Copyright 2022 by IEEE.

2.1.3.2 Indoor LBS Augmentation

Many researchers have focused on the development of outdoor location-based augmentation. Other researchers have explored the development of indoor augmented reality systems for LBS with AR. Due to the rapid development of mobile technology, wireless communication, location-based services (LBS) have made augmented reality possible. The advantages of augmented reality are that it complements reality, instead of placing users in a purely virtual environment like virtual reality (Smit & Barnett, 2010).

Reitmayr and Schmalstieg (2003) described two applications based on augmented reality indoor tracking systems. They use the visual tracking of fiducial markers to build the Signpost indoor navigation system (the user is looking for a specific location in the building), and the library book search and retrieval application (the reader to find the required books on the shelf), after experimental tests by 2 or 3 students found that the application's performance required posting more fiducial markers to improve tracking quality.

Piekarski et al. (2004) present a prototype that mixes three LBS usage tracking applications: indoor, outdoor and combined. Through GPS, direction sensing devices, and markers covering the above three kinds of uses, when the indoor and outdoor transitions are made, the AR application can be kept uninterrupted. All tracking results will be input into a calculation engine called "Tinmith-Metro" system to coordinate the system to produce the final result (see Figure 2.14).

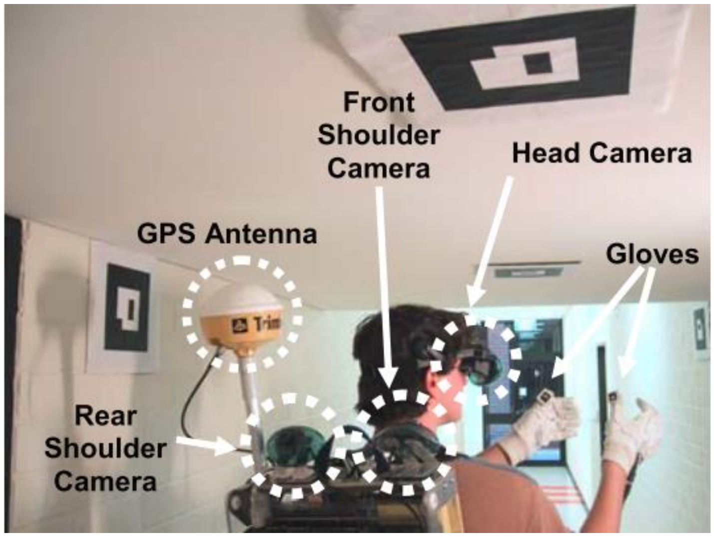


Figure 2. 14 Hardware configuration for mixed tracking. From "Integrated head and hand tracking for indoor and outdoor augmented reality," by W. Piekarski, B. Avery, B. H. Thomas, and P. Malbezin, 2004, IEEE Virtual Reality 2004, p. 11(https://doi.org/10.1109/VR.2004.1310050). Copyright 2004 by IEEE.

Smit and Barnett (2010) compare three different indoor navigation techniques, focusing on non-traditional mark-based augmented reality navigation systems and traditional indoor navigation technologies (navigation boards and 2D maps) used in two different usage environments. The technology compares and records quantitative and qualitative data to discover the interrelationship between location-based outdoor services and these navigation technologies.

2.1.3.3 Outdoor LBS Augmentation

Höllerer et al. (1999) introduced the mobile augmented reality system (MARS) testbed based on location-aware computing, which includes a backpack with a head-tracked, see-through, head-worn display and the hand-held computer with the map UI. Through this experimental prototype, the user can use virtual information to annotate the real world and explore the combined environment (see Figure 2.15).

Figure 2. 15 The outdoor AR effect of the path. From "Exploring MARS: developing indoor and outdoor user interfaces to a mobile augmented reality system" by T. Höllerer, S. Feiner, T. Terauchi, G. Rashid, and D. Hallaway, 1999, Computers & Graphics, 23(6), p. 780(https://doi.org/10.1016/S0097-8493(99)00103-X), Reprinted with permission.

Roberts et al. (2002) introduced a working prototype of the AR and GPS, INS (inertial navigation system) combined underground data visualisation application developed by the University of Nottingham, which uses digitally stored information to be graphically superimposed on real-world views. The author uses GPS traditional measurement tools to measure and obtain the low-precision data view of buried pipes and cables data. The graphics data is superimposed on the real-world view by AR technology.

Honkamaa et al. (2007) propose an interactive outdoor mobile augmentation method using marker less tracking and GPS. The marker less mode allows for the temporary use of any 3D model without prior knowledge or calibration. The GPS method to define augmentation objects and their locations using Google Earth KML files, the user can view 3D objects placed on Google Earth in the field, and no further data conversion steps are required. The marker-less mode is used to visualise new concert halls in downtown Helsinki, while GPS mode is used to visualise pulp mill recovery boilers (see Figure 2.16).

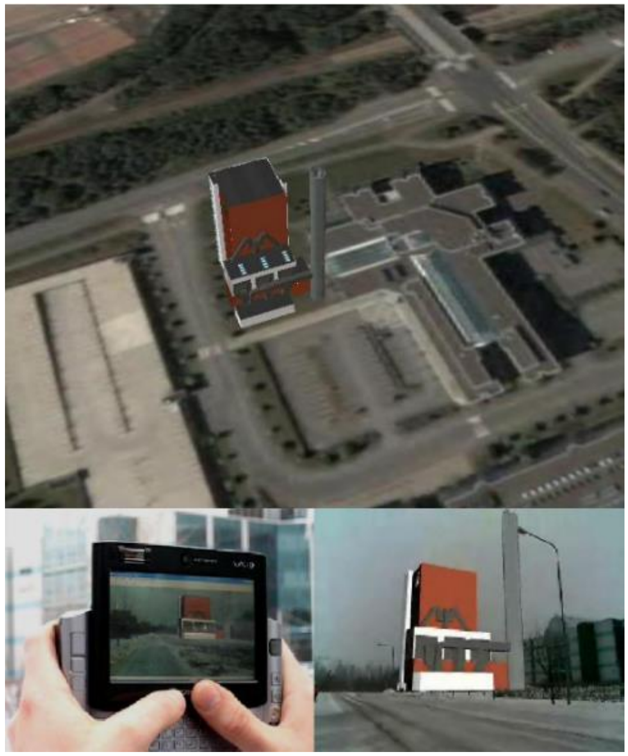


Figure 2. 16 The AR effect combines the GPS information of the user's geographic location with the Google Earth information. From "Interactive outdoor mobile augmentation using markerless tracking and GPS" by P. Honkamaa, S. Siltanen, J. Jäppinen, C. Woodward, and O. Korkalo, 2007, Virtual Reality International Conference (VRIC), p. 285. Copyright 2007 by ACM.

In 2009, Earthmine integrated the concept of visual mapping deeper into the real world by improving the quality of visualisation and indexing objects in the landscape. Using the Earthmine outdoor AR browser, application overlay tags appear in the view of the physical world (see Figure 2.17). This POIs tag information is bound to the physical objects when the user changes to another view; these POI tags will move synchronously.

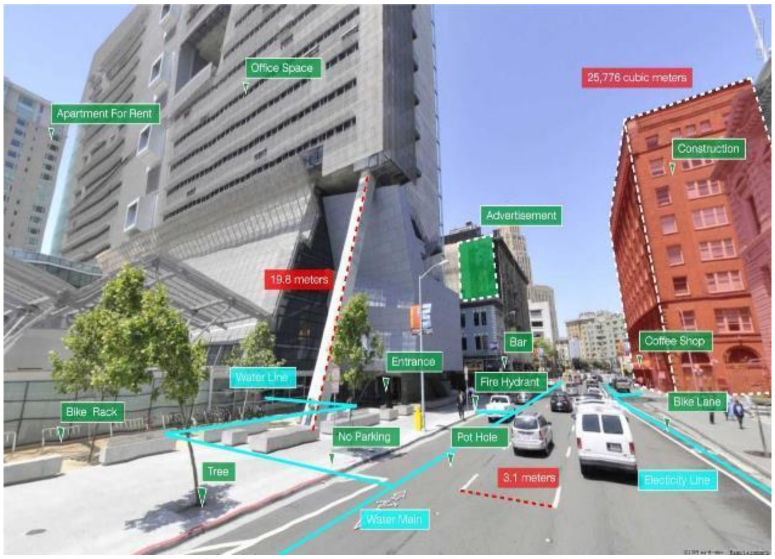


Figure 2. 17 Earthmine AR browser. From "3-D Maps, Camera Phones Put 'Reality' in Augmented Reality" by E. V. Buskirk, 2009, Wired, (https://www.wired.com/2009/12/3d-maps-camera-phones-put-reality-in-augmented-reality/). In the public domain.

In November 2009, Junaio (www.metaio.com) developed the first augmented reality browser to overcome GPS navigation accuracy limitations through LLA markers (latitude, longitude, altitude markers). The Junaio AR browser mainly uses GPS to locate physical coordinates, the compass to determine the direction, the accelerometer to measure the acceleration, and the three data to identify the precise location and direction of the user, and then use the latitude and longitude data of the specific address to obtain relevant information from the server. Finally, this information is superimposed on the camera interface of the user's handheld device (see Figure 2.18).

Figure 2. 18 Junaio AR browser. From "Metaio Announcing Mobile Augmented Reality Platform – Junaio" by O, Inbar, 2009, Game Alfresco, (https://gamesalfresco.com/2009/09/18/metaio-announcing-mobile-augmented-reality-platform-junaio/). In the public domain.

In 2011, Layar (www.layar.com) also launched a location-based augmented reality application based on the Android and iPhone platforms. Users can browse the physical locations they are interested in, and the application instantly retrieves the corresponding geotag information from the Internet and superimposes it on the physical location based on GPS or mobile network signals (see Figure 2.19).

Figure 2. 19 Layar AR browser. From "Layar Reality Browser available in Ovi Store" by R, Blandford, 2011, All About Symbian, (http://www.allaboutsymbian.com/news/item/12643_Layar_Reality_Browser_availabl.php). In the public domain.

In the beginning of 2015, Wikitude (www.wikitude.com) launched an Android, iPhone, and Symbian platform app. It extracts information from Wikipedia and overlay's geographic location data on display (see Figure 2.20).

Figure 2. 20 Wikitude AR browser. From "APP OF THE WEEK: WIKITUDE" by Be Asia, 2015, (https://asia.be.com/lifestyle/tech/apps/app-week-wikitude-34606.html). In the public domain.

In recent years, most mobile devices that people have purchased include Global Positioning System (GPS) chips and A-GPS chips to provide location-based service. Location awareness in mobile learning applications with mobile devices is now a reality (Tan et al., 2011). In particular, Pokémon Go is an augmented reality game developed by Niantic in 2016. As the player moves, their avatar moves through the game, and the player gets a reward for collecting the Pokémon placed in the real world (see Figure 2.21). By looking for rewards, players are motivated to engage in physical activity (Pokémon Go, 2016).

Figure 2. 21 Scenes from Pokémon GO. Capturing Pokémon (left), moving in the virtual world (right). From "The Pokémon GO experience: A location-based augmented reality mobile game goes mainstream" by J. Paavilainen, H. Korhonen, K. Alha, J. Stenros, E. Koskinen, and F. Mayra, 2017, the 2017 CHI conference on human factors in computing systems, p. 2494 (https://doi.org/10.1145/3025452.3025871). Copyright 2017 by ACM.

Dünser et al. (2012) have launched an outdoor AR prototype application that uses a handheld AR device (mobile phone) camera to capture input and overlay virtual POI related information to the phone camera view (see Figure 2.22). The authors finally conducted experimental evaluations and data analysis on performance, user satisfaction and navigation behaviour. The results show that AR + 2D map outdoor navigation is the best choice for AR, 2D maps and AR + 2D maps.

Figure 2. 22 The effect of AR navigation. From "Exploring the use of handheld AR for outdoor navigation" by A. Dünser, M. Billinghurst, J. Wen, V. Lehtinen, and A. Nurminen, 2012, Computers & Graphics, 36(8), p. 1088 (https://doi.org/10.1016/j.cag.2012.10.001). Reprinted with permission.

Peña-Rios et al. (2018) introduced an application that helps land surveyors and mobile planners directly modify the visual immersive 3D geography of the interval type-2 fuzzy logic mechanism superimposed on a paper map on site. The reference data is used to support the planning and design of the infrastructure (see Figure 2.23a). The user provides feedback of immersive visualisation that uses a head-mounted display (HMD) to overlay 3D spatial perception information from a georeferenced information system (see Figure 2.23b).

Figure 2. 23 a) POIs near-by (left); b) user view from HMD (right). From "A Type-2 Fuzzy Logic Based System for Augmented Reality Visualisation of Georeferenced Data" by A. Peña-Rios, H. Hagras, M. Gardner, and G. Owusu, 2018, 2018 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), p. 5 (https://doi.org/10.1109/FUZZ-IEEE.2018.8491467). Copyright 2018 by ACM.

A recent case study of location-based augmentation is combination location, marker-less and play video. In Li (2018) thesis, the author developed a prototype to test the performance of augmented reality video playback on an Android phone, see Figure 2.24. The purpose of the prototype is to meet requirements of blending multimedia for navigating and POIARs and evaluation of the video AR and its influencing factors.

Figure 2. 24 The prototype of VideoAR application. From "Playing videos in an augmented reality setting on an Android mobile platform" by S. Li, 2018, The University of Waikato Research Repositories, Research Commons, p. 33 (https://hdl.handle.net/10289/12158). Copyright 2018 by University of Waikato.

In New Zealand, the company (geogames.com) focuses on the development of geospatial augmented reality mobile games, using innovative concepts that combine outdoor activities and mobile gaming. This application overlays 3D models and animations on outdoor venues via mobile devices and mobile games (see Figure 2.25).

Figure 2. 25 The demo of magical park AR application. From Magical Park - the World's First Digital Playground by Geo AR Game, n.d.(https://www.geoargames.com/about). Copyright n.d. by Geo AR Game.

Hansen et al. (2020) proposed an AR prototype for reconstructing utility excavation visualisations to understand what an underground utility looks like before, during, and after excavation. The Figure 2.26 shows respondents visualizing underground utilities.

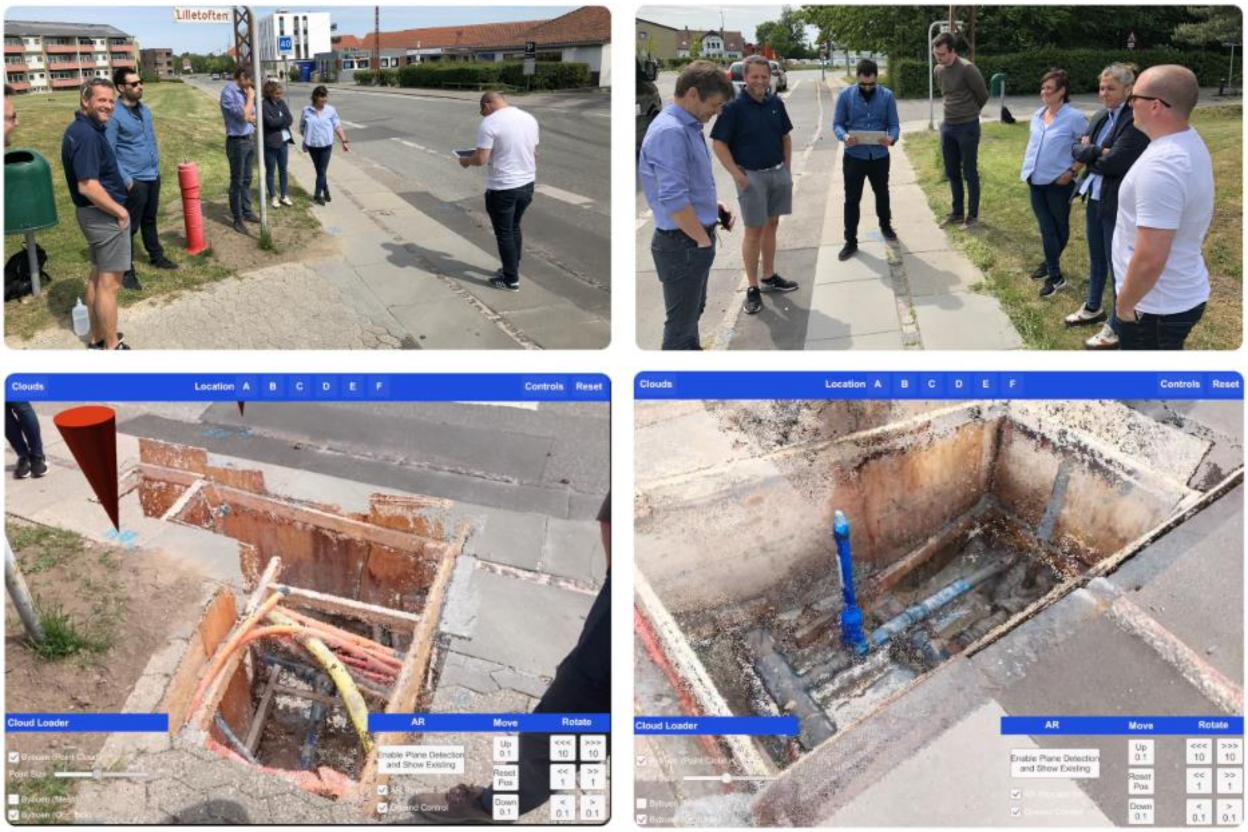


Figure 2. 26 An AR prototype of underground utilities. From "Combining reality capture and augmented reality to visualise subsurface utilities in the field," by L. H. Hansen, S. C. S. Wyke, and E. Kjems, 2020, the 37th International Symposium on Automation and Robotics in Construction (ISARC 2020), p. 707. (https://doi.org/10.22260/ISARC2020/0098). CC BY-NC.

Boos et al. (2022) introduced AR technology as a new method of visualising and communicating with architectural project participants. This visualisation of the building exterior structure and its detailed virtual visualisation data can help participants to demonstrate the future building appearance on the spot, which is convenient for participants to evaluate the building and the impact of things on the surrounding environment. Figure 2.27 shows the AR demonstration of the on-site architectural project.

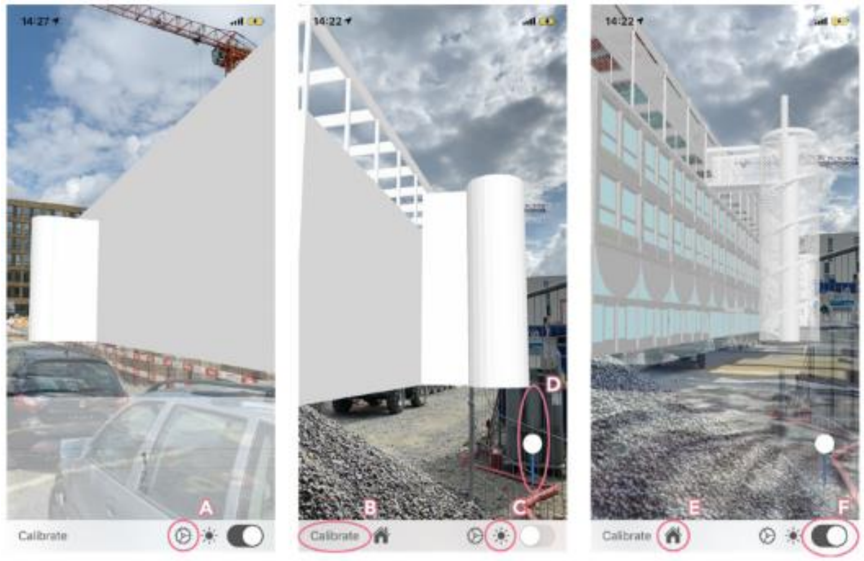


Figure 2. 27 AR effects of the on-site architectural project. From “An augmented reality study for public participation in urban planning” by U. C. Boos, T. Reichenbacher, P. Kiefer, and C. Sailer, 2022, Journal of Location Based Services, p. 56(https://doi.org/10.1080/17489725.2022.2086309). CC BY-NC.

Augmented reality applications based on indoor and outdoor location-aware methods use LBS technology (GPS) to overlay augmented information into physical locations, buildings, parks, and even underground. Table 2.3 shows a summary of relevant features found in the literature.

Table 2. 3 Summary of AR prototypes of location-based augmentation.

Author(s)	Title	Indoor	Outdoor	Location -based data	Reacts to user location	No location	Visuali sation	Inter-action	Visualisation type			Visualisation placement		Location-aware method	Relevant features
									2D	2.5D	3D	within the items	extends beyond the items		
Smailagic and Martin (1997)	Metronaut: A wearable computer with sensing and global communication capabilities		Y	Y	Y		Y	Y	Y			N/A		barcode and pager	Metronaut can be applied to location-aware augmentation
Abowd et al., (1997)	Cyberguide: A mobile context-aware tour guide		Y	Y	Y		Y	Y	Y			N/A		infrare	Provide an immersive user experience for exploring the campus
Höllerer et al., (1999)	Exploring MARS: developing indoor and outdoor user interfaces to a mobile augmented reality system	Y	Y	Y	Y		Y	Y			Y	N/A		GPS	The user can use virtual information to annotate the real world and explore the combined environment
Roberts et al. (2002)	The Use of Augmented Reality, GPS and INS for Subsurface Data Visualisation		Y	Y	Y		Y		Y			N/A		AR+GPS/INS	The graphics data is covered by AR technology into the real world view
Thomas et al., (2002)	First Person Indoor/Outdoor Augmented Reality Application: ARQuake	Y	Y	Y	Y		Y	Y			Y	N/A		GPS Marker	A way to implement AR technology using inexpensive off-the-shelf software easily
Reitmayr and Schmalstieg (2003)	Location based Applications for Mobile Augmented Reality	Y		Y	Y		Y	Y			Y	N/A		Marker	The application's performance required posting more fiducial markers to improve tracking quality
Piekarski et al., (2004)	Integrated Head and Hand Tracking for Indoor and Outdoor Augmented Reality	Y	Y	Y	Y		Y				Y	N/A		GPS/orientation sensors/Marker	A prototype that mixes three LBS usage tracking application: indoor, outdoor and combined
Honkamaa et al., (2007)	Interactive outdoor mobile augmentation using markerless tracking and GPS		Y	Y	Y		Y	Y			Y	N/A		Markerless tracking/GPS	augmented on-site building visualization with markerless tracking and GPS
Buskirk (2009)	Earthmine Browser		Y	Y	Y		Y	Y	Y			N/A		GPS	visual mapping deeper into the real world by improving the quality of virtualization and indexing objects in the landscape
Inbar (2009)	Junaio Browser		Y	Y	Y		Y	Y	Y	Y		N/A		Compass/accelerometer s/GPS	Combine the position and field of view of the user with a combination of compass, accelerometer and GPS data, and retrieve data based on geographic coordinates
Smit and Barnett (2010)	A comparison of Augmented Reality Indoor Navigation Systems with Traditional Techniques	Y		Y	Y		Y	Y	Y			N/A		Navigation board / 2D maps / Marker	A comparison of augmented reality indoor navigation about three techniques
Blandford (2011)	Layar Browser		Y	Y	Y		Y	Y	Y	Y		N/A		GPS/Mobile network signals	geotag information from the Internet and superimposes it on the physical location
Dünser et al., (2012)	Exploring the use of handheld AR for outdoor navigation		Y	Y	Y		Y	Y	Y			N/A		Navigate message	overlay virtual point of interest (POI) related information to the phone camera to evaluate performance, user satisfaction and navigation behaviour in three conditions (AR,2D-map, AR+2D-map)
"APP" (2015)	Wikitude Browser		Y	Y	Y		Y	Y	Y	Y		N/A		GPS	extracts information from Wikipedia and overlays geographic location data on display
Geogame (2017)	Magical park		Y	Y	Y		Y	Y			Y	N/A		GPS	Augmented reality mobile game, using innovative concepts that combine outdoor activities and mobile gaming
Peña-Rios et al., (2018)	A Type-2 Fuzzy Logic Based System for Augmented Reality Visualisation of Georeferenced Data		Y	Y	Y		Y	Y			Y	N/A		AR+fuzzy logic+GIS	The user provides feedback of immersive visualisation that uses a head-mounted display (HMD) to overlay 3D spatial perception information from georeferenced information system
Li (2018)	Playing videos in an augmented reality setting on an Android mobile platform		Y	Y	Y		Y	Y	Y			N/A		Markerless tracking / GPS	Use Maxst software to develop VideoAR on Android for navigating and POIARs,evaluation of VideoAR and its influencing factors
Hansen et al., (2020)	Combining reality capture and augmented reality to visualise subsurface utilities in the field		Y	Y	Y		Y	Y			Y	N/A		GPS + GIS	Provides added meaning and value in outdoor utilities
Boos et al., (2022)	An augmented reality study for public participation in urban planning		Y	Y	Y		Y	Y			Y	N/A		GPS	Increase public willingness to participate in construction projects

2.1.3.4 Location-Based Augmentation Summary

The development of a mobile augmented reality with location-based identified the following challenges (Bhorkar, 2017; Geiger et al., 2014; Neges et al., 2017):

- Need innovative concepts and interactive methods to improve the interest of LBS augmented reality applications and the meaning of LBS storytelling.
- Security issues and privacy issues come from the AR LBS application.
- The blend of indoor navigation methods such as WLAN, RFID, Indoor-GPS, 3D-Maps/SLAM, IMU.
- Integration and coordination between various sensors and LBS applications.

We think location-based augmentation include the following challenges,

- The seamless transition between indoor LBS and outdoor LBS.
- In the field of indoor LBS, Wi-Fi triangulation and iBeacons availability need further verification.
- Develop visual and auditory aids for AR visualisation systems to highlight specific areas or elements of interest.

We identified that all analysed 17 location-based augmentation use LBS data and react to user location, but have visualisation and interaction issues.

2.1.4 AR-Supported Data Visualisation

The visualisation includes scientific visualisation and information visualisation (Olshannikova et al., 2015). Information visualisation was introduced as a sub-area of HCI (Human Computer Interaction) 30 years ago, which provides a graphical interface to display complex data and improve people's ability of understanding and cognitive. This is because visualisation can be able to easily present abstract features and obtain information through the formation of the mental model of the data (Olshannikova et al., 2015).

Visualisation technology is being applied with ever-increasing frequency to datasets and documents, with the datasets having become larger in size and more complex, and with this term being known by more and more people (Roberts et al., 2014). In particular, the field of maps combined with spatial perception and visualisation became more complex (Roberts et al., 2002).

We selected five relevant articles that are closely related to AR data visualisation.

Suthau et al. (2002) proposed a prototyping technique that uses AR techniques to superimpose stereoscopic projections on the liver surgical operating area to enhance the perception of the surgical site. Several organisations have jointly established the "AR Work" research group, which is mainly aimed at AR technical support for open liver surgery, to develop a prospective technology to superimpose computer-generated virtual information on real patient images. In the conceptual framework, the author discusses the importance of visual depth perception and stereo AR systems, and the role of displays in optical flat HMDs, and finally shows a conceptual map of augmented reality prototypes in liver surgery.

Hedley et al. (2002) describe two applications that combine AR and geographic visualisation. These researchers used AR, VR and computer vision techniques to allow multiple users to interact to view 3D virtual terrain models on the map and use AR technology to scale the geographic data visualisation interface, AR marker interactions and annotations. As a result of this work, the application of AR interactive technology has prospered (see Figure 2.28).

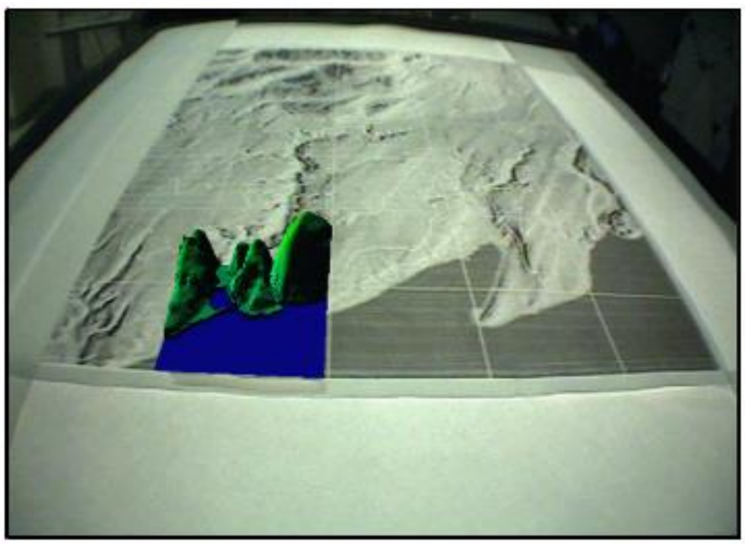


Figure 2. 28 The AR view of terrain. From "Explorations in the use of augmented reality for geographic visualization" by N. R. Hedley, M. Billinghurst, L. Postner, R. May, and H. Kato, 2002, Presence, 11(2), p. 124(http://doi.org/10.1162/1054746021470577). CC BY-NC.

King et al. (2005) describe a visual ARVino system that combines AR and GIS, and which uses ESRI ArcGIS commercial GIS system data (harvest yield monitoring values and the normalised difference vegetation index (NDVI)) which is superimposed on the environment of field trials. The researchers also used VR to observe ground textures and collaborative techniques to solve colour, long-plane viewing and sunlight problems. After the application of these technologies, the viticulture experts provided positive comments (see Figure 2.29).

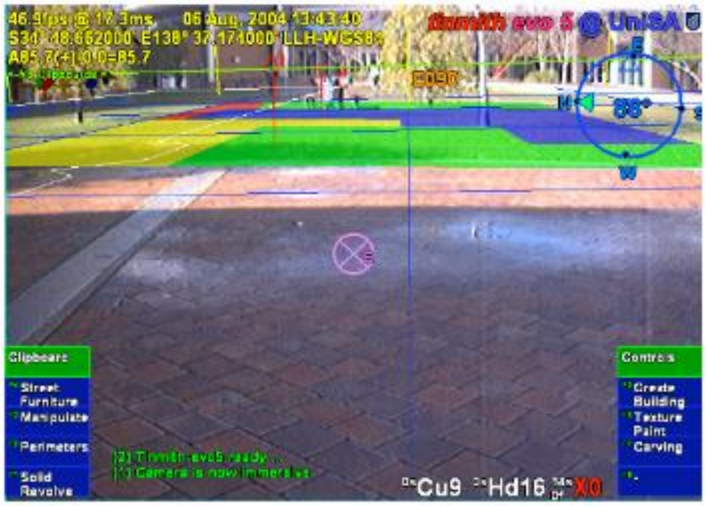


Figure 2. 29 The AR view of superimposed harvest yield monitoring values. From "ARVino—outdoor augmented reality visualisation of viticulture GIS data." by G. R. King, W. Piekarski, and B. H. Thomas, 2005, Fourth IEEE/ACM International Symposium on Mixed and Augmented Reality, p. 53(https://doi.org/10.1109/ISMAR.2005.14). Copyright 2005 by IEEE.

Sobel et al. (2014) provided a solution for motion measurement that improves measurement accuracy and repeatability. The researchers used a set of motion capture systems, including several camera calibrations and coordinated generation points connected in a straight line, in order to create test results for the range of motion so that they could visualise the image clearly, and then overlay the virtual angle and data onto the tester's limb using AR technology (see Figure 2.30).

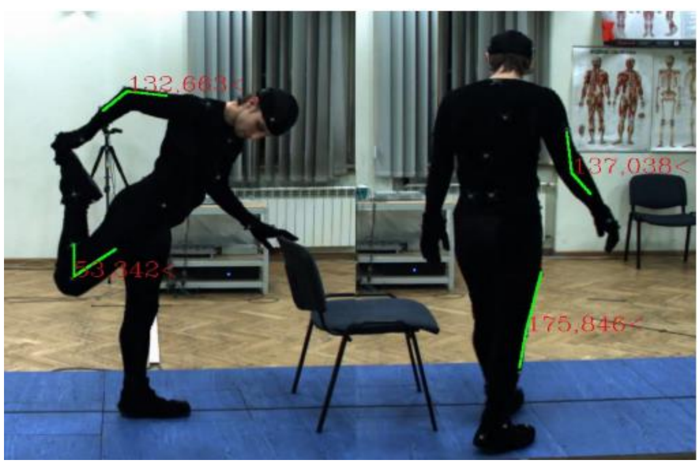


Figure 2. 30 Joint motion and angle AR visualisation. From "Range of Motion Measurements Using Motion Capture Data and Augmented Reality Visualisation" by D. Sobel, J. Kwiatkowski, A. Ryt, M. Domzal, K. Jedrasiak, L. Janik, and A. Nawrat, 2014, Visualisation. In International Conference on Computer Vision and Graphics, p. 600(https://doi.org/10.1007/978-3-319-11331-9_71). Reprinted with permission.

Debarba et al. (2018) describe an AR visualisation tool for athlete motion analysis. Based on a previous bone anatomy mode, in which a healthcare professional attaches the model hologram to the athlete's body through a HoloLens display. The tool records the athlete's trajectory in real time for playback and motion damage assessment and analysis (see Figure 2.31).

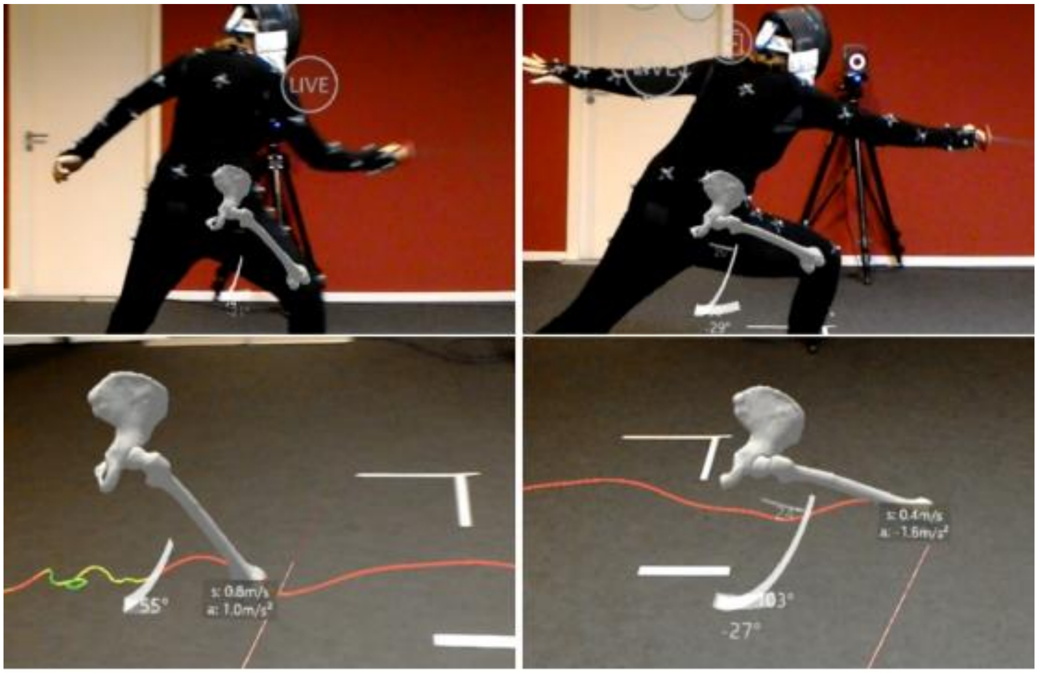


Figure 2. 31 Joint AR visualisation of a fencing attack. From "Augmented Reality Visualization of Joint Movements for Rehabilitation and Sports Medicine" by H. G. Debarba, M. E. de Oliveira, A. Lädermann, S. Chagué, and C. Charbonnier, 2018, 2018 Twentieth Symposium on Virtual and Augmented Reality (SVR), p. 114(https://doi.org/10.1109/SVR.2018.00027). Copyright 2018 by IEEE.

Data visualisation technology can be combined with AR and GIS technology for medical, geographic and agricultural applications. The following table (Table 2.4) summarises the characteristics of the five prototypes.

Table 2. 4 Summary of AR prototypes of data visualisation.

Author(s)	Title	Indoor	Outdoor	Location-based data	Reacts to user location	No location	Visualisation	Inter-action	Visualisation type			Visualisation placement		Fields	Combine techniques	Relevant features
									2D	2.5D	3D	within the items	extends beyond the items			
Suthau et al., (2002)	A concept work for Augmented Reality visualisation based on a medical application in liver surgery	Y				Y	Y				Y	Y		Medical	AR+DKFZ's ARION™	the superimpose virtual computer-generated information with real patient image data
Hedley et al., (2002)	Explorations in the use of Augmented Reality for Geographic Visualization	Y		Y		Y	Y	Y	Y			Y		Geographic	AR+VR+Computer Vision	the two applications that combine AR and geographic visualization
King et al., (2005)	ARVino - Outdoor Augmented Reality Visualisation of Viticulture GIS Data		Y	Y	Y		Y		Y			Y		Agricultural GIS	AR+GIS	introduction of a mobile augmented reality systen (MARS) testbed for the use of indoor and outdoo
Sobel et al., (2014)	Range of Motion Measurements Using Motion Capture Data and Augmented Reality Visualisation	Y				Y	Y		Y			Y		Motion Measurements	AR	a solution that increase the accuracy and repeatability of the measurements
Debarba et al., (2018)	Augmented Reality Visualization of Joint Movements for Rehabilitation and Sports Medicine	Y				Y	Y				Y	Y		Sports Medicine	AR HoloLens	A visualization tool for athlete motion analysis tha displays skeletal model holograms on the athlete's body through a Hololens display.

AR-Supported Data Visualisation Summary

The development of a mobile AR with data visualisation identified the following challenges:

- Seek to link the visualisation to 3D models. (Haynes & Lange, 2016)
- Adding collaborative capabilities (Peña-Rios et al., 2018)
- The impact of medically enhanced data visualisation concepts on its clinical applicability (Mewes et al., 2018)

We think the challenge of augmented data visualisation currently:

- The challenge between the visual presentation of complex data and AR performance
- The blend of real-time rendering techniques, real-time data visualisation, real-time interaction
- Accuracy of rapid update of visual data with real-world target objects (topography, medical industry)

Our analysis of the aforementioned 5 papers (see last section) shows that only 2 of the AR visualisations use location-based data and only 1 of the AR visualisations is based on user geolocation.

2.1.5 Discussion on Augmented Reality Research to date

Location-based data is a combination of geolocation and digital data. Although the physical location is a crucial index representing a small space, it can correspond to a considerable information repository of the address in the digital domain. Location-based data can complement the real world as information in the virtual world. For example, the required information that a user needs when they have a specific task to fulfil. Using visual data provided by an AR system can help users accomplish a variety of tasks. The effect of visualisation depends mainly on the related visualisation hardware and software platforms (Suomela & Lehikoinen, 2004).

Augmented reality can improve visual display to help users gain more sense of the surrounding environment, and understand abstract content. For example, occlusion technology and depth perception technology can be applied to AR.

In preparation for research, we read 332 papers and reports and selected 68 prototypes for analysis from the following four categories: augmented picture books, augmented maps/atlases, location-based augmentation, and AR-supported data visualisation. Our reading also focused on location-based visualisation, the interaction of LBD, user geolocation within or beyond the object, and the seamless transition between indoor LBS and outdoor LBS. The following table (Table 2.5) summarises the data and characteristics of the related work.

Table 2. 5 Summary of the related work.

	Papers	Indoor	Outdoor	Location-based data	Reacts to user location	No location	Visualisation	Interaction	Visualisation type			Visualisation placement	
									2D	2.5D	3D	within the items	extends beyond the items
AR Prototypes of Picture Books	31	N/A	N/A	1	N/A	31	31	20	N/A	2	29	26	5
AR Prototypes of Maps/Atlas	13	8	5	13	6	N/A	13	10	7	2	4	11	2
AR Prototypes of LBS	19	5	17	19	19	N/A	19	17	10	3	9	N/A	N/A
AR Prototypes of Data Visualisation	5	4	1	2	1	4	5	1	3	N/A	2	5	N/A

As summarised in Table 2.5, we observed that only one augmented picture book included location-based data, while no books reacted to the user's location. All augmented maps/atlases used location-based data, with 6 of the 13 maps reacting to the user's location. Furthermore, all AR LBS used location-based data and reacted to the user's location, while only 2 of 5 AR-supported data visualisations used location-based data and only 1 of 5 the AR-supported data visualisations reacted to the user's location. We also compared their visualisation, both within the item or beyond it. These figures show all the AR picture books using 2.5D and 3D visualisation, with most of these visualisations being within the book. Most of the augmented maps/atlases use 2D and 2.5D visualisations and most of these visualisations are within the maps. The 2D and 2.5D information in AR LBS and AR data visualisations contain more than 3D information. This is a question that needs to be researched.

We identified the lack of a link between visual location-based content and the AR experience of readers of picture books. The current AR picture book functions rarely focus on location-based applications. However, in the field of applications, such as maps and LBS, AR visualisation technology has become a significant data display method, especially in the field measurement, military, geographic information industry, data visualisation requirements, meaning visualisation technology bottlenecks have become more prominent. The challenges include data rendering and AR visualisation capabilities, integration of real-time rendering technologies, real-time interaction of data visualisation techniques and scenes, visualisation of content and accuracy of coverage of target scenes. We are interested in investigating how to visualise information about a location when the user is not in that location.

POI is the main form of location-based data visualisation, but there should be other methods of visualising location-based data in a mobile AR application beyond POI approaches. We will focus on this research question.

In summary, we have researched AR research to date, and we are starting to research navigation research to date.

2.2 Navigation Research to date

This section presents an overview of work related to AR navigation, car navigation, wayfinding, indoor navigation and navigation interface. In addition, we also research POI shown in AR view. We focus on how to use AR for navigation visualisation, with respect to how, for example, navigation is displayed in AR view and how navigation is displayed in POI.

When comparing the literature, we used five categories to identify the relationship between what the literature says and our research topic:

(1) Intended indoor or outdoor use.

(2) System focusses on location's relative information.

(3) Which interactive method to use.

(4) Interaction with GPS, image and SLAM; and

(5) POI 2D, 2.5D or 3D visualisation in AR view.

2.2.1 AR Navigation

Navigation is defined by the American Practical Navigator as "the process of planning, recording, and controlling the movement of a craft or vehicle from one place to another" (Bowditch, 2002, p.799). "Navigation" is derived from the Latin "navis" and "agere", similar to the Greek word "natics"(Hofmann-Wellenhof et al., 2003, p.2).

Navigation refers to the process of moving a three-dimensional object to a determined position. In the process of moving the object, the object state vector of the moving trajectory and position, speed and attitude will be involved. The navigation track will guide the object to move on the predetermined route to a given destination, although the movement track cannot interact with the object (Hofmann-Wellenhof et al., 2003).

Traditional navigation systems generally refer to vehicle navigation and pedestrian navigation. (Narzt et al., 2006). Navigation combined with AR can make the navigation system user interface more realistic and friendly (Bhorkar, 2017). Other purposes of AR navigation systems lie outside the scope of this thesis, for example, dental surgery (Wang et al., 2014), military, aircraft, naval, etc.

There are three main ways of navigation, including celestial: GPS, as well as map and compass. Another term is inertial navigation, which refers to navigation's error growing over time, and relying on an independent reference to limit its error growth without the need for a GPS signal.

Narzt et al. (2006) proposed that this type of navigation system will provide detailed navigation instructions, and in some specific scenarios will also display the 3D rendering of the path. However, navigation systems run on dedicated devices (usually smartphones or small computers), and require the user to move while interacting with the navigation software. This approach leads to user dissatisfaction and accidents.

Azuma (1997) proposed six directions for AR potential applications, one of which includes the military aircraft navigation. In Section 2.1.3, we introduce a hybrid positioning system consisting of picture recognition, and/or tracking system and HMD use (head-mounted displays).

In this section, we categorize the key elements of navigation, such as car navigation, wayfinding, indoor navigation, and navigation interface. Next, we will discuss each key navigation element that is relevant to our topic.

2.2.1.1 Car Navigation

Augmented reality navigation systems display navigation by usually displaying arrows pointing in a desired direction or by providing an abstract form of information map and a "bird's eye view" of the expected route (Bhorkar, 2017).

Narzt et al. (2003) describe a method based on AR mobile navigation, after acquiring location and direction information from a sensor, and displaying it on the display device through the AR view. Narzt et al. (2004) describe a car mobile navigation system, which delivers through AR navigation information a seamless integration of the real world. Figure 2.32 shows the car's heading with a green path superimposed on the navigation system display.

Figure 2. 32 Translucent path for navigation Reprinted with permission. From "A new visualization concept for navigation systems." by W. Narzt, G. Pomberger, A. Ferscha, D. Kolb, R. Müller, J. Wieghardt, and C. Lindinger, 2004, ERCIM Workshop on User Interfaces for All, p. 442(https://doi.org/10.1007/978-3-540-30111-0_38). Reprinted with permission.

Subsequent studies show that Narzt et al. (2006) developed a visualization paradigm for navigation systems that enhances user interaction by use of anticipation. Figure 2.33 shows the hand-held device directly connected to the car navigation computer, while a video jacket is additionally inserted to receive the video signal from the camera.

Figure 2. 33 AR car navigation prototype. From "Augmented reality navigation systems" by W. Narzt, G. Pomberger, A. Ferscha, D. Kolb, R. Müller, J. Wieghardt, and C. Lindinger, 2006, Universal Access in the Information Society, 4(3), p. 184(https://doi.org/10.1007/s10209-005-0017-5).Reprinted with permission.

Sawano and Okada (2005) also have researched AR car-navigation with a similar interest. The ordinary display shows a 3D simulation map rather than the actual scenery. In this approach, the system overlays navigation information on images captured using the vehicle's integrated cameras. Figure 2.34 shows the process of the application design and implementation.

(a) Ordinary display

(b) Actual scenery

(c) Ideal display

(d) Experimental result

Figure 2. 34 The process of the application design and implementation. From “A car-navigation system based on augmented reality” by H. Sawano, and M. Okada, 2005, ACM SIGGRAPH 2005 Sketches, p. 119(https://doi.org/10.1145/1187112.1187255). Copyright 2005 by ACM.

Schneider et al. (2019) introduced a system whereby AR information could be displayed on the windshield of a vehicle using a simulation method in the real world. Figure 2.35 shows a fishbone indicator superimposed on the windshield of a vehicle. Schneider et al. (2019) proposes that we should use the fishbone concept as a navigation indicator and test the masking effect caused by the fishbone indicator.

Figure 2. 35 Fish bone indicator for AR HUB car navigation. From "A field study to collect expert knowledge for the development of AR HUD navigation concepts" by M. Schneider, A. Bruder, M. Necker, T. Schluesener, N. Henze, and C. Wolff, the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings, p. 360 (https://doi.org/10.1145/3349263.3351339). Copyright 2019 by ACM.

The Phiar Company helps people experience the world in a whole new way through their AR navigation platform. The AI-based platform displays the virtual arrow direction superimposed on the real road, which facilitates the driver's visual navigation to the correct destination. Figure 2.36 shows the scenario of the Phiar platform during car navigation.

Figure 2. 36 The Phiar platform for car navigation. From "Phiar raises $3 million for an AR navigation app for drivers" by Techcrunch, 2018 (https://techcrunch.com/2018/11/28/phiar-nabs-3-million-for-an-ar-navigation-app-for-drivers/). Copyright 2018 by Techcrunch.

2.2.1.2 Wayfinding

Navigation and wayfinding are a symbiotic relationship. The routes connect the same two nodes, some of which belong to the most frequently used segments. Other routes deviate from most people's choices and use unpopular network segments to connect two nodes. The navigation takes this into full consideration when choosing the route, and the route selection is left to the user.

Passini (1996) explains the difference between spatial orientation and wayfinding: spatial orientation is about a person's “ability to mentally represent the spatial characteristics of a setting” and “to situate him or herself within that representation” (p. 321) and wayfinding is broader as it “includes all the mental processes which are involved in purposeful mobility” (p. 322).

Hile et al. (2008) conducted a user study that showed that the instructions for AR applied to pedestrian navigation are beneficial to users. Figure 2.37 shows the navigation prototype from the user study tour.

Figure 2. 37 Top: The electronic map shows the red route, and the blue point is the current GPS position. Bottom: The upper right corner shows the photo of the next address to visit. From “Landmark-based pedestrian navigation from collections of geotagged photos,” by H. Hile, R. Vedantham, G. Cuellar, A. Liu, N. Gelfand, R. Grzeszczuk, and G. Borriello, 2008, the 7th international conference on mobile and ubiquitous multimedia, p. 149 (https://doi.org/10.1145/1543137.1543167). Copyright 2008 by ACM.

Kim et al. (2015) describe how they did an exploratory research study on user experience and requirements of wayfinding in a hospital that was based on the user requirements to develop and implement an AR-based wayfinding system. The results show AR reduced participants' wayfinding time and cognitive workload. Figure 2.38 shows the implementation process of wayfinding using this AR system.

Figure 2. 38 Wayfinding with augmented reality. From “Implementing an augmented reality-enabled wayfinding system through studying user experience and requirements in complex environments,” by M. J. Kim, X. Wang, S. Han, and Y. Wang, 2015, Visualization in Engineering, 3(1), p. 10(https://doi.org/10.1186/s40327-015-0026-2). CC BY-NC.

Yokoi et al. (2015) introduced a large-scale underground space path finding assistance system using AR. This system displays known landmarks that are not visible in the indoor environment on the handheld device to help users locate and find indoor paths. The prototype system will display the 3D model superimposed on the field of view of the camera, demonstrating the system's pathfinding efficiency. The Figure 2.39 shows the snapshot of application in the system’s pathfinding.

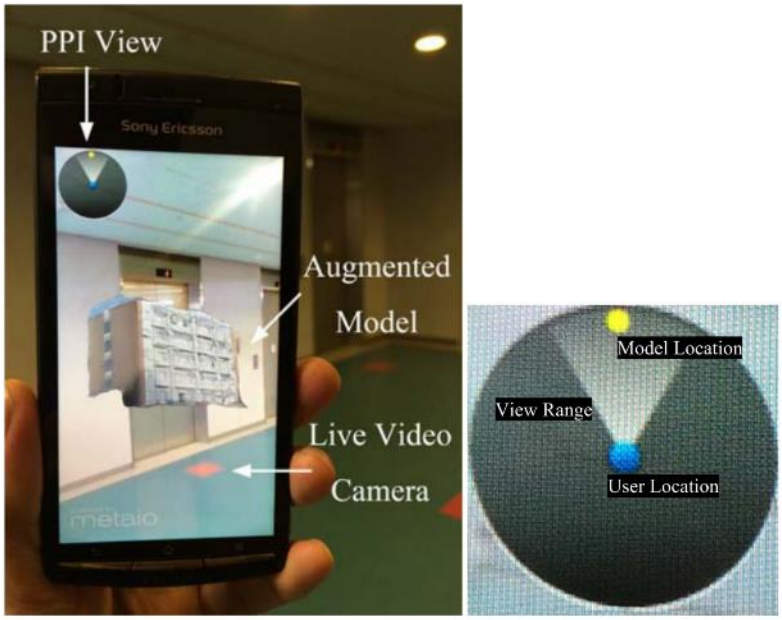


Figure 2. 39 Snapshot of Application (left) and, Plan Position Indicator (right). From "Way-finding assistance system for underground facilities using augmented reality" by K. Yokoi, N. Yabuki, T. Fukuda, T. Michikawa, and A. Motamedi, 2015, Remote Sensing & Spatial Information Sciences, p. 40. (https://doi.org/10.5194/isprsarchives-XL-4-W5-37-2015). CC BY-NC.

Muchtar et al. (2017) developed a prototype based on tracking using the coordinates of the participant's mobile phone, and using the GPS user-view on the camera to show the direction of potential assets in the nearest area to the participant's position. The following picture (Figure 2.40) shows potential asset information including two inverted triangles, presenting information on two assets, asset names and location, distance.

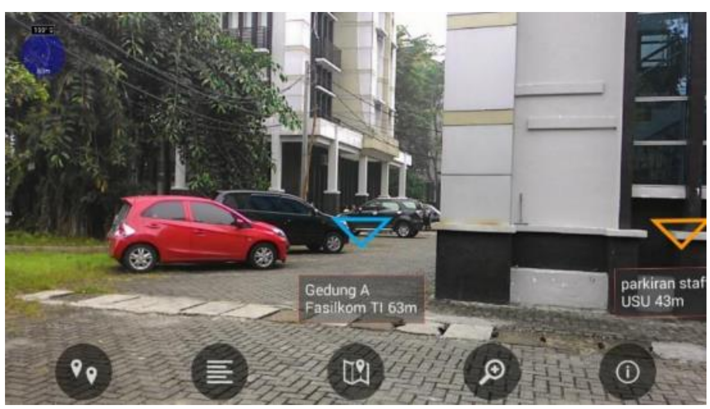


Figure 2. 40 Potential asset information shown in the participant's mobile screen. From "Augmented reality for searching potential assets in medan using GPS based tracking" by M. Muchtar, M. Syahputra, N. Syahputra, S. Ashrafia, and R. Rahmat, 2017, Journal of Physics: Conference Series. p. 5(https://doi.org/10.1088/1742-6596/801/1/012010). CC BY-NC.

Yahoo Japan company announced the function of Yahoo! map in 2018, the map released augmented reality navigation for pedestrians, the navigation uses the camera of the mobile phone to provide users with an "in-world" visualisation of the route to the destination, and superimpose the visual effects and path markers on the three dimensions of the actual landscape. Furthermore, the virtual road signs along with the path help pedestrians to confirm the direction and the rest of the distance with augmented reality. The Figure 2.41 shows the screenshot of the application, and the number 1-4 of the second picture shows routine, direction, the rest of distance and destination respectively.

Figure 2. 41 Yahoo! map augmented reality function. From “「Yahoo! MAP」に AR 機能　“迷わないナビ” 目的地まで矢印で案内,” by 太田智美，2018，IT Media, (https://www.itmedia.co.jp/news/articles/1803/05/news096.html). Copyright 2018 by Yahoo.

Diao and Shih (2018) describe a study that used a mobile AR indoor navigation system, using pathfinding to navigate a path to avoid the potential blockage of unexpected objects. Figure 2.42 shows the navigation path.

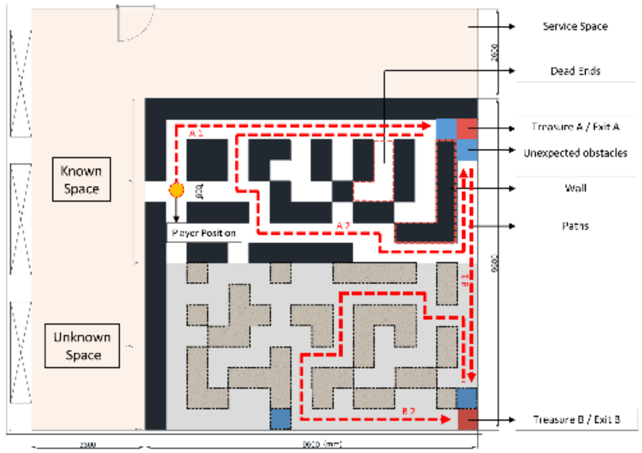


Figure 2. 42 Navigation path visualisation. From "A mobile smartphone AR system for pathfinding in a dark environment." by P. H. Diao, and N. J. Shih, 2018, Sensors 2018, 18(10), 3442, p. 5 (https://doi.org/10.3390/s18103442). CC BY-NC.

Brata and Liang (2019) developed an AR App that helps participants to access information about bus stop locations, enabling a step-by-step guide for the participant to navigate their way to the bus stop on foot. The Figure 2.43 shows the step-by-step navigation view of the prototype.

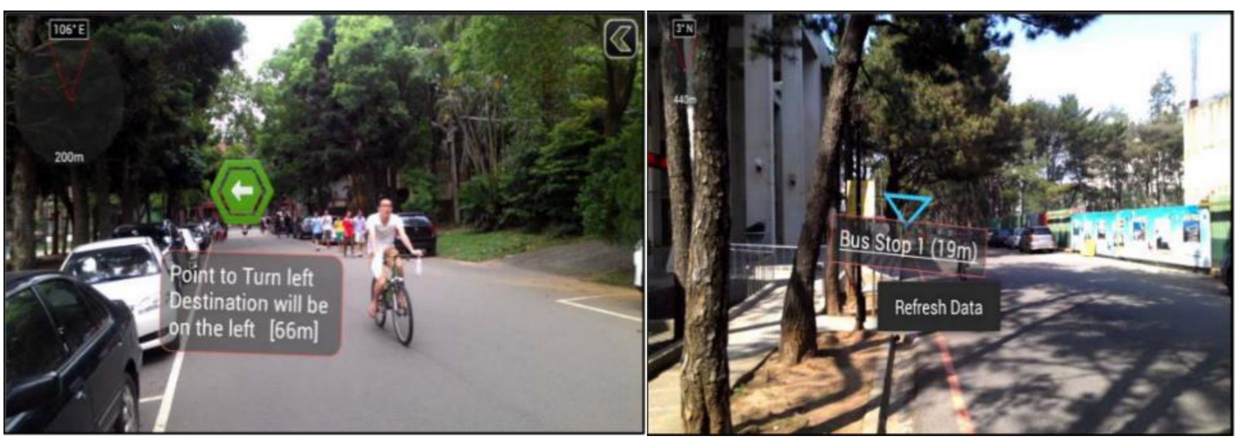


Figure 2. 43 Step-by-step guidance (left) and POI information (right). From "An effective approach to develop location-based augmented reality information support" by K. C. Brata, and D. Liang, 2019, International Journal of Electrical & Computer Engineering, 9(4), p. 3065 (http://doi.org/10.11591/ijece.v9i4.pp3060-3068). CC BY-NC.

Indoor navigation and positioning systems are two aspects of the same field. The purpose of the positioning system is to obtain the user's location and search for the target address, while the purpose of the indoor navigation system is to determine the path from the user's location to the destination. In order to quickly search for different routes, the intersections within the building are added in advance to the database, enabling those transfer points to be directly connected. This data can be used to recommend different routes based on different travel purposes.

Gerstweiler et al. (2016) introduced an indoor tracking prototype, an indoor navigation prototype based on continuous 3D position and an orientation information visualization of indoor locations, showing distances in centimetres. The Figure 2.44 shows a user visualising their way through the gate on a tablet.

Figure 2. 44 Red stop sign on wrong passage (left) path visualisation for this user (right). From “HyMoTrack: A mobile AR navigation system for complex indoor environments” by G. Gerstweiler, E. Vonach, and H. Kaufmann, 2016, Sensors, 16(1), p.17 (https://doi.org/10.3390/s16010017). CC BY-NC.

Al Rabbaa et al. (2019) introduced the MRsive system, which is an indoor wayfinding and interaction system at the Art Gallery of Ontario in Canada. In order to help the visitor with their indoor wayfinding and navigation, this system displays a virtual pathfinding cues-prompt that is superimposed on the corridors and passages in the AR view. In addition, this system provides image recognition of artworks and displays artwork-related information. Figure 2.45 shows the screenshots of a guided walk.

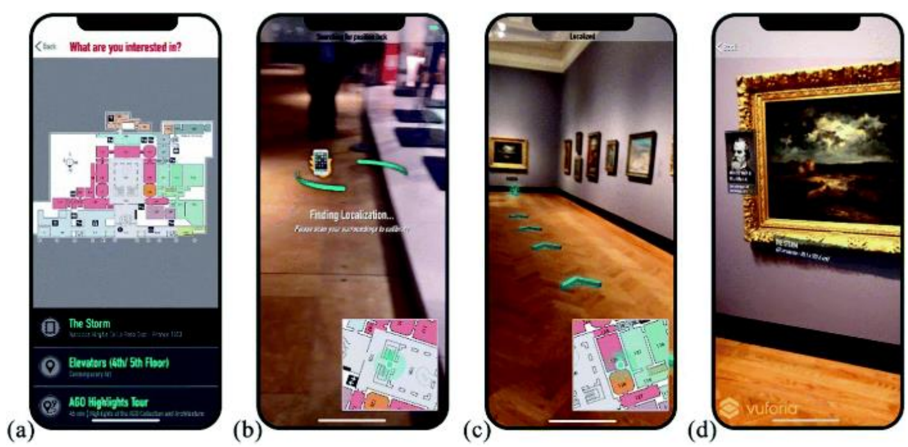


Figure 2. 45 (a) Choose where the user wants to go (left) (b) Locate the user’s space (centre-left) (c)Virtual arrow on the path (centre-right) (d) Interacting with the target (right). From “MRsive: An Augmented Reality Tool for Enhancing Wayfinding and Engagement with Art in Museums” by J. Al Rabbaa, A. Morris, and S. Somanath, 2019, HCII 2019: HCI International 2019 - Posters, p. 539 (https://doi.org/10.1007/978-3-030-23525-3_73), Reprinted with permission.

Al Delail et al. (2013) describe a positioning system based on indoor images, which uses AR and an inertial navigation system (INS) of smartphones, and demonstrates some positioning and navigation functions that combine AR functions with inertial navigation. Figure 2.46 shows 360-degree points-of-interest view in indoor navigation.

Figure 2. 46 Indoor 360-degree points-of-interest view. From "Indoor localization and navigation using smartphones augmented reality and inertial tracking," by B. Al. Delail, L. Weruaga, M. J. Zemerly, and J. W. P. Ng, 2013, Twentieth International Conference on Electronics, Circuits, and Systems (ICECS). p. 932 (https://doi.org/10.1109/ICECS.2013.6815564). Copyright by 2013 IEEE.

Mobidev has provided a video demonstration of indoor navigation based on Google's AR Core. The user scans the special sign at the beginning of the navigation path, selects the destination, and displays the route to locate the path indicated by the arrow in the AR view. The Figure 2.47 shows the effects of the way finding.

Figure 2. 47 Indoor navigation based on augmented reality by Mobidev. From Augmented Reality For Corporate Campus Navigation: Video Demo, by Mobidev, 2019 (https://mobidev.biz/blog/indoor-navigation-augmented-reality-demo-video). Copyright 2019 by Mobidev.

2.2.1.4 Navigation Interface

Currently, navigation information from an AR perspective can be presented to users in a number of ways. For example, map navigation shows pointing the arrow towards the destination direction or directional indicators, which are provided when semi-transparent colours appear on the road.

Narzt et al. (2006) suggest that the user experience design of the AR view should be based on the user's usage perspective. Bark et al. (2014) mention that navigation instructions, navigation cues and assistance, using audio, should add to the navigation interface design. Figure 2.48 shows the live view feature of Google map pedestrian navigation.

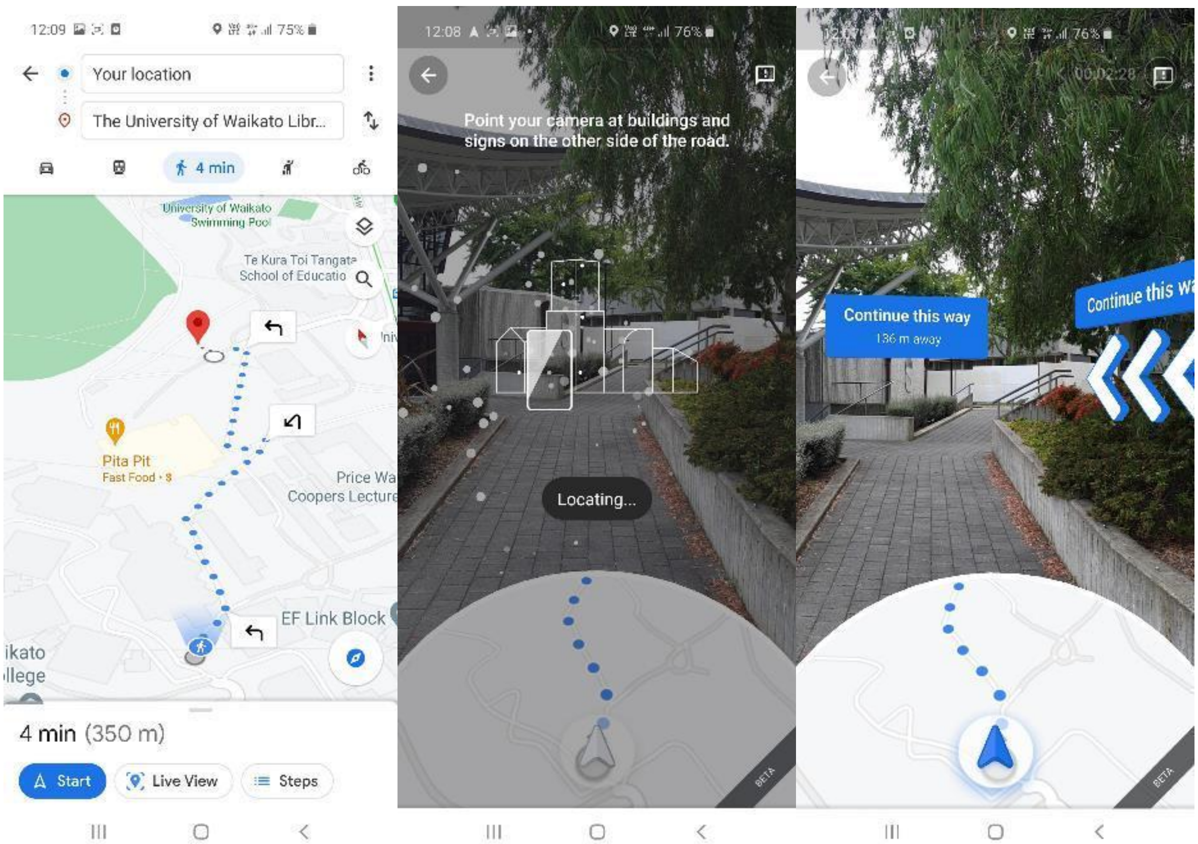


Figure 2. 48 Google map navigation. Screenshot from Google Map App by Qimo Zhang.

Reiner et al. (2020) have already noted that there is an inconsistency with Google's map approach that can be seen when they introduced Mirror in the Sky (MitS), in which a simulated mirror is presented to the upper field of view, which reflects the topographical layout of the user's location. Figure 2.49 shows a navigation interface that appears in the top of the camera view (Mirror in the Sky) and appears in the bottom of the camera view.

Figure 2. 49 Navigation interface displayed on the top and bottom views of the display. From “A mirror in the sky: assessment of an augmented reality method for depicting navigational information” by A. J. Reiner, J. G. Hollands, G. A. Jamieson, and S. Boustila, 2020, Ergonomics, 63(5), p. 553 (https://doi.org/10.1080/00140139.2020.1737738). Copyright 2020 by Taylor & Francis.

Huang et al. (2020) developed an indoor navigation prototype of 1,800 square meters, based on 35 Lbeacons installed on the ceiling as indoor positioning devices, which can provide an accuracy of 3-5 meters, and use AR technology to provide users with the correct destination instructions. Figure 2.50 shows the screenshot of the application and photos of Lbeacons mounted on the ceiling.

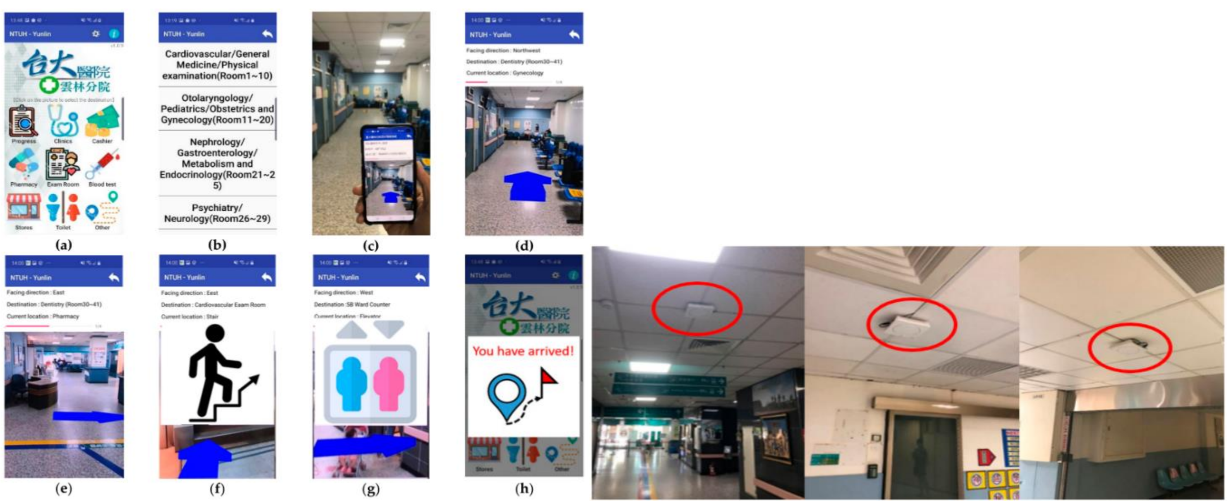


Figure 2. 50 Screenshot of the application and photos of Lbeacons mounted on the ceiling. From “ARBIN: Augmented Reality Based Indoor Navigation System,” by B. C. Huang, J. Hsu, E. T. H. Chu, and H. M. Wu, 2020, Sensors, 20(20), p. 5-17 (https://doi.org/10.3390/s20205890). CC BY-NC.

2.2.1.5 AR Navigation Summary & Discussion

Augmented reality is an emerging technology that can improve the user experience of real-world navigation in relation to the user's first point of view and in a way that is similar to that experienced in video games. This technology helps users' wayfinding and recognition of POI in unfamiliar areas, and furthermore improves safety and effective movement.

The increasing maturity of AR technology has increased the popularity of AR navigation, and the increasingly perfected user experience has also improved users' acceptance of AR navigation.

First, we classify AR navigation into the following categories: car navigation, wayfinding, indoor navigation, and navigation interface. Second, we identified their similarities and differences, mainly focusing on the navigation scene with special attention given to interactive sensors, visualization types and location-based data.

The following table (Table 2.6) summarises the data and characteristics of the related work of car navigation, wayfinding and indoor navigation.

Table 2. 6 Summary of the related work of Car navigation, Wayfinding and Indoor Navigation.

	Indoor	Outdoor	Location -based data	Direction	Interactive GPS	Interactive Image	Interaction Sensors compass gyroscope	Visualisation type		
								2D	2.5D	3D
Car Navigation										
Narzt et al. (2004)		Y	Y	Y	Y			Y		
Narzt et al. (et al. (2006)		Y	Y	Y	Y		Y	Y		
Sawano and Okada (2005)		Y	Y	Y	Y			Y		
Schneider et al. (2019)		Y	Y	Y	Y			Y		
Wayfinding										
Hile et al. (2008)		Y	Y	Y	Y			Y		
Kim et al., (2015)	Y		Y	Y		Y		Y		
Yokoi et al., (2015)	Y		Y		Y					Y
Muchtar et al., (2017)		Y	Y		Y			Y		
Yahoo Japan (2018)		Y	Y		Y			Y		
Diao and Shih (2018)	Y		Y		SLAM (Simultaneous localization and mapping)				Y	
Brata and Liang (2019)		Y	Y	Y	Y			Y		
Indoor Navigation										
Gerstweiler et al. (2016)	Y		Y	Y			Y	Y	Y	
Al Rabbaa et al., (2019)	Y		Y	Y			Y	Y	Y	
Al Delail et al., (2013)	Y		Y	Y		Y		Y		
Al Delail, Weruaga, Zemerly and Ng (2013)	Y		Y				Y	Y		
Mobidev Inc	Y		Y	Y	SLAM (Simultaneous localization and mapping)			Y		
Navigation Interface										
Google map navigation		Y	Y	Y	Y				Y	
Reiner et al. (2020)		Y	Y		Y			Y		
Huang et al. (2020)	Y		Y	Y			Y		Y	

In Section 2.2.1.1 Car Navigation, all articles show that car drivers can use the AR perspective to virtually overlay colour-coded lines and directional arrows on the road that the car is actually driving on, and furthermore overlay the road name, ETA (expected) arrival time and other driver-assisted information.

Wayfinding is different from navigation, which focuses on finding the correct or most suitable route. The functional focus is on the design of the instruction information superimposed on the mobile phone, so that the user can understand the information provided, allowing them to be guided to the destination.

If car navigation is based on outdoor navigation, indoor navigation uses AR indicator directions for iPhone (depth sensing) and Android (SLAM) to provide wayfinding to the destination.

2.2.2 POI Shown in AR View

POI shown in an AR view, displays information about POIs in mobile AR. Some researchers have called engagement with this information visualizing off-screen objects (Schinke et al., 2010). These researchers concluded that from the user's experience, 3D arrows provide a clear advantage over map-like methods.

Schinke et al. (2010) proposed the use of an AR arrow to indicate the existence of POIs. Participants' fast speed and use of visualisation technology enables them to more accurately explain the location of the POI. Figure 2.51 shows the arrow indicating a POI object.

Figure 2. 51 Arrow indicates the POI object. From "Visualization of off-screen objects in mobile augmented reality," by T. Schinke, N. Henze, and S. Boll, 2010, 12th international conference on Human computer interaction with mobile devices and services, p. 314 (https://doi.org/10.1109/ISMAR.2008.4637347). Copyright 2010 by IEEE.

Ruta et al. (2014) research proposed to embed a marker overlay in OpenStreetMap. This was done by providing POI explanations through the use of visual cues, enabling a quick and easy interaction. Figure 2.52 shows the visual POI with related information.

Figure 2. 52 Visual POI with the related information. From "A semantic-enhanced augmented reality tool for OpenStreetMap POI discovery" by M. Ruta, F. Scioscia, D. De Filippis, S. Ieva, M. Binetti, and E. Di Sciascio, Transportation Research Procedia, 3, p. 486 (https://doi.org/10.1016/j.trpro.2014.10.029). Reprinted with permission.

Hui et al. (2014) demonstrated that after users obtain POI data, they can record related data while simultaneously superimposing video and other information on the POI. Figure 2.53 shows the POI picture and routing that are connected to the user's standing position.

Figure 2. 53 POI picture and routing connect with user position. From "Mobile Augmented Reality of Tourism-Yilan Hot Spring" by L. Hui, F. Y. Hung, Y. L. Chien, W. Y. Tsai, and J. J. Shie, 2014, 2014 7th International Conference on Ubi-Media Computing and Workshops, p. 214 (https://doi.org/10.1109/U-MEDIA.2014.46). Copyright 2014 by IEEE.

Fedosov and Misslinger (2014) present a POI design for mobile AR using the Junaio AR browser in natural and uncontrolled environments. The study recruited 22 participants to identify the shortcomings of previous POI visualisation systems, and then explored a strategy for adaptively displaying POI visualisations on the screen. Figure 2.54 shows the redesigned POI visualization system after participant evaluation in their study.

Figure 2. 54 POI visualisation system. From "Location based experience design for mobile augmented reality" by A. Fedosov, and S. Misslinger, 2014, 2014 ACM SIGCHI symposium on Engineering interactive computing systems, p. 186 (https://doi.org/10.1145/2607023.2611449). Copyright 2014 by ACM.

Ruta et al. (2015) proposed the use of POI discovery for semantic enhancement in AR and accessibility-oriented indoor/outdoor navigation. Participants can match the user's profile with the surrounding POI notes on OpenStreetMap. Figure 2.55 shows the user's profile with the surrounding POI notes on OpenStreetMap.

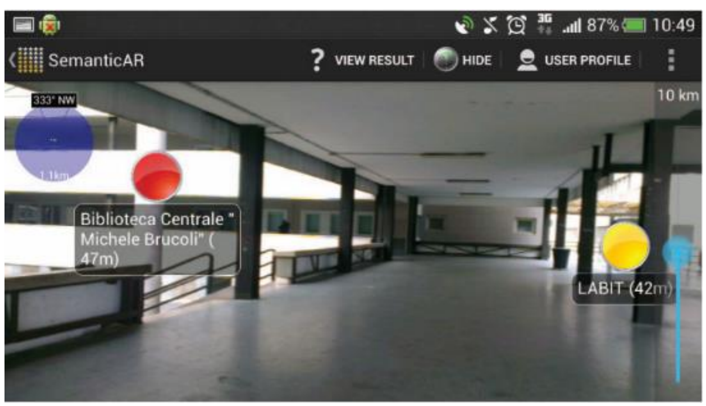


Figure 2. 55 User profile with the surrounding POI notes on OpenStreetMap. From "Indoor/outdoor mobile navigation via knowledge-based POI discovery in augmented reality," by M. Ruta, F. Scioscia, S. Ieva, D. De Filippis, and E. Di Sciascio, 2015, 2015 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT), p. 29 (https://doi.org/10.1109/WI-IAT.2015.243). Copyright 2015 by IEEE.

Besharat et al. (2016) came up with appropriate POI visualization methods to test enhanced paper map navigation that could be tested on tourists in a preliminary walk-through situation.

Sekhavat and Parsons (2018) explored how the wayfinding and navigation using location-based and marker-based AR technologies affect the quality of user experience. Figure 2.56 shows how POI can be augmented in a real scene.

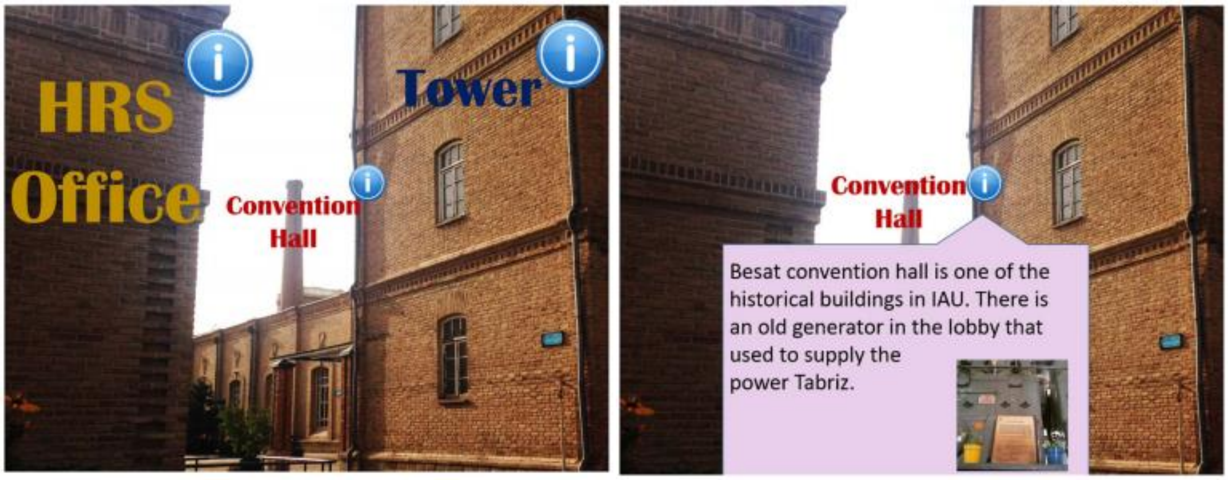


Figure 2. 56 POI augmented in a real scene. From "The effect of tracking technique on the quality of user experience for augmented reality mobile navigation" by Y. A. Sekhavat, and J. Parsons, 2018, Multimedia Tools and Applications, 77(10), P. 11646-11647 (https://doi.org/10.1007/s11042-017-4810-y). Reprinted with permission.

Carmo et al. (2020) have indicated that they are able to combine the AR view with the display of POI locations on the map to improve users' understanding of nearby POIs, by using hints relating to off-screen POI in the frame of the AR view boundary, and by providing a thumbnail view for the user. Figure 2.57 shows the display of POI on the AR view at the location.

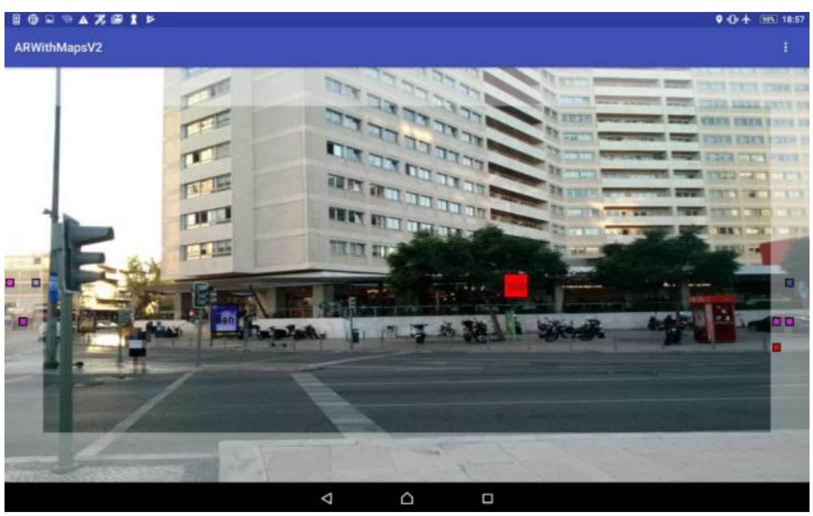


Figure 2. 57 AR view with the display of POI locations. From "Augmented Reality with Maps for Off-Screen POI Awareness." by M. B. Carmo, A. P. Afonso, M. Melo, B. Rocha, and V. Botan, 2020, Twenty-fourth International Conference Information Visualisation (IV), IEEE. p. 458 (https://doi.org/10.1109/IV51561.2020.00079). Copyright 2020 by IEEE.

2.2.2.1 POI Shown in AR View Summary

Augmented reality navigation is the research focus of our investigation, and POI display is used for AR view display on mobile phones, which is also the research focus of AR navigation. The exploration of the above two aspects aims to realize the narrative navigation in this investigation and, furthermore, how to use AR navigation, and the research situation that employs a POI AR display.

We discovered a lot of interesting phenomena in AR walking navigation, such as, for example, the use of continuous virtual arrows that can be superimposed on a road, providing a variety of AR information. There are also avatar navigation prompts, radar navigation prompts, distance and direction prompts, text information prompts, etc.

POI displays in an AR view is the first AR effect that participants explored when using a navigation application. According to the participant involved in the relevant scene, POI displays of different shapes, such as water droplets, cubes, and squares can be presented.

We have extracted ten common features from each section, and analysed the results of the following table.

Table 2. 7 Summary of the data and characteristics of the related work.

No.	Publications	Visual object	POI Visualisation (2D/3D)	Overlay information	Indoor/outdoor/ other
1	Schinke et al. (2010)	Arrow	2D	None	Outdoor
2	Ruta et al. (2014)	Circle with different colour	2D	Title and distance	Outdoor
3	Hui et al., (2014)	Building picture	2D	Title	Outdoor
4	Fedosov and Misslinger (2014)	Pin (water drop) and annotation	2D	Title and distance	Outdoor
5	Ruta et al., (2015)	Circle with different colour	2D	Title and distance	Indoor/outdoor
6	Besharat et al., (2016)	Cube	3D	ETA and distance	On the map
7	Sekhavat and Parsons (2018)	Interactive icons	2D	Description	Outdoor
8	Carmo et al., (2020)	Square	2D	Title	Outdoor

2.2.3 Discussion on Navigation Research to date

AR navigation is the research focus of the thesis, and POI display is used for AR view display on mobile phones, which is also the research focus of AR navigation. The exploration of the above two aspects aims to realize the narrative navigation of this paper, how to use AR navigation, and the research situation of POI AR display.

We found a lot of interesting phenomena in AR walking navigation, such as continuous virtual arrows superimposed on the road, showing a variety of AR information. There are also avatar navigation prompts, radar navigation prompts, distance and direction prompts, text information prompts, etc.

POI display in AR view is the first AR effect that participants are explored in a navigation application. According to the participant involved in the relevant scene, POI displays of different shapes will be presented, such as water droplets, cubes, and squares.

We extracted ten common features of each section, and analysed the result of the following Table 2.8.

Table 2. 8 Summary of the related work.

	Literature	Indoor	Outdoor	Location based data	Direction	Interactive GPS	Interactive Image	Interactive SLAM	Interaction Sensors compass gyroscope	Visualisation type		
										2D	2.5D	3D
AR Navigation												
Car Navigation	4		4	4	4	4			1	4		
Wayfinding	7	3	4	7	7	5	1	1		5	1	1
Indoor Navigation	5	5		5	3			1	3			
Navigation Interface	3	1	2	3	3	2			1			
POI Shown in AR View												
POI Shown in AR View	8	1	7	7	7	7	1			8		

As can be seen in Table 2.8, we identified 27 publications or AR applications showing location-based data and AR interactions, in which the navigation method tends to be the same, while the POI shape and display appear different depending on the application of the POI display. Although car navigation and indoor navigation belong to different categories, they both use the same navigation mode and use arrows to direct the user to the destination. Wayfinding focuses on the selection of different routes from the starting point to the destination, and provides further hints when the pathway/road forks and converges with different routes, allowing users to choose the correct route to reach their destination.

In summary, we have researched AR navigation and POI shown in AR view, anticipating that these two aspects of our investigation would enhance our knowledge of the digital prototype of AR narrative navigation.

2.3 Summary

In this chapter, we considered two aspects to analyse the state of the art: augmented reality and navigation. In augmented reality research, we examined augmented picture books, augmented maps/atlases, location-based augmentation and AR-supported data visualisation to analyse AR narrative storytelling. This aspect of the section focused on AR's role in the narrative process, analysing AR interactive and reactive locations and visualisation types.

In the navigation research, we investigated car navigation, wayfinding, indoor navigation and navigation interfaces. In addition, we have focused on the display of POIs in the AR view, and investigated the methods and approaches used for POI information display.

In summary, our related work in augmented reality and navigation research identifies the following commonalities:

(1) Either include location-based data or reacting to user location
(2) Interaction issues
(3) Visual indicator presentation
(4) POI visualisation
(5) Visualisation type of navigation information

In answering our key research question: *how to use Augmented Reality to visualise location-based information for navigation in a storytelling context, we* will address these key commonalities.

Chapter 3 Initial Digital Prototype

This chapter reports on our Initial Digital Prototype that focuses on narrative navigation using AR. POI are a core element of narrative navigation and we explore in our initial digital prototype which POI are suitable in our context. We particularly looked into options for POI to be avatars of the story chapter, and to design displays that are clear and free from environmental interference. In this chapter, we explore a number of options of using Augmented Reality to visualise location-based information for navigation in a linear storytelling context. We first sketched this design using the current concept and datasets (see Section 3.1). We then designed and tested which single POI display would be suitable for prototyping in the AR environment (Section 3.2). We finally experimented with how best to display the POI order within a storyline context, which we present in Section 3.3.

The Initial Digital Prototype was developed for the Android environment, and uses Unity 3D and C# as script control language to realize specific functions. The AR functions are based on the Vuforia engine. The outdoor GPS function uses an SDK from the unity asset store. We used example GPS locations of physical objects in a defined geographic location; specifically, significant trees in Hamilton, New Zealand. For the prototypes in this chapter, these tree locations were used to develop example POIs, for the purposes of visualising a story relating to those trees. Participants who are interested in tree stories can use the prototype to learn about the story of trees in the Hamilton area.

3.1 POI Scene Sketches

Our exploration began by looking into how to show the POI relating to a story, while indicating the narrative order.

For Scene Sketch Prototype 1, we used a Pokémon Go style tilted 2D map to display POI locations, as shown in Figure 3.1. In this prototype, three embedded red spheres are used to correspond to the respective coordinates of three POIs in the real environment.

Figure 3. 1 Scene Sketch Prototype 1, three POIs location on the map (Map data: ©Mapbox).

We identified in our analysis in Section 2.1.2.1 for Augmented Maps/Atlas, that 2D maps have data visualisation and map interaction issues. This 2D map interaction lacks immersion and a sense of direction from the above inference. It does not give the full advantage of AR elements as it doesn't overlay virtual objects onto the real world.

For Scene Sketch Prototype 2, we further explored 3D AR terrain maps, see Figure 3.2. The POI visualisation was simplified into 2D markers displayed above the 3D terrain model of Waikato in the AR view.

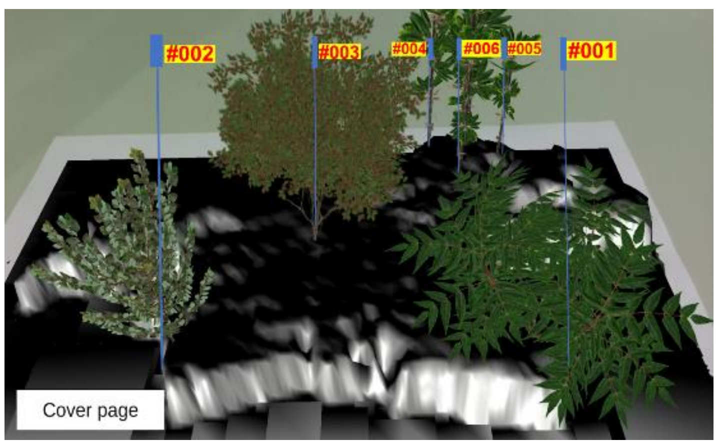


Figure 3. 2 More POI data visualisation of 3D terrain model of Waikato.

The map was found to be too complicated to create on the fly, and was furthermore resource-hungry. Although the 3D terrain model displayed an almost lifelike appearance, AR cannot show changes in position and height in real time. However, we took inspiration from the concept of the POI flags and textual information.

In sum, Scene Sketch Prototype 1 (tilted 2D map), and Scene Sketch Prototype 2 (3D map +2D text) do not display a real-time interaction with each POI and are complicated to create. We therefore explored a single POI display in AR view, as discussed in the next section.

3.2 POI Display Exploration

After the scene-level, we explored how to visualise location-based POI data that may appear in a story context as viewed through the mobile phone's camera. We first needed to choose a suitable object for signalling the POI, ideally a shape that both feels intuitive and obvious for the participants as a signal for locations. Due to challenges in identifying the contours of the landscape (for example, buildings), we decided to show the POI suspended in the air instead of touching the ground.

We designed a POI show in AR view that needs to display a POI avatar and text information. From the perspective of functional requirements, the location and information content of the avatar in AR view change dynamically with the user's movement. Based on the interference of the outdoor environment on the user's use, it is necessary to consider designing a simple and intuitive Avatar and information content. Therefore, we need to validate our design through experiments and determine the criteria for a POI approach suitable for narrative navigation.

To do this, we once more selected a simple 3D sphere as the POI avatar, which changes in size, depending on the distance to the participant (see Figure 3.3).

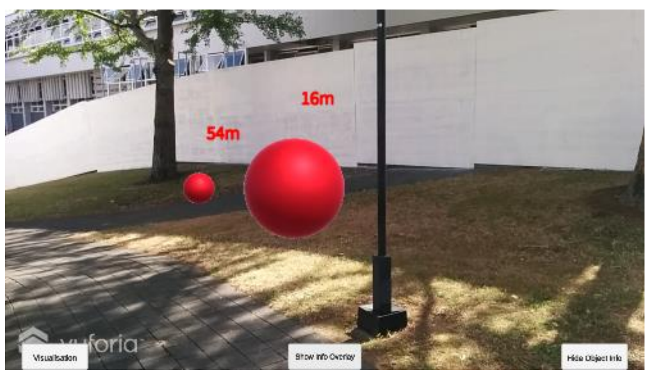


Figure 3. 3 Two spheres shown in campus of the University of Waikato (outdoor).

However, we observed conflicts between the POI during testing. The 3D red sphere is very eye-catching, the sphere is circular on the mobile phone and cannot display either the angle or direction of its orientation. It is also difficult to connect the avatar of the sphere with the tree as a POI. In addition, when we see the large sphere and small sphere in Figure 3.4, we spontaneously privilege the physical size of the POI instead of privileged the distance between the POI and user's location. In the AR view, the more distant POI is represented by a small sphere, while the large sphere makes that POI closer to the user.

Next, we used a tree 3D model as POI avatar, see Figure 3.4.

Figure 3. 4 Two tree models at the University of Waikato (outdoor).

The advantage of the tree avatar is that it is easy to be associated with the content of the story. However, even if it is floating in the air, it is easy to blend into the background of trees or grass, so it is not easy to identify.

In addition, the tree avatar display is very tall but very thin, which can easily cause the avatar to exceed the top or bottom border of the mobile phone display. The content of the story chapters of the tree is not limited to the same kind of tree, but the avatar of all kinds of trees is the same, which leads to the user being easily misled and unable to distinguish between different tree species. However, if different avatars were displayed, the POI display would be too complicated.

For our third choice, we experimented with a 3D flag as a POI avatar (see Figure 3.5), as a means of showing a flag with no angled POI in the AR view. Figure 3.6 shows two flags with angle POI in AR view.

Figure 3. 5 Flag with no angled POI in AR view.

Figure 3. 6 Flags with angled POIs in AR view.

The advantage of the 3D flag avatar is that it has a suitable aspect ratio, and it does not make the user feel incongruous when it appears beyond the boundaries of the mobile phone display. Also, the 3D flag avatar, with a black background floating in the air, won't interfere with the background itself. A 3D flag avatar with no angle visible area is normal, but an angled 3D flag reduces the visible area of the flag.

So far, the size of each avatar relates to their distance from the user's location. When the distance between the user and the POI is significant, the avatar becomes too small (and thus hard to see) or the distance between the user and the POI is shorter, and the avatar becomes too big (thus obstructing the view). We therefore concluded that we need the POI avatars to not change in size in response to the distance they appear to be from the user.

With regards to the fourth prototype, we used a 2D flag as a POI indicator (see Figure 3.7). The flag uses a fixed size on a real-world background, eliminating angle and directional indications.

In this experiment, we added the distance to the POI to each flag and used different colours to identify different POI.

Figure 3. 7 Two flags of final design at the University of Waikato (outdoor).

As a result of the experiment, the 2D flag avatar is identified as the best POI display for our Initial Digital Prototype. The related Table 2.7 of the POI shown in AR view also shows that 7 of 8 POI visualisations are POIs using 2D avatar as the visual AR application indicator.

Our analysis concluded that using a 2D flag avatar is a good way to avoid the above problem. Two dimensioned flattened and fixed-size flag avatars make the appearance of all POI avatars highly consistent and maintain the user's perception of the directionality of the mobile AR interface.

We also added high-contrast-coloured numbers to the 2D flag avatar with a black background to indicate the distance between the user's location and the POI.

3.3 Prototyping Narrative Order

Having settled on using the flag icon for POI indication, we wanted to explore how the five-chapter story order (a central concept of narrative navigation) would be presented.

Firstly, we started by setting the order of story chapters to follow the order colours of the POIs, these colours being white, magenta, green, red, and yellow. We did this because the Initial Digital Prototype needs to capture the image of the rear camera in real time, and the display of the content superimposed on the image needs to consider both current and various lighting and natural environments, especially the outdoor environment. The colour order presents the chapter order of the story, and the visual POI colour allows participants to see the direction and distance of the target POI more clearly.

Second, we used black as the POI background colour, as black is difficult to mix with other colours, and because it shows up clearly in most weather conditions. The colours that contrast with black are white, magenta, green, red, and yellow, which are the colours which represent the distance between the location of the user station and the location where the story chapter is located.

Third, we needed to find a way to visualise the order of the stories in a way that was obvious to the participants and easy to understand. We explored and implemented two ways of ordering the stories: bottom-to-top and top-to-bottom to display POIs separately. The bottom-to-top POIs display means that flags shown near the bottom refer to near objects, and flags shown near the top refer to objects that are in the distance, and vice versa, the top-to-bottom POIs display presents the top is near and the bottom is far in distance.

Finally, we explored the POI avatar display through the following question: how can we find a reasonable way for the AR view to display multiple POIs clearly and neatly on one screen?

POI Display in AR View Description

First, we assume that the choice of a location needs to be based on the resolution of the test phone. Neither the leftmost nor the rightmost POI can be displayed beyond the left and right borders of the screen. We called this location an overview location. When the participant stands in the overview location (see Starting Point in Figure 3.8 A), the participant sees a view within the triangle through the camera. From this perspective, the participant sees a plane perspective view (see Figure 3.8 B). We converted the five story chapters into their corresponding AR virtual objects (see Figure 3.8 C), which were then superimposed on the real scene in order of ordering the bottom-to-top of the story (see Figure 3.8 D1) or ordering the top-to-bottom story (see Figure 3.8 D2). Figure 3.8 shows the AR system diagram of the Initial Digital Prototype.

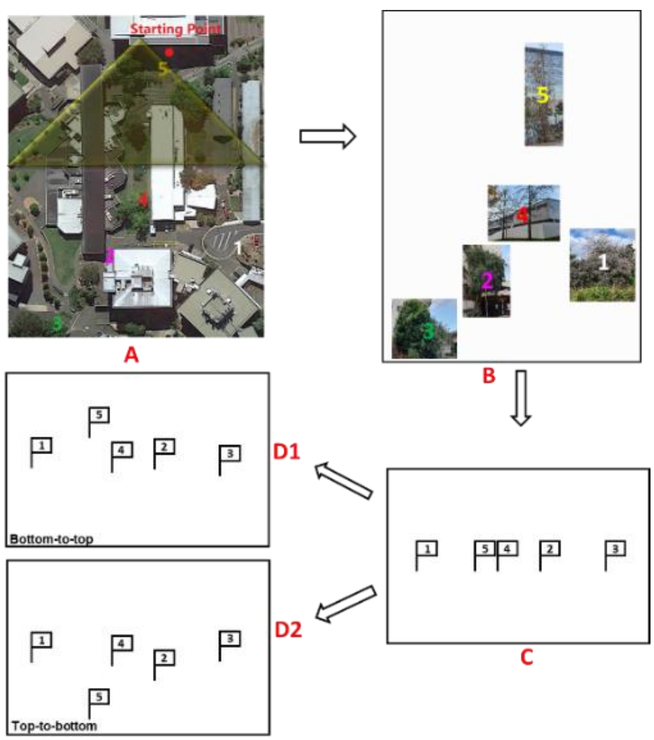


Figure 3. 8 The AR system diagram of the Initial Digital Prototype (Maps data: Google, ©2020).

Following the design shown in Figure 3.8 D1 and Figure 3.8 D2, we developed the bottom-to-top of the story version and the top-to-bottom story versions of the Initial Digital Prototype. Next, we did a walk-through, and we stood in an overview location. The test mobile phone with the Initial Digital Prototype showed the 5 POIs avatar in the AR view. The following screenshots show the test results of the two versions. The order of the narrative POIs at this time is indicated by the marker height: the lowest marker represents the first/next narrative POI (version A, see Figure 3.9a), and the highest marker represents the next narrative POI (version B, see Figure 3.9b).

Figure 3. 9 a) Version A test of Outdoor AR: ordering bottom to top (left) b) Version B test of Outdoor AR: ordering top to bottom (right).

Each black flag represents a story chapter in the story, and the numbers with different colours indicate the straight-line distance between the participant's location and the story chapter. The order of the five story chapters from top-to-bottom or bottom-to-top is sorted by distance, meaning that the story chapters that are further apart in both versions are displayed either at the top or at the bottom.

3.4 Discussion & Summary

In this chapter, we explored which scene and which POI avatars are suitable for Initial Digital Prototyping. In Section 3.1, we designed two Scene Sketch Prototypes, the first prototype used tilted 2D map and the prototype 2 used 3D map + 2D text. The two Scene Sketch Prototypes were difficult to use to show real-time interactions with each POI. Next we explored a single POI display in AR view.

Many researchers (Carmo et al. (2020), Fedosov & Misslinger (2014), Hui et al. (2014), Ruta et al. (2014), Ruta et al. (2015), Schinke et al., 2010), Sekhavat & Parsons (2018)) have used 2D avatars as POI display features in AR view (see Table 2.7). We wanted to test in our research whether 2D avatars are suitable for POI display in AR. From the study described in this chapter, we have been able to identify the pros and cons of 2D vs 3D avatars in AR, as outlined in Table 3.1.

Table 3. 1 Comparison of 2D avatar and 3D avatar in AR view.

	Avatar	Pro	Con
1	2D Avatar	Same image size, no deformation	not vivid avatar
		Intuitive and clear feeling	monotonous and dull
2	3D Avatar	can catch the participant eyes and pay attention	need to suitable for real environment
		AR effect give feels of presence and participation for the participant	need participant to see avatar's front appearance

In Section 3.3, we developed Initial Digital Prototyping including two versions: bottom-to-top and top-to-bottom display POIs and focus on each POI narrative order in AR view of a story.

The finding of Initial Digital Prototype is to find which POI is suitable for the display design and function design of the narrative navigation prototype. We designed a 2D black background flag as the POI avatar, and used different colours to represent different POIs. The numbers in the flags represent the distance from the POI to the participant's location. All flags are presented in a flat view through the camera.

In the next chapter, we describe our prototype evaluation in the form of a user study.

Chapter 4 Prototype User Study

In this chapter, we focus on the evaluation of the Initial Digital Prototype introduced in Section 3.3, with the aim to identify which version of the ordering visualisation is better suited to guide users through the order of the linear story. This chapter presents expanded findings based on the early publication *Narrative Navigation: Visualizing Story Order and Locations in Augmented Reality* (Zhang et al., 2020).

4.1 Study Setup

The study was carried out at the University of Waikato. The application was set up with five narrative elements (prominent tree locations, see Figure 4.1). Each participant was guided to a starting point (see top of Figure 4.1). We used different colours to represent POIs (trees): white, magenta, green, red, and yellow. The location of the trees in the application visualisation corresponds to the screen position of the icon. Participants followed the guidance of the initial digital prototype, and were asked to visit each tree in order.

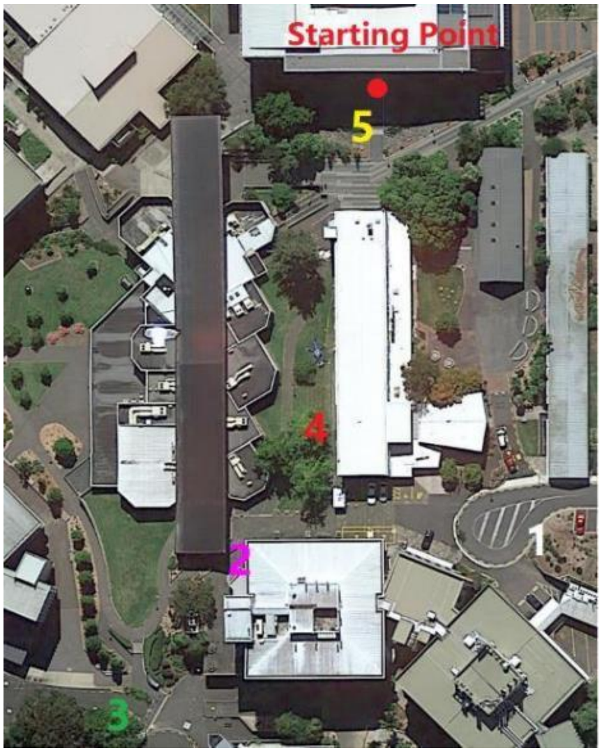


Figure 4. 1 Five POIs metadata for the user study (Maps data: Google, ©2020)

4.2 Participants

Over the two trials, 15 University students and lecturers participated in the Prototype walk-through, with ages ranging from 20 years to 50 years, 8 females and 7 males. Ten participants were from the School of Computer Science, 2 were from the School of Engineering and 3 participants from the Design Department. Twelve of the participants were Bachelor, Master and PhD students, and 3 participants were university lecturers. Here Computer Science and Engineering belong to Computer Science Background, Designer belongs to Non-Computer Science background.

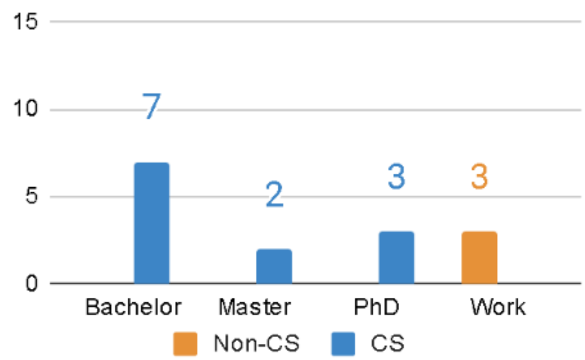


Figure 4. 2 Demographic information

4.3 Study Process and Interview

Ethical approval for this study was given by the Departmental Ethics Committee. All participants consented to participation in this study and agreed to be interviewed.

The interview is a process of gathering information. In the interview, the interviewer prepares questions, and the interviewee answers these questions. The purpose of interviews in our study is to look for the best way in which to identify the display of the AR story location in five story chapters to a user. Interviews were conducted face-to-face and were designed according to different situations. Interviews are normally of the following three types: structured interviews, semi-structured interviews, and unstructured interviews. We set two pre-study questions to collect demographic data, two questions to collect all participants' background of map navigation and location-based augmented reality, and four preference choice questions to know participants' feedback of our narrative navigation concept. We chose to use a semi-structured interview, using fixed questions with the option to ask additional questions that narrowed participants' responses and avoided irrelevant answers.

Participants were tasked with first engaging with two pre-study questions and walk-through two versions of the Initial Digital Prototype before answering four questions at the end of the interview. During the walk-through, the participants used two versions of the APP on our Android phones, followed the tour route in Figure 4.1, and visited each tree one by one.

The study proceeded as follows: with the two initial questions, we aimed to survey participants' preliminary experience (see question Q1 and Q2 in Table 4.1). The participants then used versions A and B of the prototyping. Half of the participants began with Version A (ordering bottom-to-top) of the prototyping, the other half began with Version B (ordering top-to-bottom) of the prototyping. During the participants' participation in the prototyping test, they were asked to follow the narrative to the correct position. We made written notes when the participant reached the correct location. After using the prototyping, participants were then asked questions Q3 to Q6 (see Table 4.1).

The following table shows the questions including demographic information, background questions, and preferences questions.

Table 4. 1 Questions asked about application perceptions interface.

Part 1: Demographic Questions	
DQ1	Age, Occupation
DQ2	Computer science background / Non computer science background
Part 2: Background Questions	
Q1	Do you have experience using a map for navigation? (never, rarely, occasionally, often)
Q2	Do you have experience using location-based augmented reality? (never, rarely, occasionally, often)
Part 3: Preferences Questions	
Q3	Do you prefer version A or version B? Why?
Q4	Please rate how much you agree with the following sentence: "It was easy to navigate to the correct next location in the story". (completely agree, somewhat agree, neutral, somewhat disagree, completely disagree)
Q5	For your preferred version: If you could change two things, what would these be?
Q6	Any other comments or questions?

After asking pre-study questions shown in Table 4.1, we guided each participant to do a field test with the two versions of the Initial Digital Prototype. Finally, after prototyping the testing, the participants were asked the preferences questions. This interview would no longer than 30 minutes.

4.4 Results

Here we outline the results of our user study.

4.4.1 Background and navigation results

The results of Question 1 (Do you have experience using a map for navigation?) are shown in Figure 4.3. We can see that almost all participants had experience of mobile map navigation.

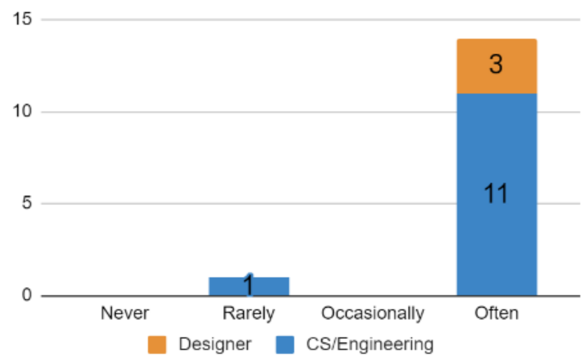


Figure 4. 3 Experience with mobile map navigation - Q1.

The results of Question 2 (Do you have experience using location-based augmented reality?) are shown in Figure 4.4. We see that the participants had almost no experience of working with location-based AR.

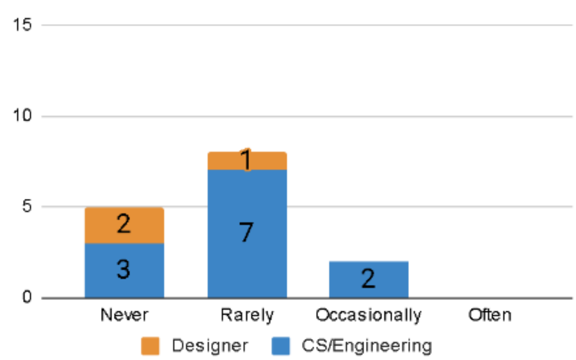


Figure 4. 4 Experience with location-based AR - Q2.

Nine of the 15 participants successfully managed to identify the next location in the narrative.

The other participants could either not decide on the correct location based on the information provided, or struggled to identify the location as they moved closer. Some people arrived at the right location and yet only found it by turning around and looking for it.

4.4.2 Reflection on Study Experience

Figure 4.5 shows 12 of 15 participants preferred version A of the Initial Prototyping. These 12 participants commented that having the marker indicating the next location shown closest to the bottom was more in line with their expectations in terms of the closest location to visit. These participants felt that the top position on the mobile phone screen represents a far distance location (later to visit) and the bottom position of the mobile phone screen represents a near distance location (earlier to visit). A mismatch between the order and distance on the mobile phone screen can cause cognitive problems.

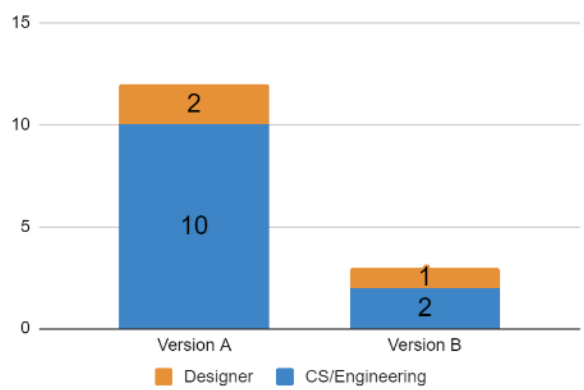


Figure 4. 5 Preference for Version A and Version B - Q3.

Figure 4.6 shows the results for Question 4 (Ease of use). Only 5 of 15 participants thought this application was somewhat easier to navigate to the correct next location, while 9 of 15 participants did not think this to be the case.

We note that all 3 design participants strongly disagreed with the claim that the visualisation was easy to use.

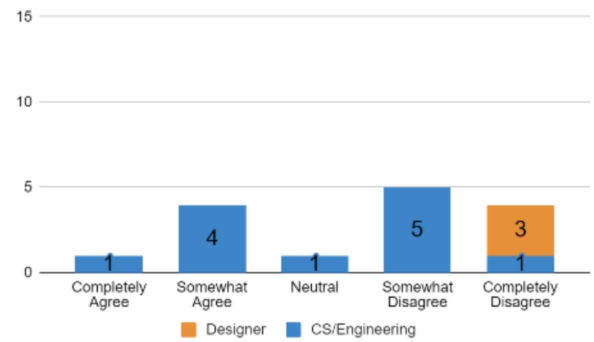


Figure 4. 6 It was easy to navigate to the correct next location in the story - Q4.

Question Q5 asked for suggestions on what to change in the visualisation. Several participants suggested providing more object information and more information about the direction (for example, through virtual arrows) to find the correct location.

Comments for Q6 (Any other comments or questions?) also confirmed that the visualisation should enhance the connection between the story and the geography, and show more information about locations through the mobile interface. Several participants indicated, in their answers to questions Q5 and Q6 that they thought directional arrow would help find the right tree.

Table 4. 2 Summary of participant feedback on directional perception

Participant ID	Which question	Participants answers
P1	Q5	*"When [getting] closer to a tree [it is] better to blink the icon with a small sound notification, touch on a flag and see the information about the tree before visiting [..] it."*
P3	Q5	*"I think [it] needs to add a direction indicator […]."*
P4	Q5	*"There is a need for a better explanation of […] what is indicated as a location in the story; I seem to be disconnected from trees in any real interface."*
P13	Q5	*"Add compass direction and [location details] "*
P14	Q5	*"Increase objects specific direction and reduce GPS deviation"*
P8	Q6	*"I suggest adding an indicator arrow to direct users to the tree; distance alone cannot give participants clear instructions."*
P13	Q6	*"Add a navigation function for easy walking, driving, and cycling."*

4.4.3 Additional Observations

During the user study, some participants found the app may lose GPS signal for some time, and the navigation lags behind the user's movements. At other times, the GPS signal was not accurate and showed deviation from the actual locations. Both of these features/phenomena were confusing for the participants and need to be addressed.

4.4.4 Summary of Observations

Several participants in the user study had difficulty identifying the correct location, or quickly navigating to the correct place in the story. We summarized the participants' feedback using the following statements to best capture their opinions:

- The icon of the nearest location in the narrative should be shown at the bottom of the mobile screen (Version A).
- It is difficult for the application's navigation method to find the correct tree location.
- It is hard to understand location-based AR navigation when using location markers.
- The connection between AR and storytelling needs to be made stronger.
- Add navigation paths and directions to the user destination.

Most participants thought that Version A (bottom to top) was easier to follow than Version B (top to bottom). Participants preferred that the bottom of the mobile phone screen displayed the next tree to visit. Nine of the 15 participants did not find the application easy to use. Some participants proposed that the App should add new functions, such as direction and object information.

4.5 Discussion and Summary

This chapter explored the user preferences for POI visualisation order (top-to-bottom or bottom-to-top) on the mobile screen, and the ease of use.

This user study found that it was hard for this group of participants to navigate to even just 5 selected locations that are indicated with typical POI markers using AR. This is an interesting observation as our study replicated the visual methods used in most of the existing AR location frameworks. The only difference was that instead of using the markers as additional location information, users were tasked with identifying and walking towards a specific location (connected to a narrative structure). This may explain/indicate why many newer works on AR navigation focus on single points to be reached instead of showing the complete selection of POIs. Unfortunately, this is not applicable for narrative navigation, as the user needs to have the option of engaging with a later part of the story that is nearer their current location, instead of walking to the next part and having to return. When participants see many POIs shown in AR view overlayed on their camera view, it was difficult for them to focus on the linear view of the POI order.

From the number of comments from participants asking for navigational arrows and directions, it became apparent that the participants expected much better navigation assistance relating to those aspects of the story that require detailed data about the surrounding geography. This goes beyond what is typically provided in AR interfaces or in interfaces for narration that use maps with POI indications.

While not made explicit by any participant, the researchers formed the impression that the participants expected the nearest place to be the next place in the narrative structure. This aspect needs to be explored further.

The identification of the correct place was hindered by the number of trees available in the vicinity. While many participants managed to walk toward the correct location, the fine details of identifying the correct ones were found to be poorly supported. Here, the use of an AR visualisation radar function to retain information of areas behind the users, and indication of near range of a desired location could be helpful.

We observed that the concept of narrative navigation (navigating to the next place in a story) was difficult for the participants to grasp. In our test App, the narration would not be included but only simulated, and our results have indicated that narrative content should be used in the next digital prototype.

show that this aspect should be fully implemented for testing as narrative navigation would seem to be an unfamiliar concept. This prototyping explored the use of AR markers to aid narrative navigation.

We analysed the six questions of the interview, and found some interesting opinions for further research. Many users expected single location navigation to replicate the familiar mobile map navigation.

We explored two options for visualising story order and locations in AR, and found that the participants strongly preferred the story order of the “bottom to top” (Version A) approach.

The gap between the proportion of participants with computer background and non-computer background is too large, and the threat to the internal and external validity of the experiment needs to be considered.

In summary, from an analysis of the results, we found that need to be explored more fully:

1) How to sort the story order
2) Whether the POI sort order should be determined by distance or by story

In the next chapter, we follow these two questions to expand the research further.

Chapter 5 Order by distance vs order by story (Paper Prototype Study)

This aspect of our investigation is driven by the observations reported in Chapter 5 relating to the question of how to sort the story order by distance or by story. In order to accelerate our study of user responses, we developed a Paper Prototype to collect participants' feedback.

5.1 Design of Paper Prototype

We here use a paper prototype instead of a digital prototype because paper prototypes can be created and updated more quickly. Paper prototypes also don't have the time expense and environmental distractions of walkthroughs.

The design of the Paper Prototype involves addressing the question of how to navigate a location-based story using AR. This design required displaying distance, story order, and directions visually on a mobile screen to assist participants in conducting narrative navigation.

Design Change of POI Avatar

We still followed the design of the Initial Digital Prototype and had the participants visit five locations in order to experience the story. Based on the feedback reported in Chapter 5, we revised the black background of the flag's avatar, and introduced red markers (stylized flags) to indicate the next location in the story, and blue markers for all other locations.

Design Change of POIs Height on Screen

Another change involved setting the height of each flag to display on the screen, at a different height, to display distance or story flow. The story order by distance extends from the bottom flag to the top flag, or from top flag to the bottom flag. The longitudinal distance between each POI is designed to be equidistant, so that participants will not misunderstand that the distance corresponds to the actual distance between POIs. For example, Figure 5.1 shows the story order by distance as it extends from the bottom flag to the top flag.

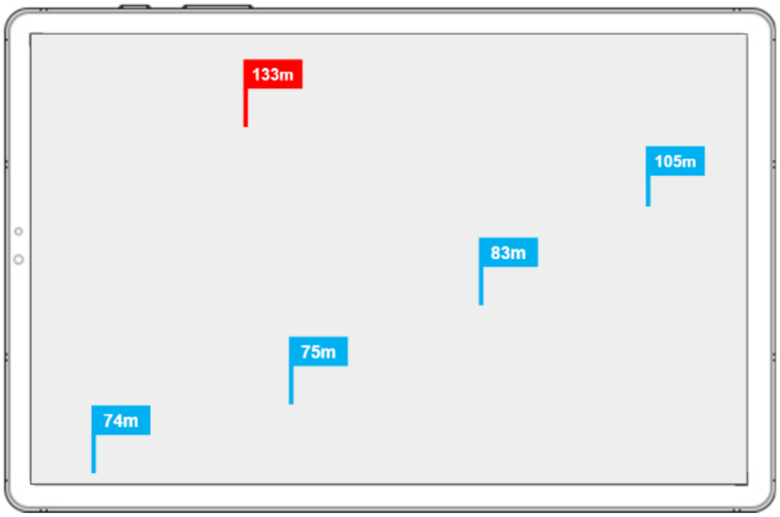


Figure 5. 1 The user interface (UI) design of the prototype.

Design Change of POIs Order on Screen

We combined four different ways of representing information in the prototype. We needed to show the user how to navigate from the first location to the next location, as well as in what order to navigate each of the locations in the interface displays. The interface shows 5 locations to navigate to (see Figure 5.1), therefore a user needs to understand in what order to visit these locations. This means there are four ways of representing this information (see Table 5.1). Near-Low (Distance) orders flags by distance with flags at the bottom of the screen being close to the viewer (by distance) and flags at the top of the screen being far from the viewer (by distance). Similarly, Near-High (Distance) orders flags by distance with flags at the top of the screen being close to the viewer (by distance) and flags at the bottom of the screen being far from the viewer (by distance). When ordering the flags by story order, Next-Low (Story) orders flags by story or chapter order with flags at the bottom of the screen being the next chapter in the story for the viewer to visit and flags at the top of the screen being later chapters in the story. Similarly Next-High (Story) orders flags by story order with flags at the top of the screen being the next chapter in the story for the viewer to visit and flags at the bottom of the screen being later chapters in the story.

Table 5. 1 Order element of representing information.

Name	Code	Order	Description
Near-Low (Distance)	NL-D	Order by distance	high is far / low is near in distance
Near-High (Distance)	NH-D	Order by distance	high is near in distance/ low is far
Next-Low (Story)	NL-S	Order by story flow	high is last / low is next in story
Next-High (Story)	NH-S	Order by story flow	high is next in story/ low is last

Design Change of Participants involvement

We would hire more participants in the Paper Prototype than the Initial Digital Prototype, and would focused on discussing the different opinions of participants' perceptions of the information from computer science background and non-computer science background.

5.2 Evaluation Setup

Our evaluation is based on four-story order, which includes two "order by distance" and two "order by story flow" examples. We describe the evaluation setup for each different story order.

5.2.1 Story Chapter Design

We introduce the design of the story chapter, and the POI display in AR view as well as the concept of 'overview' location.

We still used the map of Initial Prototype, and we have added two 'Overview' locations (see white number 1 and number 2 on the red background in Figure 5.2). The map in Figure 5.2 shows the location of each story chapter (see the sky-blue numbers 1, 2, 3, 4, and 5 on the left in Figure 5.2) and AR view seen in Overview 1 (top right in Figure 5.2) and AR view seen in overview 2 (bottom right in Figure 5.2) in the story.

Figure 5. 2 The map of the Paper Prototype (left) and AR views (right top & bottom) seen in two overview locations (Captured by Qimo Zhang) (Maps Data: Google, ©2020).

In the Paper Prototype, the AR views according to which we need to investigate the ordering of the story are based on Overview 1 and Overview 2.

In the upper right corner of Figure 5.2, the participants stand at the location of Overview 1 and look at the 5 POIs. The order of POIs displayed on the screen from left to right is the same as that displayed on the map in Figure 5.2 from left to right when participants stand at Overview 1. All POIs displayed in the AR view are sorted from top to bottom by distance, and the POIs with the longest distance are displayed at the top. The rationale of Overview 2 in the lower right corner is the same as Overview 1.

5.2.2 Order by Distance in the Five Story Chapters

In Section 4.4 on the study results, we analysed feedback from the participants on whether sorting by distance or by story order was the best way to identify the location of each chapter of an AR story.

First, we investigated the order by distance.

Near-Low (Distance)

Each flag has a different height. The flag height appears in order according to the distance indicated. The distance of flow is increasing from the bottom flag to the top flag. Figure 5.3 shows the Near-Low (Distance) prototype from the location of Overview 1 (see Figure 5.2). In Figure 5.3, we can see that the red flag is the next location to visit and is a distance of 133 metres from the user. It is positioned as the highest flag in the interface because it is the farthest flag away from the user, even though it is the next story chapter to visit. This Near-Low (Distance) prototype shows flags ordered by distance with the nearest locations at the bottom of the interface (in this case a location that is 74m from the viewer) and the farthest locations at the top of the interface (133m from the viewer). The only way for the user to understand in what order to visit the locations is through viewing the indication of the "next" story chapter, which is shown as a red flag. No other story order indication is provided for the user in this prototype. Figure 5.4 shows the Near-Low (Distance) prototype from the Overview 2 location (see Figure 5.2).

Figure 5. 3 AR view of the Near-Low (Distance) version seen in overview 1 (Captured by Qimo Zhang).

Figure 5. 4 AR view of the Near-Low (Distance) version seen in overview 2 (Captured by Qimo Zhang).

Near-High (Distance)

Each flag has a different height. The flag height appears in order according to the distance indicated. The distance flow is increasing from the top flag to the bottom flag. Figure 5.5 shows the Near-High (Distance) prototype from the location of Overview 1 (see Figure 5.2). In Figure 5.5, we can see that the red flag is the next location to visit and is a distance of 133 metres from the user. It is positioned as the lowest flag in the interface because it is the farthest flag away from the user, even though it is the next story chapter to visit. This Near-High (Distance) prototype shows flags ordered by distance with the nearest locations at the top of the interface (in this case, a location that is 74m from the viewer) and the farthest locations at the bottom of the interface

(133m from the viewer). The only way for the user to understand in what order to visit the locations is through viewing the indication of the "next" story chapter which is shown as a red flag. No other story order indication is provided for the user in this prototype. Figure 5.6 shows the Near-High (Distance) prototype from the Overview 2 location (see Figure 5.2).

Figure 5. 5 AR view of the Near-High (Distance) version seen in overview 1 (Captured by Qimo Zhang).

Figure 5. 6 AR view of the Near-High (Distance) version seen in overview 2 (Captured by Qimo Zhang).

5.2.3 Order by Story Flow in the Five Story Chapters

Second, we investigated the order by story flow.

Next-High (Story)

Each flag has a different height. The height of the flag indicates the order by the story flow. The story flow extends from the top flag to the bottom flag. Figure 5.7 shows the Near-High (Story) prototype from the location of Overview 1 (see Figure 5.2). In Figure 5.7, we can see that the red flag is the next location to visit and is a distance of 133 metres from the user. It is positioned as the highest flag in the interface because it is the first chapter of the story. This Near-High (Story) prototype shows that the flags are ordered by story, with the first story chapter at the top of the interface (in this case, the location is 133m from the viewer), while the last story chapter is at the bottom of the interface (74m from the viewer). The only way for the user to understand in what order they should visit the locations is by recognizing the indication of the "next" story chapter, which is indicated by a red flag. No other story order indication is provided for the user in this prototype. Figure 5.8 shows the Near-High (Story) prototype from the Overview 2 location (see Figure 5.2).

Figure 5. 7 AR view of the Next-High (Story) version seen in overview 1 (Captured by Qimo Zhang).

Figure 5. 8 AR view of the Next-High (Story) version seen in overview 2 (Captured by Qimo Zhang).

Next-Low (Story)

Each flag has a different height. The height of the flag indicates the order of the story flow. The story flow is increasing from the bottom flag to the top flag. Figure 5.9 shows the Near-Low (Story) prototype from the location of Overview 1 (see Figure 5.2). In Figure 5.9, we can see that the red flag is the next location to visit and is a distance of 133 metres from the user. This flag is positioned as the lowest flag in the interface because it is the first chapter of the story. This Near-Low (Story) prototype shows flags ordered by story with the first story chapter at the bottom of the interface (in this case, the location is 133m from the viewer), while the last story chapter is at the top of the interface (74m from the viewer). The only way for the user to understand in what order to visit the locations is by recognizing the indication of the “next” story chapter, which is shown as a red flag. No other story order indication is provided for the user in this prototype. Figure 5.10 shows the Near-Low (Story) prototype from the Overview 2 location (see Figure 5.2).

Figure 5. 9 AR view of the Next-Low (Story) version seen in overview 1 (Captured by Qimo Zhang).

Figure 5. 10 AR view of the Next-Low (Story) version seen in overview 2 (Captured by Qimo Zhang).

Within the field of human-machine interaction, the user-centred design process is a widely used method. Designers use surveys and interviews to understand user needs. With this approach in mind, we designed the interview through drawing on the framework to understand the user's perception of the four-story order of Paper Prototype.

5.2.4 Participants

In order to test user perceptions of directionality in mobile AR interfaces, we invited 30 participants to an individual Interview to collect feedback to explore the best way to display AR story locations to a user. All participants are members of different groups or clubs that we belong to.

Of our 30 participants, 20 of these were Computer Science (CS) PhD students, CS Master's students, CS Bachelor students, Engineering PhD students, Environmental Science PhD students, with 3 people being from the workforce. The other 10 were from Non-CS backgrounds, including Electric Engineering, postgraduate Education, postgraduate Social Science, Marketing, and postgraduate Business Management.

The interview of each participant took 20 minutes. Of all participants, 27 agreed to be audio recorded.

Before we began our research, we applied for and received ethical approval from the HECS Ethics Committee. All participants consented to participate in this study, as well as to be interviewed.

5.2.5 Interview Questions

The interview questions include general background and experience questions, four sets of navigation questions and preferences questions (see Table 5.2). The general questions focus on whether participants have experience using both a map for navigation and location-based AR.

In the first part of the three-part interview, we asked participants a demographic question to understand what background the participants had. In the second session, we surveyed participants' familiarity with map navigation and location-based AR (Q1 and Q2). After participants tested the prototype, we collected feedback on narrative navigation (Q3 to Q6) and on order by distance and order by story flow (Q7 to Q9).

Table 5. 2 Questionnaire of the paper prototype.

Part 0: Initial Questions
Ask participant's gender, age, and occupation questions.
Part 1: Background Questions
1) Do you have experience using map for navigation?
[1] Never [2] Rarely [3] Occasionally [4] Often
2) Do you have experience using location-based augmented reality?
[1] Never [2] Rarely [3] Occasionally [4] Often

Part 2: Navigation Questions
Before asking the four sets of questions, I will confirm the participant to know the correct next location and the correct order.
3a/4a/5a/6a) which location should you visit next?
3b/4b/5b/6b) in which order should you visit the five locations?
And then I observe to what extent the participant identifies the next location or the order, and whether it is easy to navigate the next location or the correct order?
3c/4c/5c/6c) How much do you agree with the following statement? I am confident that I can identify the next location in the story.
[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree
[5] Somewhat Agree [6] Agree [7] Completely Agree

3d/4d/5d/6d) How much do you agree with the following statement? Is it easy to navigate the next location in the story?
[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree
[5] Somewhat Agree [6] Agree [7] Completely Agree

3e/4e/5e/6e) How much do you agree with the following statement? I am confident that I can identify the order of the story.
[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree
[5] Somewhat Agree [6] Agree [7] Completely Agree

3f/4f/5f/6f) How much do you agree with the following statement? Is it easy to navigate the correct order of the story?
[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree
[5] Somewhat Agree [6] Agree [7] Completely Agree

Part 3: Preferences Questions
The final problem is to compare different versions in pairs, and then produce a final result.

7) Which version do you prefer in order by distance?
[1] Near-High (Distance) Version [2] Near-Low (Distance) Version
Why: ______________________

8) Which version do you prefer in order by story flow?
[1] Next-High (Story) Version [2] Next-Low (Story) Version
Why: ______________________

9) Which one of the two sets of photos do you like?
[1] Q7's answer [2] Q8's answer
Why: ______________________

5.2.6 Interview Process

We began the interview by gathering some more detailed demographic data – including, gender, age, and occupation. Then we asked the background questions. When asking the participant navigation questions, we needed to ask questions "a" to "f" separately for each story order of NL-D, NH-D, NL-S, and NH-S (Part 2 of Table 5.2). NL-D, NH-D, NL-S and NH-S have a total of 24 combined sequences. Of the 30 participants invited, the first 24 participants used the 24 combinatorial sequences, while the remaining 6 participants used 'the first to sixth' of the 24 combinatorial sequences. At the end, preference questions are asked, with the participant stating their answer and then stating the reason for their choice.

This study adopts an interview method instead of an observation method. When most of the participants do not know the concepts of location-based AR and narrative navigation, using a face-to-face questionnaire allows the researcher to clarify and explore the questions quickly at the interview site.

The interview scene is shown in Figure 5.11.

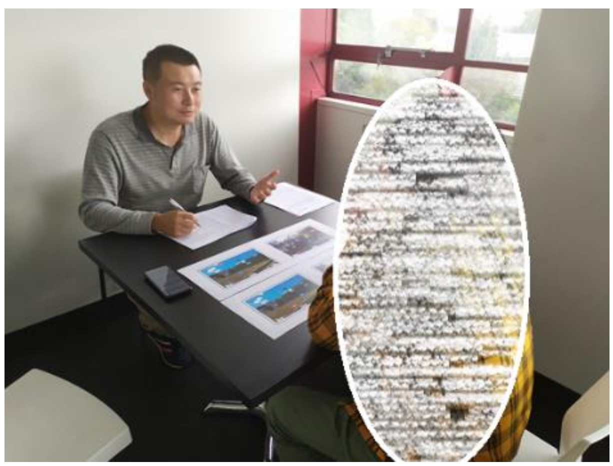


Figure 5. 11 The interview scenes. Photography by Qimo Zhang.

5.3 Results and Analysis

After we finished the interview process, we collated, categorised, and classified each answer from each participant, and compared and analysed these collected results.

5.3.1 Participant Background

The interviews were held over a period of 20 days in September 2020.

We enlisted 30 people, whose age ranged from 19 to 60 years old, 14 of whom were female and 16 were male. Twenty-seven of the participants are foundation, Bachelor, Master and PhD students, with 14 of all participants having a computer science background. Figure 5.12 and Figure 5.13 show the demographic method of the participants.

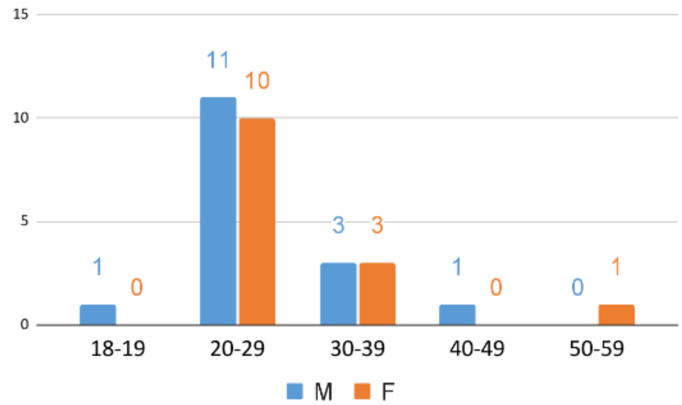


Figure 5. 12 Age of Participants.

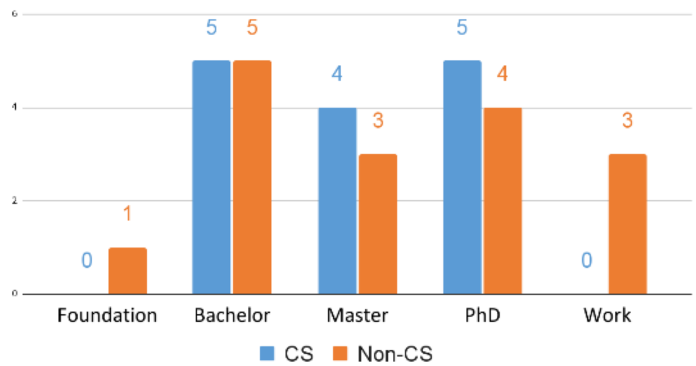


Figure 5. 13 Occupation of participants.

5.3.2 Feedback on Prototype

Here we present participant feedback on questions regarding their navigation preferences based on the situations presented to them.

The responses to questions “Do you have experience using maps for navigation?” are shown in Figure 5.14. We can see that almost all participants had experience with map navigation.

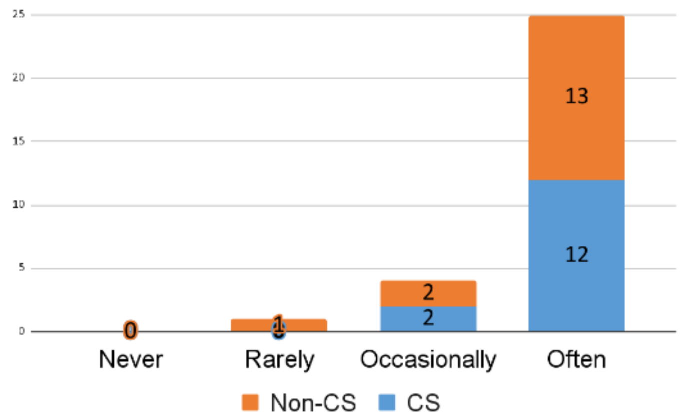


Figure 5. 14 Participants' responses of "the experience using map for navigation" - Q1.

The responses to questions "Do you have experience using location-based augmented reality?" are shown in Figure 5.15. We can see that a few participants have experienced using location-based service AR.

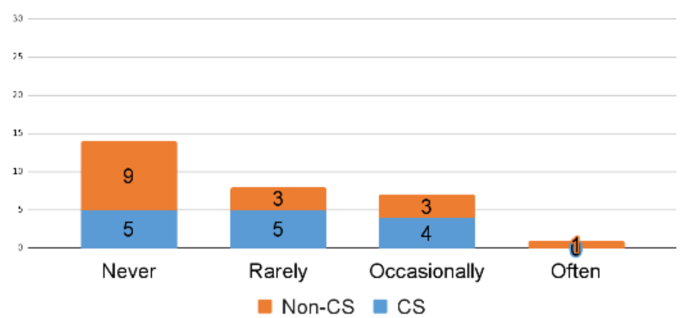


Figure 5. 15 Participants' responses about "the experience using LBS AR" - Q2.

5.3.2.1 Navigation Results

In response to the question "which location would be visited next?" the majority of participants chose the correct answer – the location with the red flag. In relation to each option, there were between 3 and 7 participants who chose the wrong answer, with more participants choosing the wrong answer in the options that showed flags sorted by distance. Figure 5.16 shows the participant's responses to the Q3a/Q4a/Q5a/Q6a.

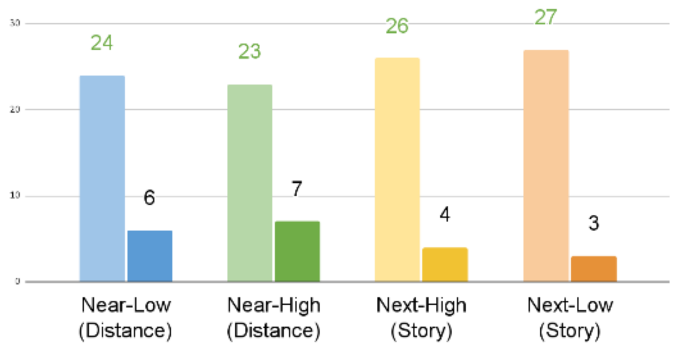


Figure 5. 16 Participants' responses about "which location should you visit next" - Q3a/Q4a/Q5a/Q6a - Correct answers are the green numbers at the top.

In response to the question "In which order should you visit the five locations?", based on order by distance (Near-High (Distance) or Near-Low (Distance)), the correct answer would have been that the order cannot be determined. Only 2 of the 30 people gave the correct answer for Near-High (Distance), and only 3 of the 30 people answered correctly for Near-Low (Distance) (see Figure 5.17). However, when the question was based on story flow, the majority of participants chose top-to-bottom, which was the correct response (Next-High (Story) and Next-Low (Story)).

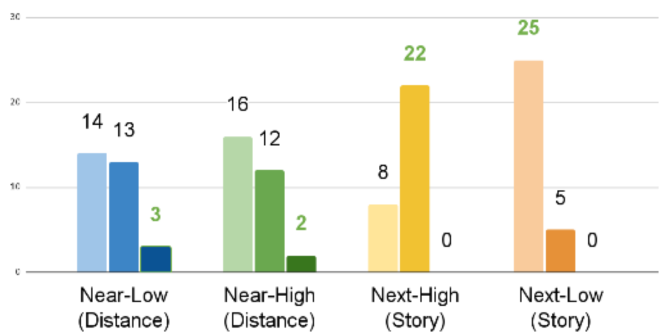


Figure 5. 17 Participants' responses about "in which order should you visit the five locations" - Q3b/Q4b/Q5b/Q6b: bottom-to-top (left), top-to-bottom (middle), or cannot tell (right) (correct answers indicated in green number).

I then asked the participants a series of questions to collect their intuitive feedback information based on the four-story order of Paper Prototype.

When we asked the participants, "How much do you agree with the following statement: I am confident that I can identify the next location in the story?" (Question 3c/4c/5c/6c) for the four situations, most participants chose "Completely Agree" and "Agree" (see Figure 5.18).

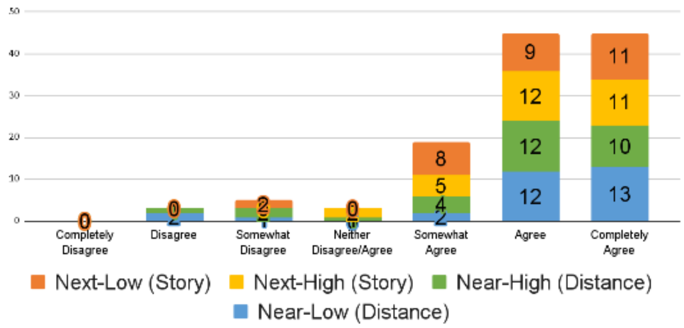


Figure 5. 18 Participants' responses about "I can identify the next location in the story" - Q3c/Q4c/Q5c/Q6c.

The answer is related to Q3a/Q4a/Q5a/Q6a (Which location should you visit next), a person who gave an incorrect answer to the Q3a/Q4a/Q5a/Q6a question, but this participant also chose "completely agree" in the Q3c/Q4c/Q5c/Q6c question; this is an interesting phenomenon. For example, of the 12 people who gave the correct answer to the above question Q3a (Near-Low (Distance)), also chose "completely agree" in response to the question Q3c (Near-Low (Distance)). The same situation also occurred in Near-High (Distance), Next-High (Story) and Next-Low (Story). Figure 5.19 shows the variance of the correct answer and the incorrect answers to questions Q3a/Q4a/Q5a/Q6a and provides the "completely agree" response to the questions Q3c/Q4c/Q5c/Q6c in relation to Near-Low (Distance), Near-High (Distance), Next-Low (Story) and Next-High (Story).

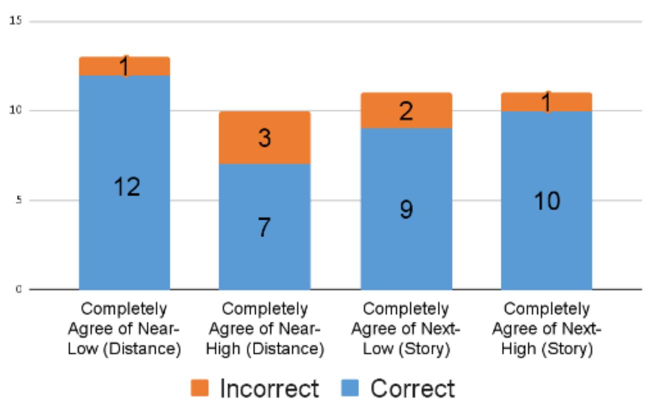


Figure 5. 19 Relative statistics of Q3a/Q4a/Q5a/Q6a and Q3c/Q4c/Q5c/Q6c.

When we asked the participants "How much do you agree with the following question? Is it easy to navigate to the next location in the story?", in the four-story order of Paper Prototype, most participants chose "Completely Agree" and "Agree" (see Figure 5.21)

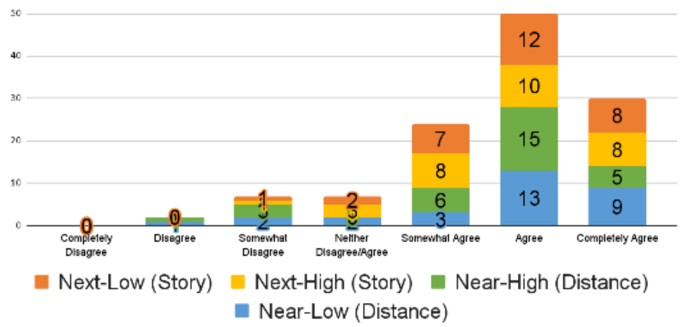


Figure 5. 20 Participants' responses about "It is easy to navigate the next location in the story" - Q3d/Q4d/Q5d/Q6d.

In relation to the responses to questions Q3a/Q4a/Q5a/Q6a (Which location should you visit next), a person who gave an incorrect answer to the Q3a/Q4a/Q5a/Q6a question, but the same person also chose "completely agree" in the Q3d/Q4d/Q5d/Q6d question; this is an interesting phenomenon. For example, the 8 people who gave the correct answer to the above question of Q3a (Near-Low (Distance)), they also selected "completely agree" in the question of Q3d (Near-Low (Distance). The same situation also occurred in Near-High (Distance), Next-High (Story) and Next-Low (Story). Figure 5.21 shows the number of the correct and the incorrect answers in response to the questions Q3a/Q4a/Q5a/Q6a and provides the "completely agree" response to the questions Q3d/Q4d/Q5d/Q6d in relation to Near-Low (Distance), Near-High (Distance), Next-Low (Story) and Next-High (Story).

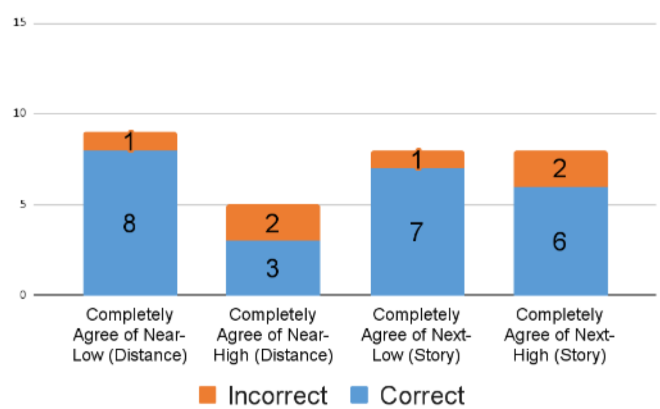


Figure 5. 21 The relative statistics of Q3a/Q4a/Q5a/Q6a and Q3d/Q4d/Q5d/Q6d.

When we asked the participants the question "How much do you agree with the following statement? I am confident that I can identify the order of the story?" in four versions most participants chose "Completely Agree" and "Agree" (see Figure 5.22).

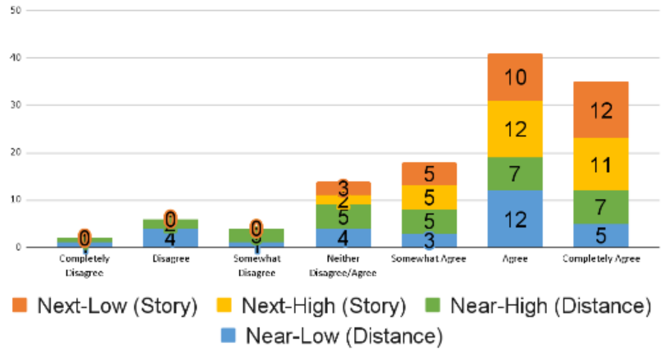


Figure 5. 22 Participants' responses about "identify the order of the story" - Q3e/Q4e/Q5e/Q6e.

The answer is related to Q3b/Q4b/Q5b/Q6b (in which order should you visit the five locations), a person who gave an incorrect answer to the Q3b/Q4b/Q5b/Q6b question, but the person also chose "completely agree" in the Q3e/Q4e/Q5e/Q6e question; this is an interesting phenomenon. For example, nobody gave the correct answer to the above question of Q3b (e.g., Near-Low (Distance)), they also chose "completely agree" in the question of Q3e (e.g. Near-Low (Distance)). The same situation also occurred in Near-High (Distance), Next-High (Story) and Next-Low (Story). Figure 5.23 shows the relative statistics of the correct answer and the incorrect answer of Q3b/Q4b/Q5b/Q6b and "completely agree" answer of Q3e/Q4e/Q5e/Q6e in Near-Low (Distance), Near-High (Distance), Next-Low (Story) and Next-High (Story).

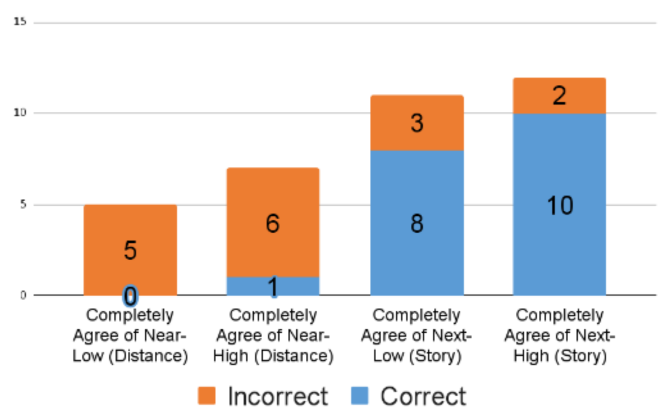


Figure 5. 23 The relative statistics of Q3b/Q4b/Q5b/Q6b and Q3e/Q4e/Q5e/Q6e.

When we asked the participants "How much do you agree with the following question? Is it easy to navigate the correct order of the story?", in the four-story order of Paper Prototype, most participants chose "Completely Agree" and "Agree" (see Figure 5.24).

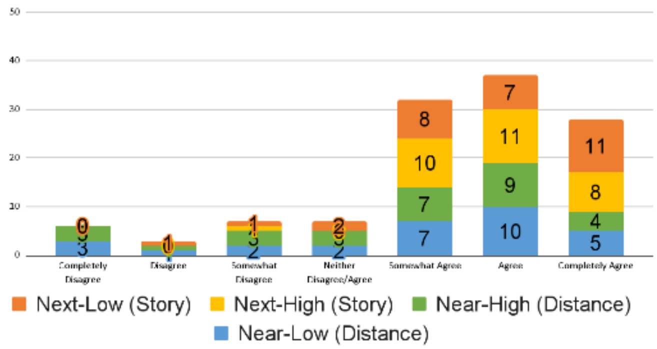


Figure 5. 24 Participants' responses about "It is easy to navigate the correct order of the story" - Q3f/Q4f/Q5f/Q6f.

The answer is related to Q3b/Q4b/Q5b/Q6b (in which order should you visit the five locations), a person who gave an incorrect answer to the Q3b/Q4b/Q5b/Q6b question, more interestingly, the person still chose "completely agree" in the Q3f/Q4f/Q5f/Q6f question. For example, nobody gave the correct answer to the above question of Q3b (Near-Low (Distance)), they also chose "Completely Agree" in the question of Q3f (Near-Low (Distance)). The same situation also occurred in Near-High (Distance), Next-High (Story) and Next-Low (Story). Figure 5.25 shows the relative statistics of the correct answer and the incorrect answer of Q3b/Q4b/Q5b/Q6b and "Completely Agree" answer of Q3f/Q4f/Q5f/Q6f in Near-Low (Distance), Near-High (Distance), Next-Low (Story) and Next-High (Story).

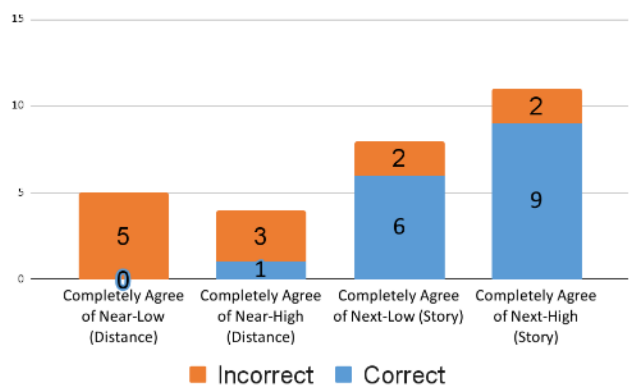


Figure 5. 25 The relative statistics of Q3b/Q4b/Q5b/Q6b and Q3f/Q4f/Q5f/Q6f.

5.3.2.2 Order by Distance

We summarised the participant answers of 'order by distance' and compared them. First, we compared the order by distance. Twenty six of the 30 participants, both CS and non-CS, chose Near-Low (Distance) (high is far / low is close), which suggests a high level of agreement (see Figure 5.26).

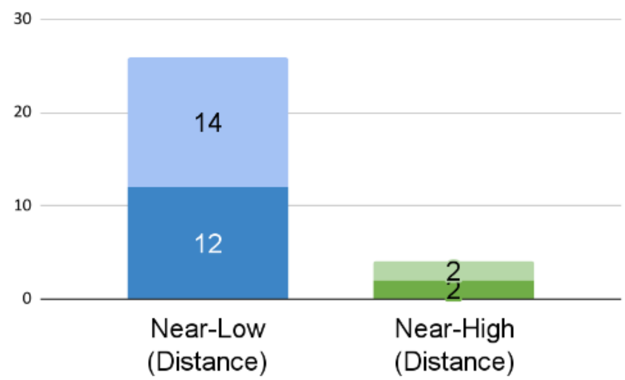


Figure 5. 26 Participants' responses about “which version do you prefer in order by distance” - Q7 - Light Colour = Non-CS Background   Dark Colour = CS Background.

Among the 26 participants who chose Near-Low (Distance), we found that the participants' answers can be divided into four groups. They are “Easy to understand”, “Further away should be at the top”, “Distance”, “Others (linear, common sense)”, see Table 5.3. In the study of classification, we think “understand”, “follow” and “follow my decision” have similar meanings in this case, so we grouped them together. In the same way, “Far should be at the top” and “the close feels should be at the bottom" have similar meanings, etc. Classification according to the similarity of answers allows us to understand the proportional distribution of participants' answers and provide guidance for the next prototype questionnaire design.

Table 5. 3 Classification of participants' responses about order by Near-Low (Distance).

Participant ID	Near-Low (Distance)	Easy to understand	Further away should be at the top	Distance	Others (linear, common sense)
1	"easy to understand and guide"	√			
2	"easy to follow"	√			
3	"distance number from small to big" (translated from Mandarin)			√	
4	"follow height order"		√		
5	"easy to follow, because order by distance"	√			
6	"easy from the top to the bottom, follow my decision"	√			
7	"Suitable for common sense" (translated from Mandarin)				√
8	"easy to navigate and understand, vision convenient" (translated from Mandarin)	√			
9	"I feel the close one should be at the bottom"		√		
10	"the closest to me should be at the bottom" (translated from Mandarin)		√		
11	"the object near the close"		√		
12	"Distance increases from bottom to top. From top to bottom easy to look" (translated from Mandarin)			√	
15	"I think that these flags are displayed linearly from bottom to top and are easy to navigate"				√
16	"the far should be the top, the close should be the bottom"		√		
17	"the close is the far (from the bottom to the top)" (translated from Mandarin)		√		
18	"my view think the far is the top"		√		
19	"make sense to me, the far display the big number" (translated from Mandarin)			√	
20	"easy view increase from the bottom to the top"	√			
22	"74 m / 75 m away, easy to access"			√	
23	"easy to understand and guide"	√			
24	"close to me"		√		
25	"easy to identity, grab information and navigate increase from the bottom to top, in place, used this one from distance here to here"	√			
26	"from the close to the far, I feel the bottom should be the close" (translated from Mandarin)		√		
27	"for me, close feels near ground, far feels in the sky, I can't touch it" (translated from Mandarin)		√		
29	"view bottom feels close me" (translated from Mandarin)		√		
30	"fit effective rule, first to close, from close to far" (translated from Mandarin)		√		
Total		**8**	**12**	**4**	**2**

Other 4 participants who chose Near-High (Distance), their answers mainly focused on "Close should be at the bottom", Table 5.4 shows the details of the answers of the 4 participants.

Table 5. 4 Classification of participants' responses about order by Near-High (Distance).

Participant ID	Near-High (Distance)	Close should be at the bottom
13	"the red one is the first one, the top red one feels far away" (translated from Mandarin)	√
14	"the red flag at the bottom makes me feel that I should visit it first" (translated from Mandarin)	√
21	"the better view from top near me"	√
28	"according to my feeling, I think the near one at the bottom easy to find" (translated from Mandarin)	√
Total		**4**

After summarizing and categorizing these answers, we found that "far should be at the top" and "easy to understand" are the main reasons leading to the choice of order by Near-Low (Distance). Correspondingly, "close should be at the bottom" is the reason for order by Near-High (Distance). The Figure 5.27 shows the classifications according to participants' answers for distance order:

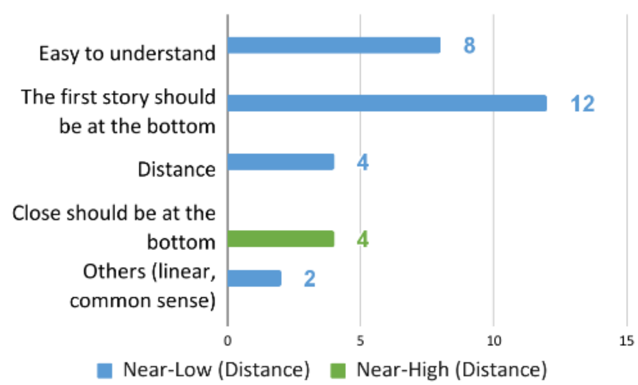


Figure 5. 27 Participants' answer classification statistics for distance order.

5.3.2.3 Order by Story Flow

In the interview, we asked each participant why they had chosen their preference. 21 of the 30 participants chose Next-Low (Story) (low is next/high is last). Most CS and Non-CS participants chose Next-Low (Story), which indicates a high level of agreement and also shows an amazing consistency. The Figure 5.28 shows the statistical result.

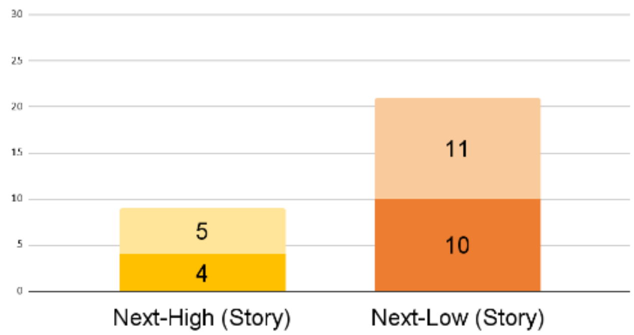


Figure 5. 28 Participants' responses about "which version do you prefer in order by story flow" - Q8 - Light Colour = Non-CS Background   Dark Colour = CS Background.

We grouped the subjective answers into four groups as described above.

Table 5. 5 Classification of participants' responses about order by Next-High (Story).

Participant ID	Next-High (Story)	Easy to understand	The first POI the story should be at the top	Distance	Others (vision)
1	"easy to understand"	√			
4	"The closest point should be the bottom, the farthest point should be the top"		√		
6	"from top to bottom, some vision easier than another"				√
7	"from top to bottom" (translated from Mandarin)		√		
8	"Also the same reason, easy to recognize to find" (translated from Mandarin)	√			
19	"make sense to me, the far display the big number" (translated from Mandarin)		√		
22	"distance near me, So I chose SH1, won't choose SH2"			√	
23	"easy to understand"	√			
25	"I like red one at the top, easy to find and grab attention, the red one of the bottom to see need to look down"		√		
Total		**3**	**4**	**1**	**1**

Table 5. 6 Classification of participants' responses about order by Next-Low (Story).

Participant ID	Next-Low (Story)	Easy to understand	The first story should be at the bottom	Distance	Others (Vision)
2	"easy to follow"	√			
3	"Close and easy to visit" (translated from Mandarin)	√			
5	"easy to follow the story order"	√			
9	"It feels better from bottom to top because people stay on the ground most of the time"		√		
10	"the first story should be at the bottom" (translated from Mandarin)		√		
11	"first location close to me, I can go to story order"		√		
12	"Follow the story develop(expand), will easy to look" (translated from Mandarin)	√			
13	"same Near-Low (Distance), the red one give very intuitive feeling" (translated from Mandarin)	√			
14	"the red one at the bottom, next location" (translated from Mandarin)		√		
15	"easy to navigate, linear"				√
16	"the red one near my stand location, so I chose the Next-Low (Story)"		√		
17	"the red one is the bottom order by story, should be the bottom" (translated from Mandarin)		√		
18	"the first story should be to showed at the bottom"		√		
20	"the first story should be at the bottom, easy make my mind (the 1st story)"		√		
21	"better view from the top"				√
24	"I want to try the best from the bottom to the top"		√		
26	"the first story should be the bottom, story order by the bottom to the top" (translated from Mandarin)		√		
27	"the first story easy to visit, in the top feels too far, maybe wrong way to access" (translated from Mandarin)		√		
28	"the first story at the bottom, fit my custom(from bottom to top)" (translated from Mandarin)		√		
29	"the first story feels it is start point, others feels uncomfortable" (translated from Mandarin)		√		
30	"the first story close me, attract me to next story" (translated from Mandarin)		√		
Total		**5**	**14**	**0**	**2**

After summarising and categorising these answers, we found that "far should be at the top" is the main reason leading to the choice of order by Next-Low (Story). Correspondingly, "The first POI in the story should be at the top” is the reason for Next-High (Story). The Figure 5.29 shows participants' answer classification statistics for story order.

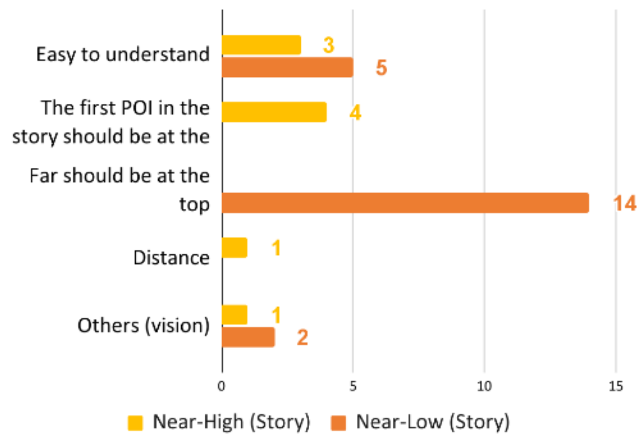


Figure 5. 29 Participants' answer classification statistics for story order.

5.3.2.4 Order by Distance or Story Flow

Finally, we compared the order by distance and order by story flow, the result showed that half of participants chose the order by distance or the order by story flow (see Figure 5.30). More interestingly, 5 CS background participants selected Near-Low (Distance) (see Figure 5.31, Figure 5.33, Figure 5.34), and 5 non-CS background participants chose Next-Low (Story) (see Figure 5.30, Figure 5.31, Figure 5.34), which means that CS background participants prefer the order by story, and non-CS background participants prefer the order by distance.

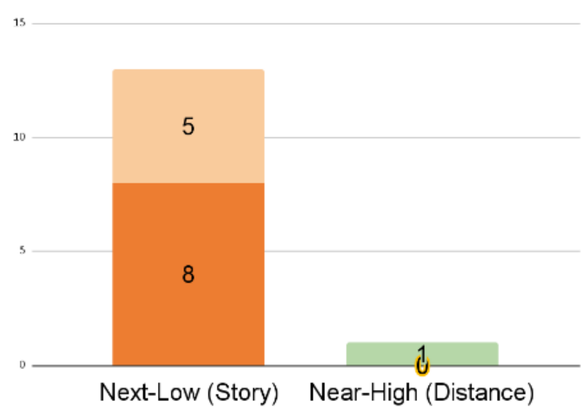


Figure 5. 30 Comparison of Next-Low (Story) and Near-Low (Distance). Light Colour = Non-CS Background   Dark Colour = CS Background.

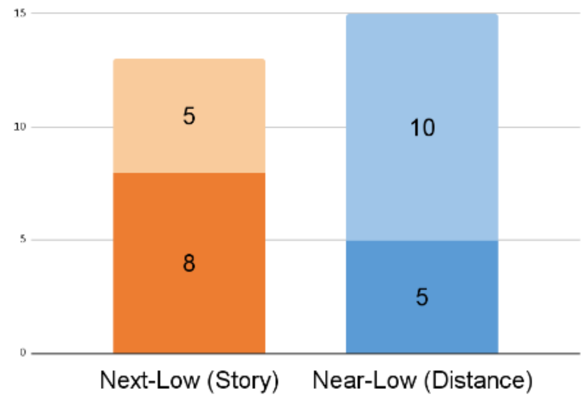


Figure 5. 31 Comparison of Next-Low (Story) and Near-High (Distance) Light Colour = Non-CS Background   Dark Colour = CS Background.

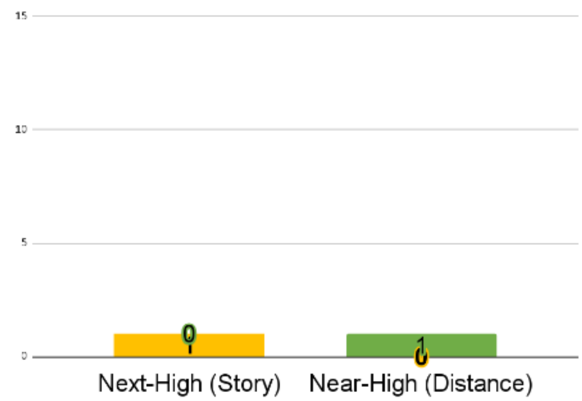


Figure 5. 32 Comparison of Next-High (Story) and Near-Low (Distance) Light Colour = Non-CS Background   Dark Colour = CS Background.

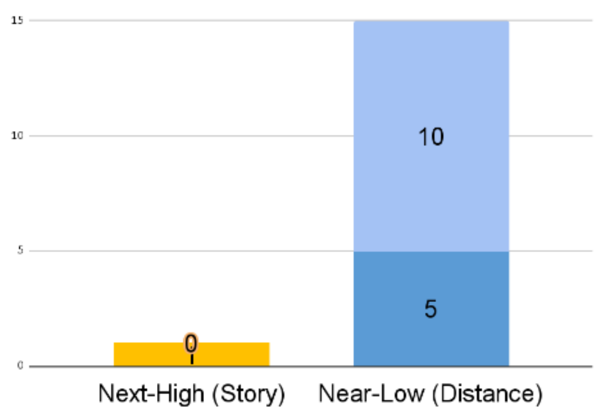


Figure 5. 33 Comparison of Next-High (Story) and Near-High (Distance) Light Colour = Non-CS Background   Dark Colour = CS Background.

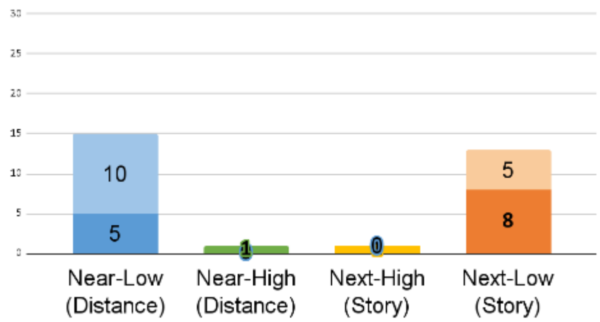


Figure 5. 34 Participants' responses about "Which one do you prefer order by distance or order by story flow" - Q9 Light Colour = Non-CS Background   Dark Colour = CS Background.

The following table summarises all participant responses to questions Q7 to Q9 and shows the statistics of these data. The vertical columns of Table 5.7 indicate the four possible combinations of answers to questions Q7 and Q8, the horizontal rows of Table 5.7 are the number of Q9 same answers for each combination of Q7 answers and Q8 answers. For instance, of all the participants who chose NL-D in Q7 and NL-S in Q8, 7 chose NL-D in Q9 and 10 chose NL-S in Q9.

Table 5. 7 Comparison of the preferred four prototypes.

	Near-Low (Distance)	Near-High (Distance)	Next-Low (Story)	Next-High (Story)
Near-Low (Distance)/ Next-Low (Story)	7		10	
Near-Low (Distance)/ Next-High (Story)	8			1
Near-High (Distance)/ Next-Low (Story)		1	3	
Near-High (Distance)/ Next-High (Story)		0		0
	15	**1**	**13**	**1**

We analysed the open answers and found that they can be divided into four groups. For example, we think "easy to understand, clear navigation", "looks very understanding, suitable for view customary" have similar meanings, so we grouped them together. Likewise, "Intuitive feeling, the close is the low, the high is the far" and "I definitely think the navigation can see the distance" have similar meanings. And so on.

Table 5. 8 Classification of participants' responses about order by Distance.

Participant ID	Near-High (Distance) / Near-Low (Distance)		Easy to understand	Close / far	Distance	Others (Vision)
1	Near-High (Distance)	"easy to understand, clear navigation"	√			
2	Near-High (Distance)	"easy to measure distance, How far to navigate to"			√	
4	Near-High (Distance)	"easy to navigate"	√			
5	Near-High (Distance)	"easy to follow, not to be confused"	√			
6	Near-High (Distance)	"Because study is the first attempt. I see easy, but I am still my vision"				√
7	Near-High (Distance)	"Intuitive feeling, the close is the low, the high is the far" (translated from Mandarin)		√		
8	Near-High (Distance)	"Very confident to use this one" (translated from Mandarin)	√			
12	Near-High (Distance)	"Looks very understand, suitable for view customary" (translated from Mandarin)	√			
20	Near-High (Distance)	"Visualisation, more like easy to navigate, easy to follow distance"			√	
22	Near-High (Distance)	"order by distance, easy to visit to these places"			√	
23	Near-High (Distance)	"easy to understand, clear navigation"	√			
25	Near-High (Distance)	"I definitely think the navigation can see the distance. I like from close to far, is my personal interest"		√		
26	Near-High (Distance)	"distance determine the story order that suits my feelings" (translated from Mandarin)			√	
27	Near-High (Distance)	"more close, more close to the ground, more far, more high, which is my idea of sequential visits" (translated from Mandarin)				√
28	Near-Low (Distance)	"The distance determine story order, most extend helps me to determine" (translated from Mandarin)			√	
30	Near-Low (Distance)	"the first to the close story from close to far let me know these stories" (translated from Mandarin)		√		
Total			**6**	**3**	**5**	**2**

Table 5. 9 Classification of participants' responses about order by Story.

Participant ID	Next-High (Story) / Next-Low (Story)		Easy to understand	Story flow	Distance	Others (Vision, Linear)
3	Next-Low (Story)	"story flow need" (translated from Mandarin)		√		
9	Next-Low (Story)	"people walking on the ground will feel (fit for) more reality"				√
10	Next-Low (Story)	"prefer to follow the story order" (translated from Mandarin)		√		
11	Next-Low (Story)	"more navigate improvement, the most friendly data management"				√
13	Next-Low (Story)	"five flags show linear continuous display" (translated from Mandarin)				√
14	Next-Low (Story)	"Good sequence, I care the order of the story, the distance can be ignored" (translated from Mandarin)		√		
15	Next-Low (Story)	"from the bottom to the top easy to follow, physical using the bottom to the top"		√		
16	Next-Low (Story)	"story order is the most important than the distance"		√		
17	Next-Low (Story)	"I prefer the story order" (translated from Mandarin)		√		
18	Next-Low (Story)	"For the integrity of the story, I choose the order by story"		√		
19	Next-High (Story)	"follow the story order, make it clearly" (translated from Mandarin)		√		
21	Next-Low (Story)	"I prefer story flow, I want to follow the exact story"		√		
24	Next-Low (Story)	"All distances shown by DH and SL are the same, I like to go from bottom to top"		√		
30	Next-Low (Story)	"the starting point at the bottom, take in everything at a glance, looks comfortable" (translated from Mandarin)	√			
Total			**1**	**10**	**0**	**3**

After summarising and categorising these answers, we found that "story flow" is the main reason for choosing order by Next-Low (Story). "Easy to understand" is the most important reason for choosing order by Near-High (Distance).

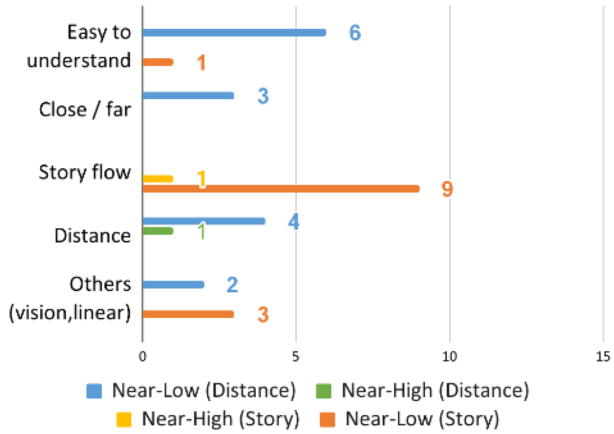


Figure 5. 35 Participants' answer classification statistics for order by distance and story flow.

There were some interesting responses to the interviews. For example, one participant saw these photos from an aesthetic and design perspective, thinking that all the story flags should be in a straight line as this would make the aesthetic more suitable to his/her logical thinking. Another participant mentioned their intuitive feeling, vision and customary way of thinking.

5.4 Discussion and Summary

This Paper Prototype exploration was based on face-to-face question-and-answer interviews with 30 participants. The main research focus was on the preference between order by story or order by distance. We conducted an interview study, which led to the following observations:

1) Although many participants have used map navigation, few have used AR-based real-time navigation. This is a similar result to that which showed up in Initial Digital Prototype (see Chapter 4).
2) Participants with the non-CS background chose order by distance more than participants with a CS background. After analysing these data, order by Near-Low (Distance) and order by Next-Low (Story) were discovered to be preferable to most participants. This is an interesting observation because our research replicates visual methods from existing AR location-based services frameworks. Many participants did not understand the story order and story interactions, which may be related to Paper Prototype interviews rather than a digital prototype that participants are field tested and real perceived.
3) Two participants were interviewed for the navigation questions of the Paper Prototype (Questions c to f of Next-Low (Story) in Table 5.2), giving either "somewhat agree" or

"disagree" answers. However, when answering the Paper Prototype preference questions, these two participants chose Next-Low (Story).

The participants expected the nearest location to interact with the next location in the narrative structure, which requires further study and discussion.

We designed a prototype that replicates location-based AR for POI and added elements of ordering (to support a connected narrative). The prototype uses information about local trees at the University of Waikato. We found that location-based data visualisation and narrative navigation are complex concepts for new users. We explored and interviewed four options for order by story flow and order by distance in AR, and found that the number of participants who liked order by story or order by distance was almost the same.

Chapter 6 Improving the Narrative Navigation Prototype

This chapter presents the improved digital prototype for narrative navigation, which was developed based on feedback and suggestions from participants who had used the Paper Prototype (as discussed in Chapter 5). We then explored the functionality of this updated prototype by conducting a walk-through of a scenario. Next, we revise the prototype implementation to address the problems encountered in the walk-through. Finally, Participant behaviour and prototype usage tracking of the mobile phone will be captured and visualised for analysis in preparation for the Final Prototype.

Section 6.1 describes the design and implementation of the Narrative Navigation Prototype. Section 6.2 discusses the insights gained during the Narrative Navigation Prototype walk-through, and Section 6.3 describes the details of the improvements to the Narrative Navigation Prototype. Section 6.4 and Section 6.5 present the use case and the details of the visualisation map for the user study. In Section 6.6, we discuss the Paper Prototype and draw some conclusions.

6.1 Narrative Navigation Prototype

As described in Chapter 5, the Paper Prototype explored four different designs: the NL-D, NH-D, NL-S and NH-S. In the category of 'order by story', most of the participants chose NL-S, and in the category of 'order by distance', most of the participants chose NL-D. We can therefore say that the Narrative Navigation Prototype design is based on the value of the NL-S and NL-D to the Paper Prototype, and furthermore, that these designs expanded and extended the value of the prototype. The Narrative Navigation Prototype is an interactive mobile application that has been programmed using Unity 3D, which is similar to the programming of the Initial Prototype described in Chapter 3.

The Narrative Navigation Prototype focuses on story connectivity and AR effects based on feedback from the Initial Digital Prototype and Paper Prototype. The mobile phone running the prototype detects the participants' location and orientation to geolocate and navigate each story chapter and find the story narration of that story chapter.

6.1.1 Dataset

We use a dataset with seven POIs locations, including five story chapters about trees and two overview locations. The five story chapters are an introduction to each tree (see Appendix C1), while the two overview locations are looking at all remaining story chapters that have not been visited.

The two overview locations were chosen based on the point at which the participant could easily see the POI avatars of the five stories displayed on the same mobile screen. The two overview locations are shown using the two red dots with arrows indicating user view direction in Figure 6.1. The POIs in the 5 story chapters correspond to story locations 1 to 5 (see blue colour number of Figure 6.1.).

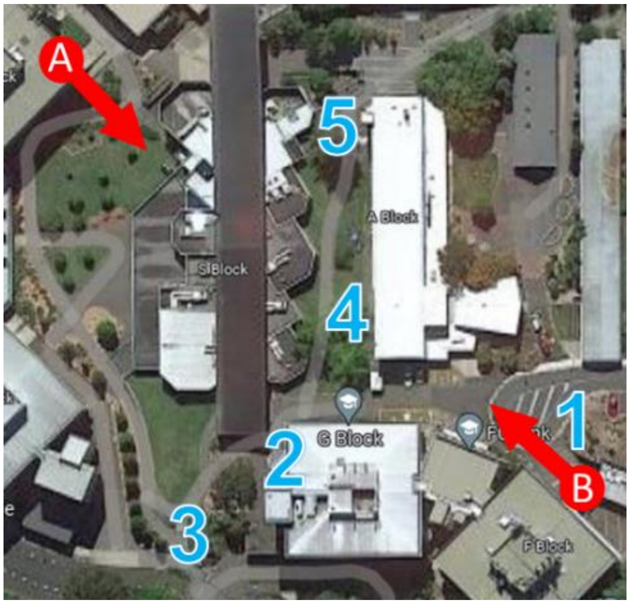


Figure 6. 1 Dataset shown in the map (Map data: Google ©2021).

The story of the 5 POIs refer to the introductions to the following trees: Kahikatea, Kitashima pine, Totara, Radiata Pine and Pohutukawa, respectively. We designed the order of visits and the content of each step to develop the Narrative Navigation Prototype based on this content. Table 6.1 shows the visiting order of the narrative navigation of the story, and the visit information of each tree story.

Table 6. 1 Visiting order of narrative navigation of story.

Route step	From	To	Observer scenes	Screenshot	Tree story information
1		Overview A	five story parts	Appendix C Figure C.2	N/A
2	Overview A	story part 1	story part 1	Appendix C Figure C.3	Kahikatea
3	story part 1	Overview B	story part 2 to story part 5	Appendix C Figure C.4	
4	Overview B	story part 2	story part 2	Appendix C Figure C.5	Norfolk Island Pine
5	story part 2	story part 3	story part 3 to story part 5	Appendix C Figure C.6	N/A
6		story part 3	story part 3	Appendix C Figure C.7	Totara
7	story part 3	story part 4	story part 4 to story part 5	Appendix C Figure C.8	N/A
8		story part 4	story part 4	Appendix C Figure C.9	Radiata Pine
9	story part 4	story part 5	story part 5	Appendix C Figure C.10	N/a
10		story part 5	story part 5	Appendix C Figure C.11	Pohutukawa

6.1.2 AR View of Narrative Navigation Prototype

Two functions have been added to the design (see Figure 6.2). The first one is the scrollbar at the right bottom corner, which we designed in order to enable switching the NL-S and NL-D. The second new function involved adding the story order number to aid recognition of story order (using yellow or red numbers in the top left corner of each flag).

The left view in Figure 6.2 shows the AR view ‘order by story’ as seen by the participants at the overview of location A. The right view in Figure 6.2 shows the AR view ‘order by distance’ as seen by the participants at the overview of location A.

Figure 6. 2 AR view of order-by-story at user view A (left), AR view of order-by-distance at user view A (right).

6.2 Walk-through Insights

Next, we did a walk-through of this prototype using a mobile phone for the user study. The purpose of the walk-through was to test the usability of the Narrative Navigation Prototype. To make the

POI appear on the mobile phone screen, we tried pointing the mobile phone towards the sky, on a horizontal plane, towards the ground, and by holding the phone as we rotated our body.

We explored the functionality of the prototype in a walk-through to identify usability issues. The walk-through uses the scenario introduced in Table 6.1, and begins with overview location A, and then follows the narrative locations: Story chapter 1, overview location B, Story chapter 2, Story chapter 3, Story chapter 4, and Story chapter 5 to visit the story details.

When we went to do the walk-through using the Narrative Navigation Prototype, we encountered four issues. We describe these issues in detail.

6.2.1 Limited Flags Shown

When we did the walk-through, we looked at the POIs displayed in the AR view in landscape mode on the mobile phone. When we changed the phone to portrait mode, the AR view screen also changed accordingly. The x-axis of the screen space of the mobile phone changes from wide to narrow, and the Y-axis changes from short to long, and the POIs display quantity will also change. The Figure 6.3 shows the changes of POI view in AR view when we changed the orientation mode of the mobile phone screen.

Figure 6. 3 AR view in portrait mode (left) and landscape mode (right) from walk-through.

We needed to explore the changes that occurred in the POI display when we changed from the landscape mode to the portrait mode on the mobile phone, in order to find out which POI display method better represents the concept of narrative navigation. Therefore, we explored the screen space size of the POI avatar, and the advantages and disadvantages of displaying multiple POIs in different screen modes. We also looked into the number of flags that can be displayed comfortably in each mode.

6.2.2 AR Camera toward Sky/Ground

When we could not see POIs in the AR view during the walk-through, we tried to point the mobile phone towards the sky or ground in order to find another POI, doing this until we found further POIs displayed on the AR view. We need to explore the effect on the POI display when the mobile phone is pointed towards the sky or the ground. Figure 6.4 shows the mobile phone when pointed towards the sky when looking for further POIs (left) and when pointed towards the ground when trying to identify more POIs (right).

Figure 6. 4 AR camera toward sky (left) and AR camera toward ground (right).

6.2.3 POIs Description Shown in AR View

The walk-through happened in sunny weather conditions. The real-world background displayed on the phone screen continued to change while we were walking. We became very concerned about what kind of information displayed during the walk-through. This includes questions such as: what information is suitable for reading when using outdoor navigation and how safe it is for participants to read the information while walking?

6.2.4 AR Navigation Hints

The route of the walk-through was designed by us, so we are familiar with the university campus where the walk-through was taking place. However, one has to ask, if participants came to an unfamiliar campus for the purpose of participating in a walk-through, what would they focus on? In addition, how can participants best explore the space in their surroundings? Given our recognition of these issues, we considered that the addition of real-time navigational hints may become an important factor in allowing participants to successfully complete the walk-through. We explore how to solve this issue in this chapter:

The four issues we identified and the questions we explore in this chapter focus on two aspects, how the POI information display is more friendly to the participants (such as, in navigation prompts), and the effect of the participant's behaviour of operating the mobile phone on the POI display. We explore the four questions in detail in the next section.

6.3 Exploring Design Options

In this section, we further explore the display of POIs on AR views in response to the four issues identified in Section 6.2:

1. How to reasonably design POI display in AR view is more suited for narrative navigation?
2. The effect of camera tilt on POI display,
3. What kind of information display on the screen is most suited for narrative navigation, and
4. The importance of real time navigation hints.

As we explore these four questions, we improve the design and describe the reasons for the improvement, after which we provide our insights on the process pursued.

We discuss the above-mentioned four issues in the following sections. The first issue is divided into two parts, Section 6.3.1 introduces the redesign of the POI avatar size display on the mobile phone screen, and Section 6.3.2 introduces the POI display quantity demonstration. Section 6.3.3 focuses on the second issue regarding camera tilt, Section 6.3.4 explores the third issue of information display, and Section 6.3.5 discusses the fourth issue of real-time navigation hints.

6.3.1 Redesign of POI Avatar Size Display

The size of the POI screen space is designed so that each flag can be clearly and smoothly displayed on the screen. When we did the screen design of the Initial Digital Prototype, the default participants used the landscape mode of the user study mobile phone for the walk-through, however participants could switch, in response to their personal preferences, to portrait mode through using the user study mobile phone's gravity sensor. We had to consider the effect of using the digital prototype in portrait mode.

The screen design was based on the resolution of the mobile phone. The width x length of the user study mobile phone (Samsung S10) is WQHD 1440 x 3040 (Pixel), in the landscape mode when running the Narrative Navigation Prototype, the Y-axis of the screen is 1440 pixels, when the portrait mode of running the Narrative Navigation Prototype, the Y-axis of the screen is 3040 pixels. Firstly, we determined the height of each flag so that it would be easy to see. Table 6.2

shows the number of POIs when using the landscape and portrait orientations on the test mobile phone.

Table 6. 2 Multi POIs display design under landscape and portrait mode in mobile phone.

	Display mode	Screen Y-axis (px)	Flag Y-axis (px)	Unobstructed Display Quantity
1	Landscape mode	1440	260	5
2	Portrait mode	3040	260	11

Landscape Mode

In landscape mode, according to the phone resolution (1440px) and flag pixels (260px), five POI flags can be clearly displayed on the screen. The red flag is the POI of story chapter 1 and displayed at the bottom of the landscape mode. Figure 6.5 shows the five POI flags are clearly displayed in landscape mode.

Figure 6. 5 Flag's space design of AR View on landscape mode.

Portrait Mode

When the orientation of mobile phones is changed from landscape mode to portrait mode, the screen position in Figure 6.6 becomes the fourth position from the bottom to the top.

According to the resolution of the mobile phone (3040px) and the pixels of the flag (260px), the unobstructed display of each flag on the screen is divided into 11 equal parts from top to bottom. Figure 6.6 shows the 11 POIs flags are clearly displayed in portrait mode.

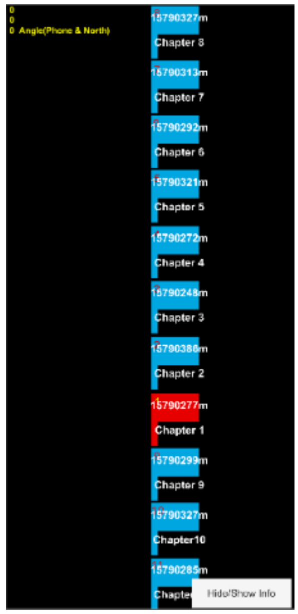


Figure 6. 6 Flag's space design of AR View on portrait mode.

Next, we explored the design further, with the aim of ensuring that participants could clearly see each flag and the numbers on the flags displayed on the mobile phone, especially when the real-world scene in the background was changing.

6.3.2 Flag Quantity Demonstration

When we did the walk-through, we saw that the POIs were constantly changing their position depending on our movement. We discovered that the POIs display quantity in both landscape mode and portrait mode on the mobile phone.

Landscape Mode

The mobile phone's Y-axis in landscape mode is only 1440px, with the AR view showing 5 POIs. If the landscape screen displays more than 5 POIs, it will be too messy. So we explored the quantity demonstration of POIs in portrait mode instead of in landscape mode.

Portrait Mode

In portrait mode, the distance between multiple POIs displayed on the phone screen will appear as being both far and near. We explore the advantages and disadvantages of POI display separately in these two cases.

When POIs are geographically far apart in portrait mode, the screen of the mobile phone when in a certain position cannot display all the POIs, and when all POIs are displayed on 2 or more screens separately. As shown in the left of Figure 6.7, 11 POIs are displayed on 2 screens. The right-hand image in Figure 6.7 shows a manually merged panorama due to the test mobile screen's resolution limitations.

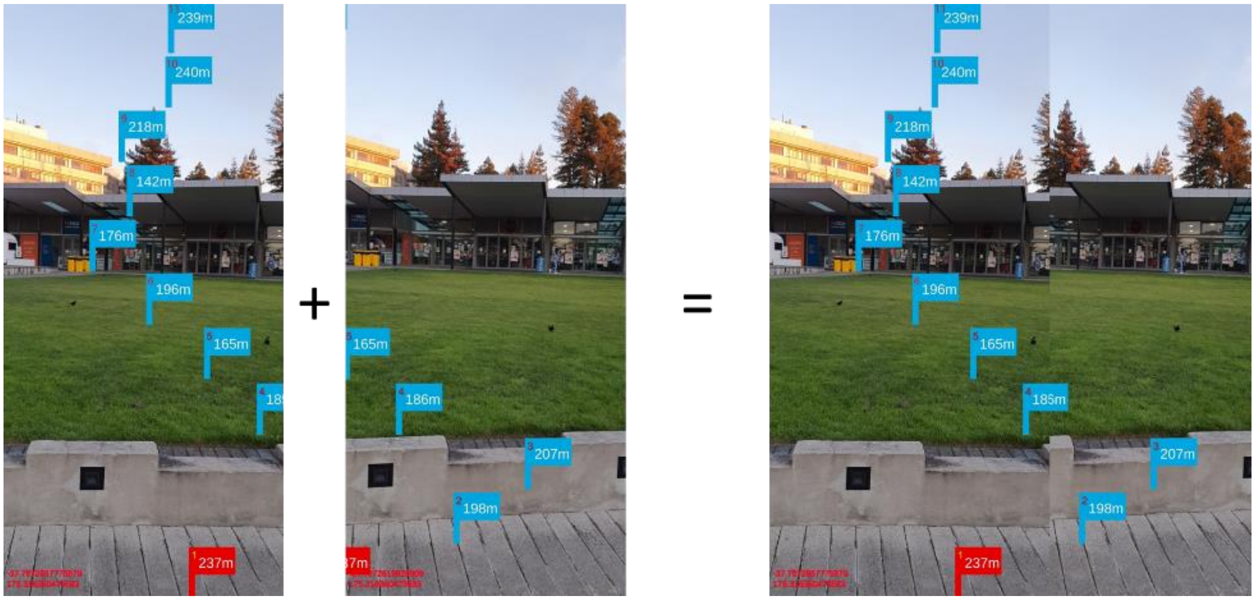


Figure 6. 7 POIs are displayed in two adjacent AR views (left, middle), manually merging the two figures (right) (panoramic view)

The advantage of this POI presentation is that it is clear and uncluttered. The disadvantage of this POI display is that it cannot see all POIs on the same screen at the same time, which is an unavoidable situation.

When POIs are geographically close together, many POIs may be displayed in a compact manner on the mobile test phone. If there are more than 11 POIs, overlapping occlusion will occur. We have designed three scenes that show 11, 22 and 33 POIs on the test mobile phone. The display effect on the real environment is shown in Figure 6.8.

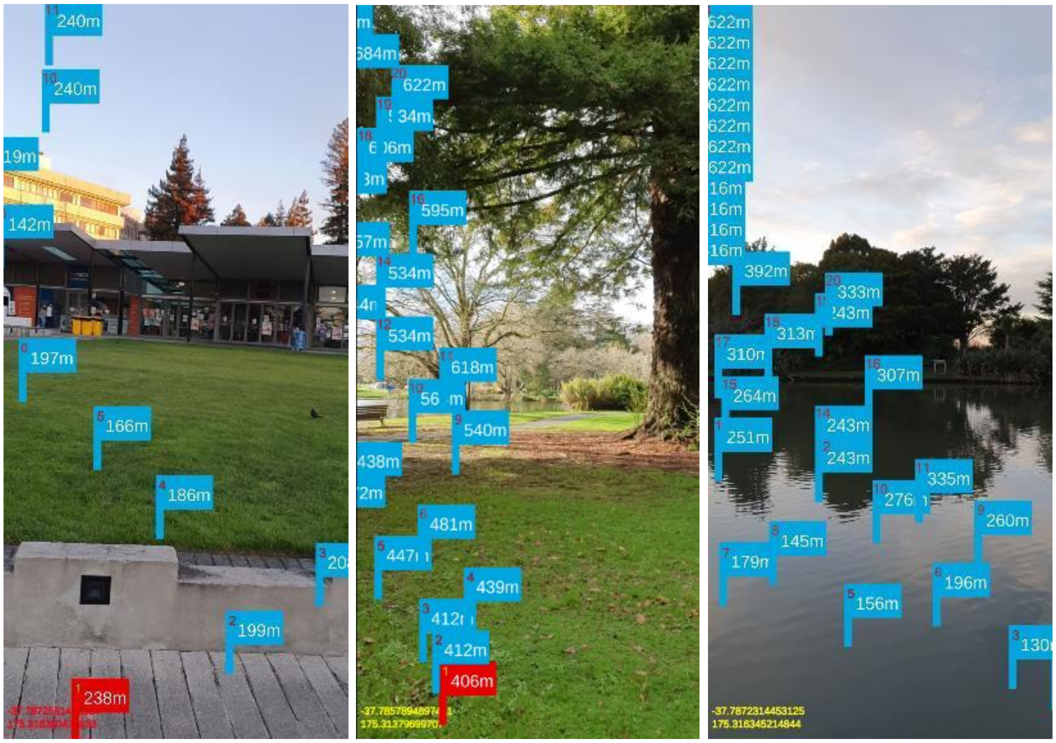


Figure 6. 8 Multiple flags shown in one screen, 11 flags (left), 22 flags (centre), 33 flags (right).

We tested displaying 11, 22, and 33 flags respectively on the mobile phone screen (see Figure 6.6). In the scene with 11 flags on the screen (see left image in Figure 6.8), participants can see that the effect is smooth and neat; in the scene with 22 flags on the screen (see middle image in Figure 6.8), overlap has occurred, and in the scene where 33 flags are displayed on the screen (see right image in Figure 6.6), the display has become chaotic and hard to see.

In order for the participants to clearly see the data, the POI layered display design must be adopted, which can also be seen in the design in Table 6.2. This means that the value (260px) of the screen display coordinate y-axis of each POI needs to be fixed.

6.3.3 Camera Tilt Movement in AR View

In this section, we explore the effect of mobile phone’s “camera toward” on POI displays, when addressing Question 2. We compared the different effects when the camera was pointed in different directions. We pointed the phone's camera at the sky, the horizontal plane, and the ground. The purpose of this experiment is to identify the upper and lower ends toward the principal vertical line, and furthermore, to explore the change in the shape of the flag and the change in the spacing between different flags. We have included a conceptual map to explain what the spacing between POIs is and how the spacing between POIs can vary in three different orientations. Figure 6.9 shows a conceptual map showing the change of spacing between POIs using three different cameras, which demonstrates the change in the shape and spacing of the POI as the camera moves along the principal vertical line. The result of this experiment is that a perspective is provided that is similar to a fish eye view. In the AR view of the horizontal plane, the participant sees a horizontal spacing (the distance between flag 1 to flag 2 in Figure 6.9) that matches the real-world perspective. In both the ground view and the sky view, the distance between flag 3 and flag 4, and between flag 5 and flag 6, will become larger.

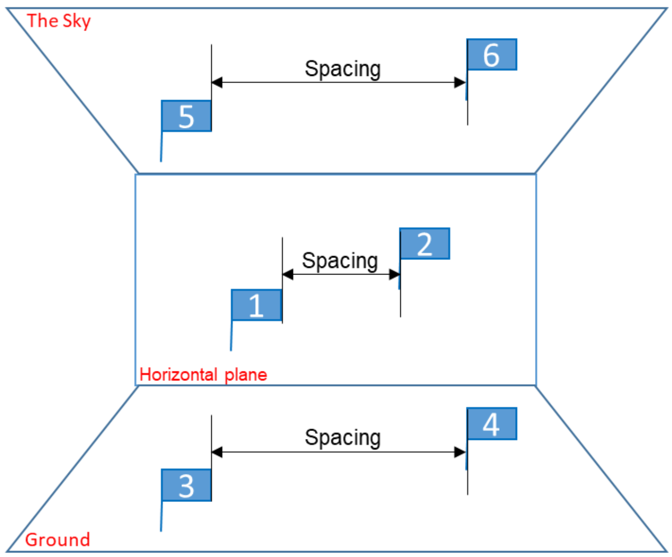


Figure 6. 9 Conceptual map of the change of the spacing when camera of mobile phone tilt movement to sky/ground.

We explored whether the POI spacing matches the design in 3 different cases at the same location. First, we tested the spacing between the POIs with the camera pointed towards the horizontal plane in the AR view during the walk-through. Figure 6.10 shows the view of the horizontal plane in the real world.

Figure 6. 10 POI display of camera toward the horizontal plane in AR view.

Next, we tested the POI display of the camera when pointed towards the sky in the AR view during the walk-through. Figure 6.11 shows 5 POIs displaying the camera pointed towards the sky in the AR view.

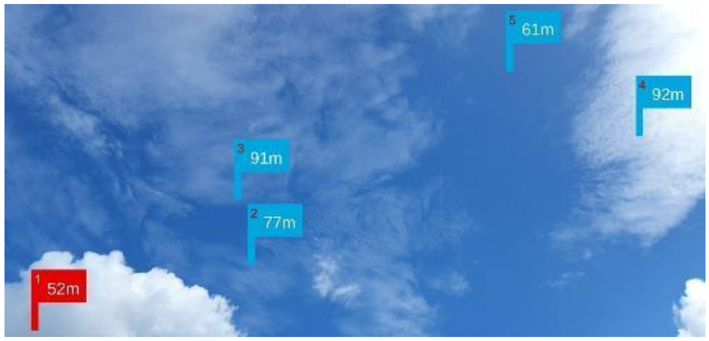


Figure 6. 11 POI display of camera toward the sky in AR view.

We found that the spacing between POIs is wider than the spacing between POIs in horizontal mode, and that the POIs of story chapter 1 and story chapter 4 are close to the left-hand and right-hand edges of the mobile screen respectively.

Finally, we tested the POI display of the camera when pointed towards the ground in the AR view during the walk-through. Figure 6.12 shows 5 POIs displaying the camera when pointed towards the ground in the AR view.

Figure 6. 12 POI display of camera toward the ground in AR view.

The spacing between the POIs in Figure 6.12 is similar to the spacing between the POIs with the camera pointing towards the sky, while the spacing between each POI in Figure 6.10 is wider when compared to the spacing in the horizontal mode.

When the flag is superimposed on the AR view, the shape of the flag image will not change regardless of the direction and angle of the AR camera; but the spacing between the two flags with the camera facing the sky or the ground is wider than the spacing between the POIs in horizontal plane mode. Table 6.3 shows the changes of the AR camera when pointed towards the sky, horizontal plane and the ground.

Table 6. 3 The changes of camera toward demonstration in same location.

	Camera towards	Flag size change	Flag direction change	Figure
1	the sky	no change	spacing become wider	Figure 6.11
2	horizontal plane		normally	Figure 6.10
3	ground		spacing become wider	Figure 6.12

To sum up, for Question 2, the effect of camera orientation on the POI shape and spacing, we are suggesting that it would be valuable to add this function to limit the participant's viewing angle so that it falls between 45 and 135 degrees; these flags will disappear when the angle of the phone's vertical line is not between 45 and 135 degrees. The goal is for the participant to keep the perspective at a safe walking-angle. It is dangerous for the participant to walk with the phone pointed towards either the sky or the ground.

6.3.4 POI Description in AR View

In this section, we explore the effect of the POI descriptions displayed in the AR views that are addressed in Question 3.

In order to test the effects of the information appearing and disappearing, we positioned a button identifying ‘hide/show info’ at the bottom of the user interface of the prototype. Users can click the button to hide or show each flag’s information. The information displayed both the distance between the POI and the participant’s standing location, and information about the story chapter which the user was engaging in.

The purpose of the experiment is to lead participants to valuing the role of the text as an information indicator. Figure 6.13 shows the effects of the title appearing and disappearing.

Figure 6. 13 POI description display (left) and no POI description display (right) in AR view.

We think showing distance information can guide participants to where they are standing and inform them of the distance between each flag, but the story chapters introduce no meaning to the display because the story chapter names are similar to the number in the upper left corner of each flag.

We noticed that the participants paid attention to their step count while focusing on the phone, paying attention to, and avoiding slips and obstacles.

All in all, we think POI information showing distance and story order is fine, while too much POI information can lead to walking safety risks.

6.3.5 Exploration of Indicated Arrow in AR View

Finally, we explore navigation direction guides in AR view, addressing Question 4: how navigation direction guides in the AR view.

We designed an indicator arrow to stimulate the participant to point the test phone towards the POI display direction.

If the screen position of the world space conversion of the red flag (the currently visited story chapter) is between -1520f and 1520f on the mobile phone screen, the red flag is displayed on the mobile phone screen. If the screen position of the red flag is greater than 3040f (screen position), it means that the red flag is far from the right-side of the current screen, and a red double arrow (>>) indication will appear on the mobile phone screen. Table 6.4 illustrates different categories of indicated arrows for 5 situations. See Appendix C1 for a more detailed explanation of world space and screen position.

Table 6. 4 Five categories Indicated Arrow.

Category	Screen System Position.X	Schematic diagram of indicate arrows
1	x > 3040f	>>
2	x < -3040f	<<
3	-1770f > x > -3040f	<
4	1520f < x < 3040f	>
5	-1520f < x < 1520f	No arrow

Figure 6.14 shows the design effects of the first category (see left-hand side in Figure 6.14) and fourth category (right-hand side in Figure 6.14) in Table 6.4. The story chapter that the participant should visit is on the participant's right-hand side of the screen. The double red arrow (see left-

hand side in Figure 6.14) indicates the extended distance between the story chapter and participant location, while a single arrow (see right-hand side in Figure 6.14) indicates the short distance between the story chapter and participant location.

Figure 6. 14 Part of indicating arrow effect design.

In this section, we explored improvements based on the four questions in Section 6.2 and achieved the following results.

1) POIs are displayed in layers; it is recommended that each POI use a height of 260px on the screen.
2) Camera toward horizontal plane is the best way to properly display each POI avatar orientation.
3) The POI information showing distance and story order only.
4) The single and double indicate arrow in AR view show.

The above improvements would be applied to the next prototype design.

6.4 Software Tracking of Participant Behaviour

Observational research involves systematically observing and recording participants' behaviour. The goal of an observational study is to obtain a snapshot of specific characteristics of the participants. Therefore, it is an essential research method to collect the environmental parameters of the participants (such as the Time, Latitude and Longitude of the standing location), the parameters of the test equipment (Camera Angle, Input Accelerometer, Orientation) and the behaviour parameters of the participants (Story chapters, Distance Walked).

This section describes the database design and data collection of participant behaviour and how to create an xml file that visualises participant behaviour map.

6.4.1 Design of the Participant Behaviour Database

After we was done exploring design options of the Narrative Navigation Prototype, we began to design the participant behaviour database for evaluation. The mobile phones recorded the participant's movement path during the user study as part of the evaluation data. First, we defined the main fields for recording participant movement tracking, such as time, real-time location, visited story chapter, the story of each story chapter, walked distance; and other statistical fields for data visualisation of maps, such as camera angle, screen orientation, tilt acceleration. We introduce the structure of the personal behaviour database of participants holding a user study mobile phone to visit the story.

Table 6. 5 The structure of participant behaviour database.

No	Field	Description	Format / Sample	Range
1	Time	Time of access point real time per second	Month/ date/year 30/09/2021 24:00:00	Time and Date
2	Latitude	the latitude of the location	-36.xxxxxx 11 decimal places	any latitude
3	Longitude	the longitude of the location	175.xxxxxx 11 decimal places	any longitude
4	Camera Angle	camera toward angle with true north	13 decimal places	0 to 360 degrees
5	Input Accelerometer	Linear acceleration of the device in the X, Y, Z directions in 3D space	(z, y, x)	-1 to 1
6	Orientation	mobile screen orientation	Landscape Portrait	landscape portrait
7	Navigate Method	story chapters	story chapter 1	story chapter 1 to story chapter 5
8	Distance Walked	the distance from the starting point	13 decimal places	meters
9	Introduction	introduce history and building	False/True	

We introduce the data collected by the phone's on-board sensors that the Narrative Navigation Prototype needs to use.

Latitude and Longitude

A geographic coordinate system is a spherical or ellipsoidal coordinate system used to directly mark unique locations on Earth. The geomagnetic field sensor of position sensors of android mobile phones can be used for the latitude and longitude of the mobile phone.

Camera angle

The camera angle is the angle between the user's study mobile phone and the true north direction, which is used to determine which angle that the camera on the test mobile phone faces. Figure 6.15 shows the camera angle between the mobile phone and the true north direction.

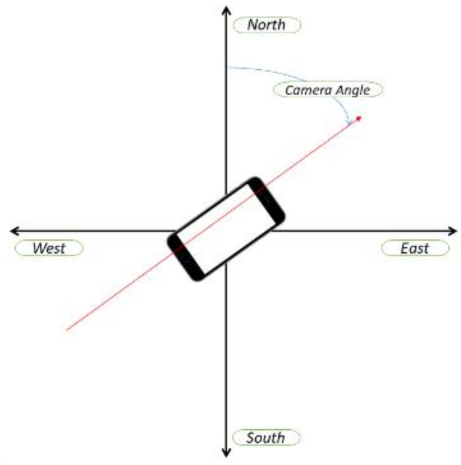


Figure 6. 15 The camera angle between mobile phone and north direction.

Acceleration

The mobile phone's accelerometer sensor of the motion sensor will report the linear acceleration changes of the device along the three main axes in 3D space; these changes being shake, tilt, swing, or rotation. The x, y and z are the three direction axes of the accelerometer, and the positive and negative directions will provide corresponding positive and negative values. As shown in Figure 6.16, positive values will be obtained when the user is moving in a positive direction, and negative values will be obtained when the user is moving in the reverse direction.

Figure 6.16 shows the positive and negative x, y, and z orientation axes of the android mobile phone.

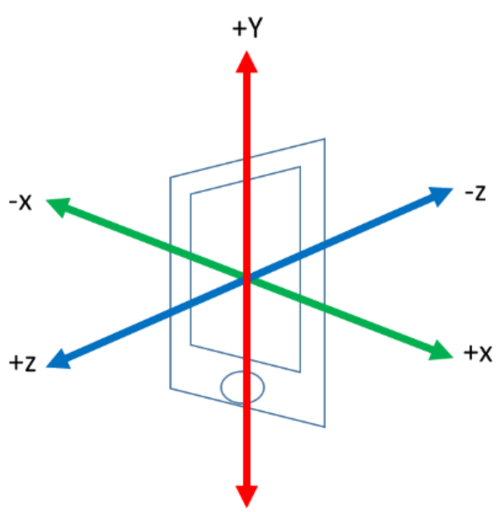


Figure 6. 16 The X, Y, Z orientation axes of Android mobile phone.

When we get X, Y, Z, the pitch value of the device is given by the following formula and acceleration value: *pitch = 180 * atan2(accelX, sqrt(accelY*accelY + accelZ*accelZ))/PI*

Orientation of the Mobile Phone Screen

The orientation of the mobile phone screen is divided into four categories: portrait, portrait upside down, landscape right and landscape left.

6.4.2 Tracking Participant Behaviour

After we designed the data structure of the dataset, and set up an XML file to record the participant movement, we created an XML file in our prototype for tracking the movement of the participants. First, we created a series of codes to record all the information of the mobile phone used in the walk-through, such as navigation method, time, latitude, longitude, distance walked, camera angle, orientation, acceleration, etc. Then, in order to output this information, we set up an XML structure. The following table outlines the code used to create the XML file:

Table 6. 6 The create an XML file with elements.

```
XmlDocument xml = new XmlDocument();
XmlElement root = xml.CreateElement("Data");

XmlElement ParticipantsInfo = xml.CreateElement("ParticipantsInfo");
    XmlElement info = xml.CreateElement("Time");
    info.InnerText = "00/00/0000 0:00:00 a.m.";
    ParticipantsInfo.AppendChild(info);
    XmlElement info1 = xml.CreateElement("Latitude");
    info1.InnerText = "0.0";
    ParticipantsInfo.AppendChild(info1);
    XmlElement info2 = xml.CreateElement("Longitude");
    info2.InnerText = "0.0";
    ParticipantsInfo.AppendChild(info2);
    XmlElement info3 = xml.CreateElement("CameraAngle");
    info5.InnerText = "0.0";
    ParticipantsInfo.AppendChild(info3);
    XmlElement info4 = xml.CreateElement("Acceleration");
    info6.InnerText = "0.0";
    ParticipantsInfo.AppendChild(info4);
    XmlElement info5 = xml.CreateElement("Orientation");
    info7.InnerText = "Portrait";
    ParticipantsInfo.AppendChild(info5);
    XmlElement info6 = xml.CreateElement("NavigationMethod");
    info.InnerText = "Digital Prototype X";
    ParticipantsInfo.AppendChild(info6);
            XmlElement info7 = xml.CreateElement("DistanceWalked");
            info4.InnerText = "0.0";
    ParticipantsInfo.AppendChild(info7);
    root.AppendChild(ParticipantsInfo);
    xml.AppendChild(root);
    xml.Save(localPath);
```

6.5 User Study Data Visualisation

The purpose of visualising the collected participants' behaviour data is to more intuitively classify the same behaviour of participants and discover individual behaviour differences. Therefore, creating a visual map of participant behaviour is very useful for studying participant behaviour observation. We use python folium as a tool to visualise POIs and related information on a map.

6.5.1 Exploring Data Visualisation

The python program that we wrote generates an HTML file with a movement track. The visualisation uses the elements shown in Table 6.7.

Table 6. 7 Description of the visual elements in the participant behaviour maps.

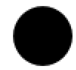
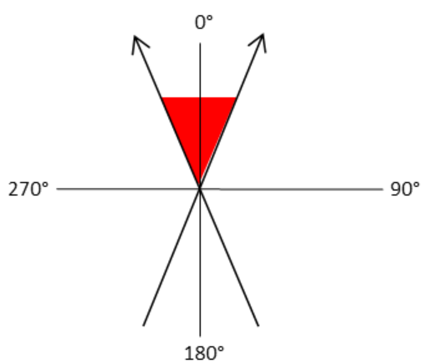
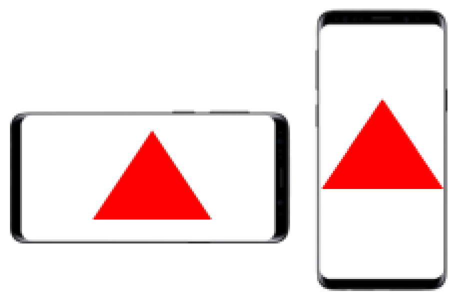
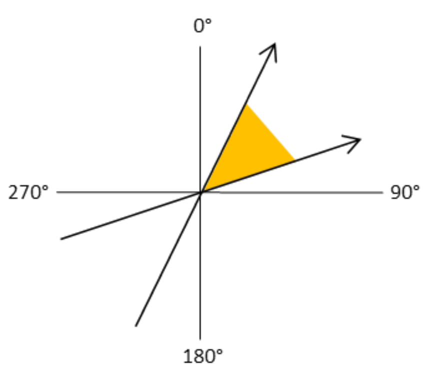
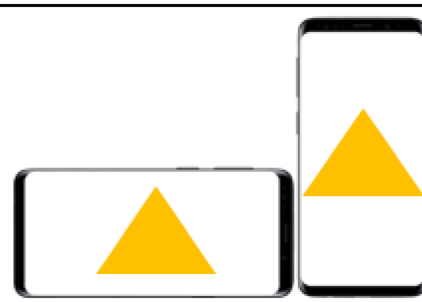
Items	Present meaning	Icon
Direction/distance person is travelling & their trail	Line (starting point to finishing point)	
Starting point and finishing point of the user study	The red flag icon presents the starting point, the finish icon presents the finishing point	
POIs	Story chapter' location in geographic space. SVG icon of each story chapter	
Location marker	Location marker for the path to visit each story chapter	
Location marker & overview point	Where the participant stood while looking out	
5M Circle of each story chapter	Participants look out for each story chapter within a 5 m radius of each story chapter	
Direction the person is looking at - camera angle	The angle between the direction the phone is looking at and true north in Landscape or Portrait	
The angle that the phone is rotated vertically (Gyroscope pitch*) of Landscape or Portrait *Values calculated from equation 1 on page 156	-22.5° > mobile >= 22.5° 	
	22.5° > mobile >= 67.5° 	

Table 6. 7 (Continued).

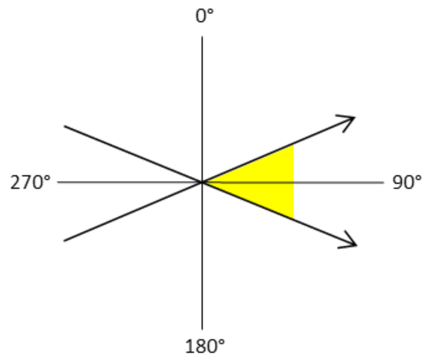
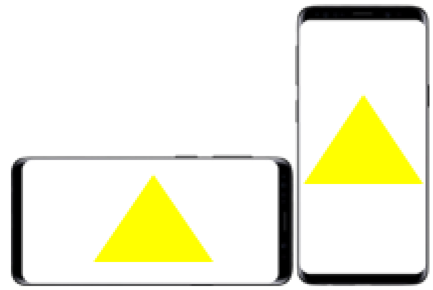
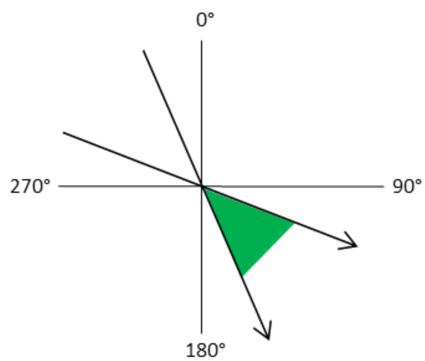
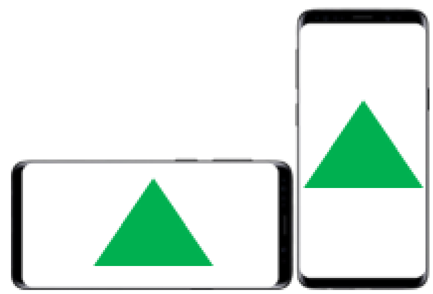
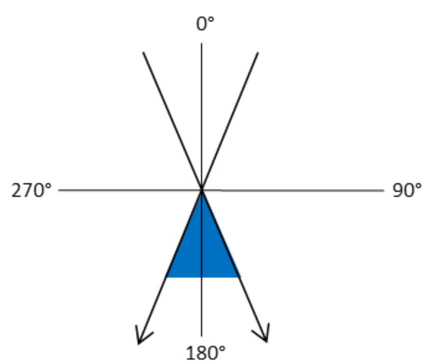
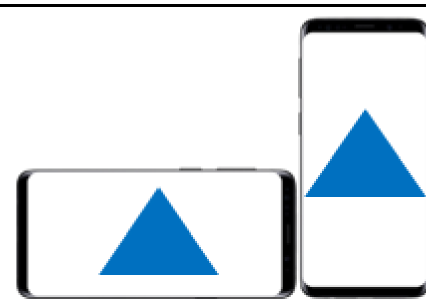
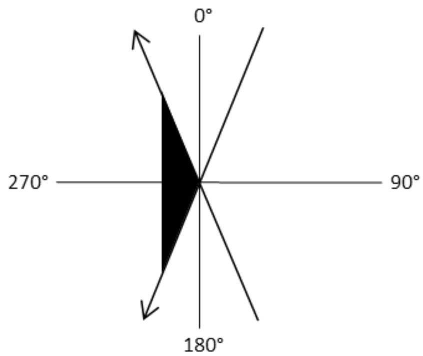
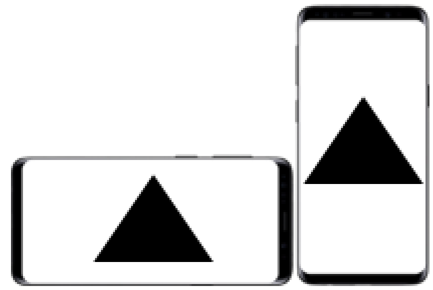
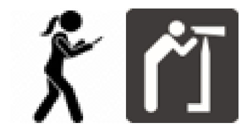
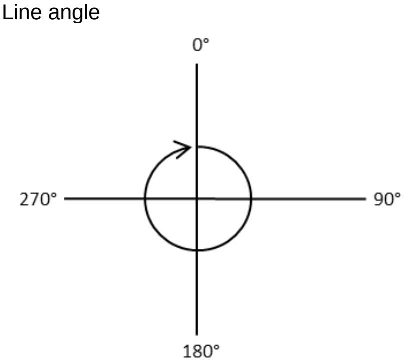
<table>
<tr><th>Items</th><th>Present meaning</th><th>Icon</th></tr>
<tr><td rowspan="3"></td><td>67.5° > mobile >= 112.5°
</td><td></td></tr>
<tr><td>112.5° > mobile >= 157.5°
</td><td></td></tr>
<tr><td>157.5° > mobile >= 202.5°
</td><td></td></tr>
</table>

Table 6. 7 (Continued).

Items	Present meaning	Icon
	Other angles 	
Pop-up message of location marker on the participant behaviour map (see Figure 6.18)	ID	Serial number
	Story chapter	Story chapter 1 to story chapter 5
	Walking or observing	
	Time (per second)	Date + Time
	Latitude + Longitude	Geolocation coordinate
	Camera Angle	Camera angle with north
	Orientation	Landscape Left Landscape Right Portrait Portrait Upside Down
	Gyroscope pitch	-22.5° > mobile pitch >= 22.5° 22.5° > mobile pitch >= 67.5° 67.5° > mobile pitch >= 112.5° 112.5° > mobile pitch >= 157.5° 157.5° > mobile pitch >= 202.5°
	Line angle 	Line angle between two location markers

After completing the participant behaviour database design and data visualisation, we walked through the prototype, generated both an XML file and a visual participant behaviour map using python, as shown in Figure 6.17. All map data is based on Google Maps.

Figure 6. 17 Example data visualisation of movement data.

As Figure 6.17 shows considerable details, we will divide it into two parts: overview description and detailed description.

Overview of the Visual Participant Behaviour Map

Figure 6.17 displays different coloured arrow icons (mostly yellow) with a mobile phone icon at each location marker, which represents the gyroscope pitch angle and camera direction of the phone in the current state. Clicking each location marker will display information such as the current time, phone angle and direction in the current state. The route between each location marker is the participant's tour route during the walkthrough phase. A circled number from 1 to 5 shows each story chapter.

We can see that the participants preferred using the horizontal plane to view the AR view, this is because almost all coloured triangles with the landscape icon and the yellow triangles in the figure represent a participant using the 67.5 to 112.5 degree-viewing angle to see the AR view. Although the participants had some time to point their phones slightly upwards (see orange in Figure 6.17), they followed the usual visit route to each story chapter of the story.

Detail Introduce the Location Marker in the Visual Map

We see two kinds of location markers. One is the black points that refer to participant’s movements. When we click this location marker (in Figure 6.17), a pop-up window will display the detailed information about this location marker, such as which story chapter, visited time, the latitude and longitude of this location, camera angle, orientation, acceleration, and the line angle.

For example, in Figure 6.18, the participant is visiting story chapter 5 at 02/15/2022 12:12:29, and after having walked to the location (Longitude: -37.7888, Latitude: 175.3175), the phone landscape is 75.96 degrees to the horizon, the camera is 62.96 degrees to true north, and the POI is 107 degrees from the previous POI. A walking icon represents this kind of POI at the top of the pop-up window. Figure 6.18 shows the detailed data of one of this kind of POI.

Figure 6. 18 Walking data of a participant's user study on 15th February 2022.

The second location marker used in Figure 6.17 is a black dot with a red circle, which identifies a location at which the participants were shown the nearest story chapter. When we click this dot, a pop-up window will display the detailed data shown in Figure 6.19.

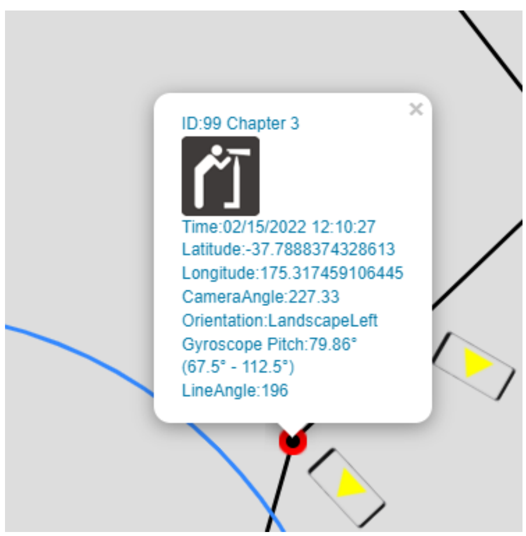


Figure 6. 19 Overview data for each chapter of a participant's user study on 15th February 2022.

6.6 Summary

In this chapter, we described the process of the Narrative Navigation Prototype walk-through and four issues that were discovered after the walk-through, around how the design of the POI affects participants' understanding of the story. For example, the number of POIs displayed on the screen, POI size, camera toward, POI information displays, and indicator arrows can improve the usability of Narrative Navigation Prototypes. We did a series of experiments and redesigned the POI design. Next, a participant behaviour database was designed, the typical user-movement data was extracted, and the data was visualised using python and Folium SDK, such that the data map of the participant's movement behaviour could be automatically generated. The preparation for the Final Prototype and evaluation for end-user research is complete.

In Section 6.1, we focused on the maps and datasets for the Narrative Navigation Prototype walk-through, and the walk-through process (screenshot in Appendix C). In Section 6.2, we described the insights for the walk-through and the four problems that we encountered. In Section 6.3, we listed the four questions that would be researched, and explored and executed the final design through the use of experiments. As a result of this work, we recommend that the Narrative Navigation Prototype redesign should incorporate 5 POIs on the horizontal screen of the mobile phone. The POI display area was in the horizontal view angle between 45 and 135 degrees, so the POI information only includes the story chapter number and the real-time distance between the story chapter location and the user's location, and added the navigation direction hints (single or double arrows) for the POI to be visited on the left-hand and right-hand sides of the test mobile phone screen.

From a software development perspective, the walk-throughs addressed a range of usability issues, such as directional arrows while walking and restricted navigational viewing angles, which were added to the Narrative Navigation Prototype.

In Sections 6.4 and 6.5, we designed the user-behaviour database and explored data visualisation of user data in preparation for the evaluation of the Final Prototype.

The positioning and navigation of POIs in the Final Prototype are based on GPS. The positioning error will increase when the location is close to the building.

Chapter 7 Evaluation of Final Prototype

In this research, we designed a questionnaire for the participants, interviewed 30 participants and analysed the result data. In addition, we designed the data visualisations of the participant's behaviour during the user study. The Chapter focused on the design of the Final Prototype, interviewed participants and observational studies with participants. The other focused on result analysis, in addition to the analysis of user feedback from Q1 to Q7, the visual map of user behaviour for each participant was also analysed. All participant's visual movement tracking maps are presented in Appendix D.

This chapter presents the setup and the results of our evaluation of the Final Prototype based on the visualisation concept of narrative navigation as described in Chapter 6. Section 7.1 focuses on the user evaluation method of the Final Prototype, including study materials, study procedure and user observation study, and Section 7.2 describes the results and analysis of the study. Section 7.3 provides a discussion and summary of this chapter.

7.1 User Study Method

To evaluate the final prototype, we added user observation research to the face-to-face questionnaire research method. Our user-study is described in three parts: study material (Section 7.1.1), study procedure (Section 7.1.2), and user-observation study in Section 7.1.3. Thirty participants used the final prototype and were interviewed face-to-face within a 20-minute period.

7.1.1 Study Materials

The study materials included: the preparation and content design of the story chapter, and interview notes.

Story Contents of the Final Prototype

In order for the story history of the University of Waikato to become more interesting and iconic campus cultural elements, we changed the tree's story to a history of the University of Waikato. The story describes the changes to some of the University of Waikato's distinctive landmarks over 58 years, listed five landmarks in detailed introduction, including facility, specificity, and the future building. Table 7.1 shows the datasets of the story in the user study.

Table 7. 1 Dataset of the story in the user-study.

No	POIs or Viewpoint	Location	AR trigger point	Information	Introduction	Building/plaque
1	Starting Point	-37.788759 175.318626	Car Park			
2	Story chapter 1	-37.788968 175.318058	within 5 meters	History of the University of Waikato from 1960 to 1969.	The University of Waikato opened in 1965. The University comprised the School of Humanities and the School of Social Sciences. In 1969 the School of Science was established	School of Science
3	Story chapter 2	-37.78885 175.31772		History of the University of Waikato from 1970 to 1979	The Waikato School of Management was established in 1972. Computer Science and Computing Services were established in 1973.	School of Computing and Mathematical Sciences
4	Story chapter 3	-37.78888 175.31741		History of the University of Waikato from 1980 to 1989	In April 1989 New Zealand's first internet connection was established right here	The plaque of First internet connection in NZ
5	Story chapter 4	-37.78848 175.31766		History of the University of Waikato from 1990 to 2000	The School of Māori and Pacific Development was formally established in 1996 and in 2016, became Te Pua Wānanga ki te Ao, Faculty of Māori and Indigenous Studies.	The former School of Māori and Pacific Development
6	Story chapter 5	-37.78859 175.31806		History of the University of Waikato from 2000 to 2021	On the main campus, work has begun on a new multipurpose hub called The Pā, which will include a marae and spaces for students to work and relax.	The Pā

Figure 7.1 shows the maps for the Final Prototype, the starting location (see red point in Figure 7.1) is located in the car park, with each participant following the yellow visit route to visit all the buildings and plaques for the story.

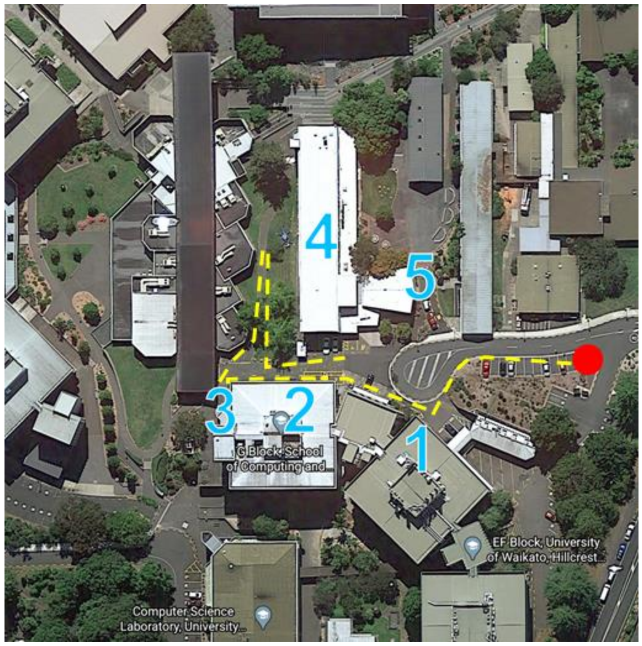


Figure 7. 1 Recommended visit order for participants (Map data: Google ©2022).

Participant Information Sheet, Research Consent Form and Researchers Interview Notes Sheet are also available. See Appendix D1.

Questionnaire of the Final Prototype

The questionnaire is divided into three parts: demographic questions, background questions, and field observation questions. Parts 1 and 2 use multiple choice questions and part 3 uses open-ended questions. Table 7.2 is the questionnaire of Final Prototype.

Table 7. 2 Questionnaire of Final Prototype.

Part 1: Demographic Questions	
DQ1	Age, Occupation
DQ2	Computer science / Non computer science
Part 2: Background Questions	
Q1	Do you have experience using maps for navigation?
Q2	Do you have experience using location-based augmented reality?
Part 3: After User Study Questions	
Q3	Please rate how much you agree with the following sentence: "It was enjoyable to use narrative navigation for the story"
Q4	Please rate how much you agree with the following sentence: "The narrative navigation for the story was easy to use".
Q5	Please rate how much you agree with the following sentence: "It was easy to navigate the location-based story using narrative navigation".
Q6	What suggestions do you have to improve this App?
Q7	Any other comments or questions?

7.1.2 Study Procedure

The research process was divided into two parts, user-study based user-observation and post-user study interviews.

The story of the user studying the Final Prototype revolves around five landmarks at the University of Waikato, including existing buildings, event memorial plaques and future buildings. Table 7.3 details the visit-steps for each participant and the associated scenarios and AR views that the participants will see.

Table 7. 3 User study steps of the Final Prototype for participant.

User study step	Scenes	Starting point of the walk	End Point of the walk or standing point	Observer scenes	Display information on AR view
1	Navigation		Starting point	Story Chapter 1 to 5	Flag 1 to Flag 5
2	Navigation	Starting point	Story chapter 1	Walk to story chapter 1	Red flag
3	Introduction		Story chapter 1	University history	Introduction 1960-1969 history, School of science
4	Navigation		Story chapter 1	Story Chapter 2 to 5	Flag 2 to Flag 5
5	Navigation	Chapter 1	Story chapter 2	Walk to story chapter 2	red flag
6	Introduction		Story chapter 2	University history	Introduction 1970-1979 history, School of Computing and Mathematical Sciences
7	Navigation		Story chapter 2	Story chapters 3 to 5	Flag 3 to Flag 5
8	Navigation	Chapter 2	Story chapter 3	walk to story chapter 3	red flag
9	Introduction		Story chapter 3	University history	Introduction 1980-1989 history,
10	Navigation		Story chapter 3	Story chapters 4 to 5	Flag 4 to Flag 5
11	Navigation	Chapter 3	Story chapter 4	walk to story chapter 4	red flag
12	Introduction		Story chapter 4	University history	Introduction 1990-1999 history, former School of Māori and Pacific Development
13	Navigation		Story chapter 4	Story chapter 5	Flag 5
14	Navigation	Chapter 4	Story chapter 5	Walk to story chapter 5	red flag
15	Introduction		Story chapter 5	University history	Introduction 2000-2021 history, The Pā (the project under construction)

User Study Procedure

We began by providing each participant with background on the research, after which we got them to sign a participant consent form. We asked them the multiple-choice questions for Parts 1 and 2 of the questionnaires (see Table 7.2), and then led them to the starting point of the user study, where we provided them with an introduction and precautions for using the Final Prototype (the next paragraph will describe this in detail). The user study is completed independently by the participants, and we accompany them to solve various emergencies. After completing the test, we asked the open-ended questions of Part 3 of the questionnaire.

Final Prototype User Study Guideline

When we lead the participants to do the user study, we first introduce the following user-study guideline to each participant.

This user-study relates to the concept of narrative navigation, in which participants will be using a mobile phone on which augmented reality is used to indicate the order of a location-based story. The story is told in 5 ordered locations. Visiting these five locations one after the other allows participants to experience the story. During the study, the participants are given a test mobile phone to use on the Final Prototype on-site. The participants follow the five-story locations on the AR view to experience each story part in their correct sequence. Participant feedback will be used to identify the best way to display the augmented reality story locations to a user.

Participants are asked to take the mobile phone running the Final Prototype towards S Block on the university campus. The participants can see five augmented flags shown on the screen of the mobile phone. The red flag is the next flag that participants should visit. When participants reach about 5 meters from this flag, a new pop-up screen and related introduction about this POI will be presented.

Final Prototype Testing Considerations

We noticed that participants needed to be careful of their step when walking, that they should pay attention and avoid slipping, and obstacles when focusing on their mobile phones. In a similar situation when using the Google Maps safety notice, Google Maps suggests that the user should put down the mobile phone when the user no longer needs directions. We explicitly told users before they began their study to take care when looking at their phones while walking to ensure they did not have an accident.

7.1.3 User Observation Study of Final Prototype

This section shows using camera views of the user study instead of what the participant (Participant ID: 12) would have experienced during the study, and the participant behaviour in how the map tracks their movement.

The Figure 7.2 shows the starting point screenshot when participants begin their walk-through. The red flag (flag 1) on the augmented reality view is the next visit location.

Figure 7. 2 The five story chapters shown on the test mobile phone at the starting point.

Figure 7.3 shows that when a participant arrives within 5 meters of story chapter 1. The test mobile phone pop-ups provide introductions that include three pages of information. The first page hints that story chapter 1 of the story has been reached, and that this story occurred at this location between 1960 and 1969 (see the left figure of Figure 7.4), while the second page describes major events that took place between 1965 and 1969, with the third page asking participants to stand outside the current School of Science (see the right figure of Figure 7.4).

Figure 7. 3 Arrived information of the chapter 1 of story.

The participant then clicks the 'Next' button, in response to which the pop-up window displays the following information:

Figure 7. 4 History introduction (left) and location introduction (right) of chapter 1 of the story.

When the participant visits story chapter 1, clicks on the 'Next' button, the prototype displays the scene in story chapter 2, and furthermore, shows story chapter 2 to story chapter 5 on screen.

The following figure shows story chapter 2 how the next visit location was presented using a red flag.

Figure 7. 5 The screenshot of the participant visits the story chapter 2.

The following figure shows the introduction of story chapter 2.

Figure 7. 6 Introduction of the participant visit the story chapter 2.

Next, having clicked the 'Next' story chapter button, the participant visits story chapter 3. The following figure shows the introduction to story chapter 3.

Figure 7. 7 The screenshot of the participant visits to story chapter 3.

Figure 7. 8 Introduction for Chapter 3 of the story.

Next, the participant visits story chapter 4. The following figure shows the introduction to story chapter 4.

Figure 7. 9 The screenshot of the participant's visit to story chapter 4.

Figure 7. 10 Introduction to Chapter 4 of the story.

When the participant clicked the 'Next' button, the following information is displayed:

The School of Māori and Pacific Development was formally established in 1996 and in 2016, became Te Pua Wānanga ki te Ao, Faculty of Māori and Indigenous Studies.

In 1991 Te Rōpū Manukura was formed as a consultative body to the University Council.

You are standing next to the former School of Māori and Pacific Development.

Finally, the participant visits story chapter 5. The following figure shows the introduction to story chapter 5.

Figure 7. 11 The screenshot of the participant's visit to story chapter 5.

Figure 7. 12 The introduction to chapter 5 of the story.

When the participant clicked the ‘next’ button, the following information will be displayed:

A new University of Waikato campus in downtown Tauranga opened in 2019.

On the main campus work has begun on a new multipurpose hub called The Pā, which will include a marae and spaces for students to work and relax.

You are looking at the construction of this new Pā.

When the participant clicked the ‘Next’ button, the final prototype test was over. We led the participants to continue the open-question interview. After the interview had finished, we exported the XML file and generated the participant behaviour map, as shown in Figure 7.13.

Figure 7. 13 The participant behaviour movement track map.

7.2 Results and Analysis

Thirty participants used the final prototype as part of the user-study. The observations and results of the study and the participant interviews are discussed in this section.

7.2.1 Participant Demographic

The user-study was held over a period of 38 days from 2nd February 2022 to 11th March 2022 during 'Red traffic light' restrictions, as outlined in New Zealand's traffic light settings (COVID-19 Protection Framework). In this case, it was very difficult to find 30 participants to participate in the user study, which involved the participation of 8 females and 22 males, whose ages ranged from 20 years old to 60 years old. Figure 7.14 shows the demographic data; while the complete details of all participants are provided in Appendix D, Table D1.1.

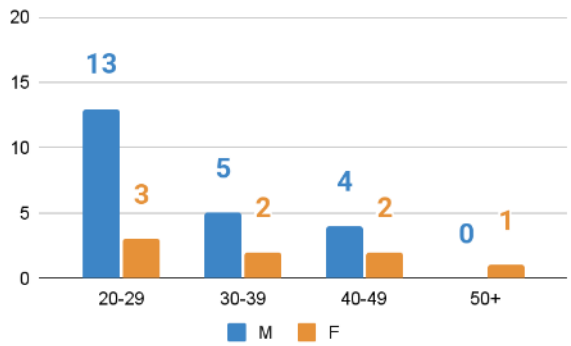


Figure 7. 14 Demographic data for user-study.

We enlisted 30 people with an age ranging from 20 years old to 50 plus years old. Figure 7.15 and Figure 7.16 show the demographics of the participants.

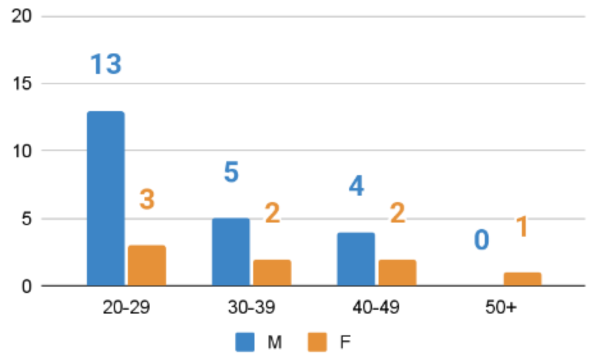


Figure 7. 15 The demographic information of the participants.

Seventeen of the 30 participants speak English, while 13 of the 30 participants speak Mandarin.

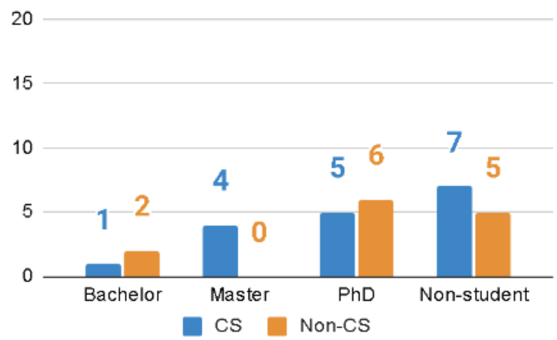


Figure 7. 16 The background of the participants.

Q1: Do you have experience using maps for navigation?

The responses to question Q1 "Do you have experience using maps for navigation?" are shown in Figure 7.17. As can be seen, almost all participants had experience with map navigation.

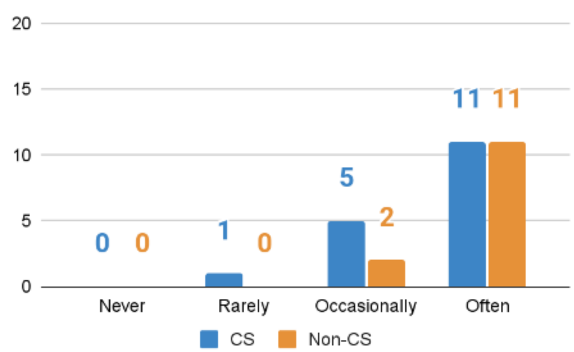


Figure 7. 17 Q1 (Do you have experience using maps for navigation) of the participants.

Twenty-two of the 30 participants chose "often to use maps for navigation" and 7 of the 30 participants chose "occasionally to use maps for navigation". Figure 7.18 shows similar results in relation to the participants' CS backgrounds or non-CS backgrounds.

Q2: Do you have experience using location-based augmented reality?

The responses to the question "Do you have experience using location-based augmented reality?" are shown in Figure 7.18.

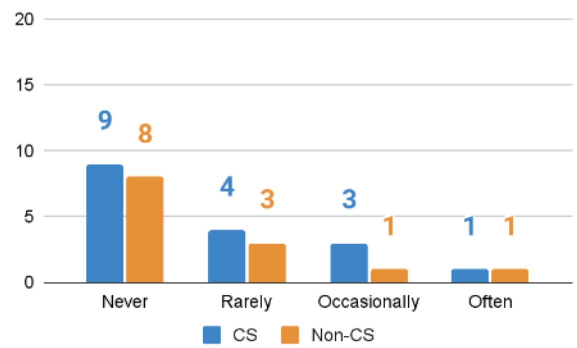


Figure 7. 18 Q2 (Do you have experience using location-based augmented reality) of the participants.

When we asked, most participants asked me what location-based augmented reality is, or how to understand location-based services in augmented reality? We asked the participants "do you know the Pokémon Go game or Google map live view?" Most participants gave a "Yes" answer. Less participants should 24 of the 30 participants chose "never" or "rarely". More interestingly, only 1 participant suppose "often" to use location-based augmented reality. The reason is the participants often use live view on Google Maps.

7.2.2 Feedback on Narrative Navigation

For the following questions are Q3 to Q5, each participant was supposed to choose an answer and provide a reason for their choice of answer.

Q3: It was enjoyable to use narrative navigation for the story

In the response to the question "It was enjoyable to use narrative navigation for the story" shown in Figure 7.19, the majority of participants chose "Agree" or "Completely Agree".

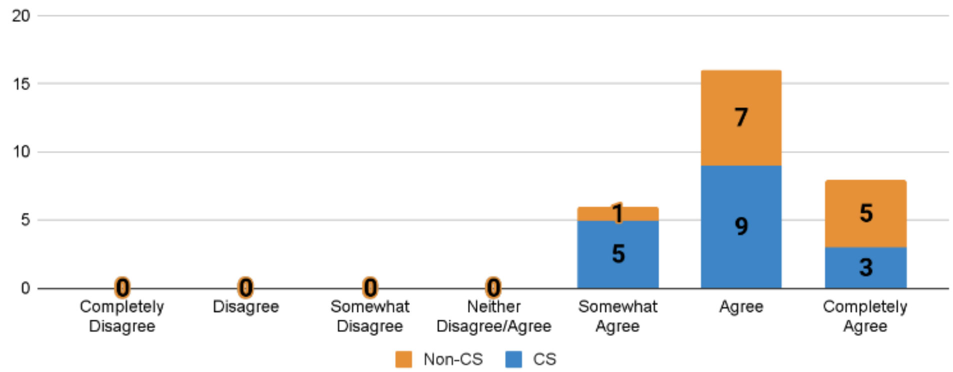


Figure 7. 19 Q3 (It was enjoyable to use narrative navigation for the story) of the participants.

In answers to question Q3, 8 of the 30 participants chose “Completely Agree”, 16 of the 30 participants chose “Agree”. Figure 7.19 shows 5 out of 17 CS background participants chose “Somewhat Agree”, while 1 out of 13 non-CS background participants chose “Somewhat Agree”.

Here are the details of the participants' responses and reasons for choosing the answers they chose.

Table 7. 4 The 30 participants answering Q3.

Participant	Likert Scale			Feedback	Translated	CS/ Non	Positive/ Negative
	Somewhat Agree (5)	Agree (6)	Completely Agree (7)				
1	5			"Sometimes flags go out of the screen and shades so it's tricky to identify."	N	Y	Negative
2			7	"Telling the history of unfamiliar places is meaningful and will inspire visitors to learn more." (translated from Mandarin)	Y	N	Positive
3			7	"Fun and novelty." (translated from Mandarin)	Y	Y	Positive
4		6		"Explore the history of a scenic spot and a university."	N	Y	Positive
5			7	"Narrative is a good test, I can get and know it this time." (translated from Mandarin)	Y	Y	Positive
6		6		"Fun and new, if you are familiar with the App, and want to visit other places use the App. Adding value is to provide information, I can see a real image and not a simulation picture or map." (translated from Mandarin)	Y	Y	Positive
7		6		"How long can I walk to the destination?"	N	Y	Positive
8			7	"Adventure, exciting, enjoy the history of campus, multi-purpose and enjoyable."	N	N	Positive
9		6		"I got to the place where I'm meant to be, and found a bit more information. It tells you the story of where I am standing. What's the purpose of the flag, because they give you more information when you're in the place, which we usually don't get with Google Maps?"	N	N	Positive
10			7	"This is my first time using augmented reality. So it was fun because I have the idea about these historical places and the evolution of the university. So I love the narrative navigation." (translated from Mandarin)	Y	N	Positive
11		6		"It is more intuitive and convenient. When you arrive at this place, there will be a corresponding introduction, so that you can know the (history) of this place more clearly and intuitively." (translated from Mandarin)	Y	Y	Positive
12		6		"The UI doesn't look like a commercial App, but it can work very well. When you arrive at each attraction, you can see an introduction, and so that you can better visit the campus."	N	Y	Positive
13	5			"It was interesting going into the different locations, and then you can promptly have some history related to that place. So if you visit a new place, you can go anywhere. It would be nice if you walk to any certain point, and you get like three to four line stories about why it is important history-wise. So I think it's a good thing. Okay, that's why I use this option. Somewhat agree with it." (translated from Mandarin)	Y	N	Negative
14		6		"It is heavier to hold the phone in your hand, and it is better to put it in your pocket to listen to the sound." (translated from Mandarin)	Y	N	Positive
15	5			1. "After the red flag disappears, the red arrow indicating the direction is not accurate" 2. "Don't visit LBS stories in chronological order, but by distance. I don't need a timeline to visit stories." (translated from Mandarin)	Y	Y	Negative

Table 7. 4 (Continued).

Participant	Likert Scale			Feedback	Translated	CS/ Non	Positive/ Negative
	Somewhat Agree (5)	Agree (6)	Completely Agree (7)				
16		6		"Novelty, time saving."	N	N	Positive
17	5			"It was a little difficult to know what chapter you were in on the screen, I kind of lost my sense of direction for the other chapters."	N	Y	Negative
18			7	"I suppose I can see the real reality and the narrative stories simultaneously, So I understand the history of the university." (translated from Mandarin)	Y	N	Positive
19			7	"Know where the starting point and end point of the logic line of the whole story are, and understand the development of history." (translated from Mandarin)	Y	N	Positive
20		6		"Very interesting, through (narrative navigation) I know the history of the (university), know what the building is used for, and you can take a self-guided tour."	N	N	Positive
21		6		"Knowing what's happening, feeling excited, It's hard for someone to see and try to move it around, you know how to use it, it's cool."	N	Y	Positive
22		6		"I think it was interesting too. Because it was innovative and interesting. It was very interesting to know what the App is and how it's working. Yeah. So it was enjoyable because I think because of the learning aspect related to the App that you're developing."	N	N	Positive
23		6		"I do like the screen where it shows the location, although I'm confused by the flags. It will be much clearer if I'm looking at it like the arrow symbol." (translated from Mandarin)	Y	N	Positive
24		6		"In previous similar Apps, there was no specific order of visits. This App has a tour order, and when you arrive at the destination, there are information and voice prompts. Without this App, even if you arrive at the location, you will not be able to know the relevant historical information." (translated from Mandarin)	Y	Y	Positive
25	5			"The App can plan the visit route, give a clear visit order, and avoid missing the visit of POI."	N	Y	Negative
26		6		1."It was visual. And it was outside." 2."More explanation of how it works."	N	N	Positive
27	5			"New experiences to use the narrative may be good for me, but hold the phone all the time."	N	Y	Negative
28			7	"The distance and display the meters as soon as you approach the distance decrease."	N	Y	Positive
29		6		"Sort of like a pathway."	N	Y	Positive
30		6		"Like a guided tour."	N	Y	Positive

According to the feedback of all participants for Q3, 24 of the 30 participants enjoyed using narrative navigation, 6 of the 30 participants partially agreed that they enjoyed using narrative navigation. The proportion of participants from non-CS background who chose to “Agree” or “Completely Agree” (92.31%) gave a positive rating 21.72% higher than that of participants from CS background who chose to “Agree” or “Completely Agree” (70.59%).

We analysed the details of the participants' choice of "somewhat agree" and found that their negative comments were mainly focused on the UI design, GPS deviation and the use of the prototype, such as inaccurate indicator of directions, holding the phone for a long time, etc.

Q4: The narrative navigation for the story was easy to use

The responses to the question “The narrative navigation for the story was easy to use” are shown in Figure 7.20, which indicates that most participants chose “Agree” or “Completely Agree”.

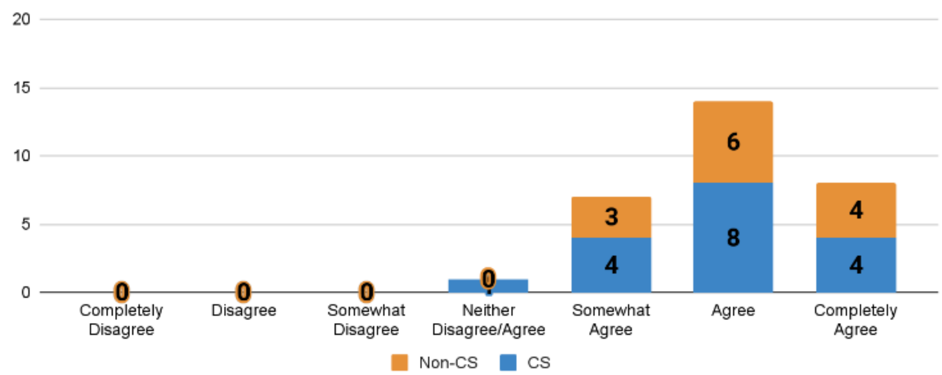


Figure 7. 20 Q4 (The narrative navigation for the story was easy to use) of the participants.

In answer to the question Q4, 8 of the 30 participants chose “Completely Agree”, while 14 of the 30 participants chose “Agree”. Figure 7.21 shows that 23.5% of CS background participants chose “Somewhat Agree”, and 23% of non-CS background participants chose “Somewhat Agree”. One of 17 participants with CS backgrounds chose “Neither Disagree/Agree”.

Table 7.5 gives an overview of the participants’ responses and reasons for their selection.

Table 7. 5 Overview of answers for Q4.

Participant	Likert Scale					Feedback	Translated	CS/ Non CS	Positive/ Negative
	Some-what Disagree (3)	Neither Disagree /Agree (4)	Some-what Agree (5)	Agree (6)	Comp -lately Agree (7)				
1			5			"Same as the previous reason (Sometimes flags go out of the screen and shades so it's tricky to identify.)"	N	Y	Negative
2					7	"Easy and convenient to get where you want to go and tell a story." (translated from Mandarin)	Y	N	Positive
3				6		"Interactivity should be improved and applied to self-guided tour scenarios." (translated from Mandarin)	Y	Y	Positive
4				6		"Based on walking alone on a route."	N	Y	Positive
5				6		"I think earlier, watch my steps and go directly without thinking and searching anymore. Easy to navigate from Point A to B of Waikato university." (translated from Mandarin)	Y	Y	Positive
6				6		"Use narrative navigation concepts that provide more information than directional signs, such as more lively and interactive content." (translated from Mandarin)	Y	Y	Positive
7				6		"When you don't know a building, you can easily learn about the building and map it to its physical location."	N	Y	Positive
8				6		"People struggle to start but after they know the functions, it is easy for them to use. So, as far as every computer is like that, it's hard to use, but after you get used to it, you're familiar with it, you can use it very well."	N	N	Positive
9				6		"Sometimes the red flag disappeared. but if you move with a little bit, it appears again."	N	N	Positive
10					7	"Because it's navigable it shows where you have to go, otherwise, there is a worry going behind, so it was so easy to know what's going on." (translated from Mandarin)	Y	N	Positive
11				6		"With real-time navigation, users don't easily get lost, and there is a distance display, which is very convenient." (translated from Mandarin)	Y	Y	Positive
12				6		"When I walk to the building, I can see the introduction of the building. If I can see the picture in the introduction like Chapter 5, and the picture corresponding to the building I am visiting, I will know more clearly, the introduction is about the building in front of me. Because I have a lot of buildings in front of me, I can't be 100% sure which building it is if it's just described in words."	N	Y	Positive
13	3					"I will say something. I will disagree with this one. Somewhat disagree. Same problem. Like maybe, I have never used location based augmented reality. That was why I was like facing a bit of difficulty to go where the direction is and if you like the flags that you had in there, if you put the flags right in the middle of the screen and go towards that position, you might be ending facing a wall or some blocked thing, you have to manoeuvre around to go to the exact position. And also, it was a bit tricky. When you go really close to the point, you need to have a certain distance from that point to where you are standing so that you can actually hear the story. If you went exactly at that point, it was like the system was not responding, or possibly it was confused about where you were standing. So that's what I felt over there." (translated from Mandarin)	Y	N	Negative

Table 7. 5 (Continued).

Participant	Likert Scale					Feedback	Translated	CS/ Non CS	Positive/ Negative
	Some-what Disagree (3)	Neither Disagree /Agree (4)	Some-what Agree (5)	Agree (6)	Comp -lately Agree (7)				
14				6		“Easier for places with few buildings but not easy to navigate LBS stories with dense buildings or poor road conditions.” (translated from Mandarin)	Y	N	Positive
15				6		“Better navigation than visiting theme parks, easy navigation with arrows and distance.” (translated from Mandarin)	Y	Y	Positive
16					7	“Campuses and museums and memorials use this type of narrative navigation very well.”	N	N	Positive
17	3					“Like on screen from the second point onwards, because the first screen you could go around, you could say, Chapter 2 and a rough location. But it was difficult from that point onwards.”	N	Y	Negative
18					7	“There is a very detailed explanation on the screen to show me the process and the locations. So, I can easily understand where they are.” (translated from Mandarin)	Y	N	Positive
19					7	“Through narrative navigation, when I see this App, I know where to go, how to get there, and where the next story chapter is.” (translated from Mandarin)	Y	N	Positive
20				6		“Before visiting, I did not know the content of these stories. But after the narrative navigation, I know the relevant information and don’t ignore this information. This function is very good.”	N	N	Positive
21				6		“Difficult to focus on the screen, sometimes it just disappeared in the atmosphere, trying to find it was probably the tricky part.”	N	Y	Positive
22		4				“I would say that initially, I was just getting to a point where I had to think how I would use it, how it is used. But after the first chapter, it was easy. Like it, it took me a while, but once I figured it out how it's working. Then it was easy, but only initially it was a little tough, but most of the time it was easy.”	N	N	Negative
23			5			“It's really easy to visualise the building, which makes it easy to point out some things. My concern is that you may be focused on the default settings or not aware of some danger or danger around us. So maybe you might miss something and then it might be dangerous.” (translated from Mandarin)	Y	N	Negative
24				6		“The App will push historical information, allowing me to understand the introduction and historical background, the pop-up prompt is very good, and even disabled people can use it.” (translated from Mandarin)	Y	Y	Positive
25				6		1. “There are directional arrows pointing you to the POI.” 2. “Better than signpost”	N	Y	Positive
26				6		“Easy to navigate once I got the idea.”	N	N	Positive
27				6		“Do you have specific numbers that you say you need to visit?”	N	Y	Positive
28					7	“The destination-based story mentioned the history of this.”	N	Y	Positive
29			5			“Probably just having a little bit more direction. Where people can go towards.”	N	Y	Negative
30			5			“Arrows that are a little tricky to, how far away it was from it.”	N	Y	Negative

According to the feedback of all participants for Q4, the proportion of participants from Non-CS backgrounds who chose to “Agree” or “Completely Agree” (76.92%) was close to that of participants with CS backgrounds (70.59%) who responded "Agree" or "Completely agree".

We analysed the details of the participants’ choices of "Somewhat Agree", “Neither Disagree/Agree” and “Somewhat Disagree” as well as, and found that their negative comments were mainly focused on the GPS deviation, prototype usage safety, such as the inability to access the POI with little precision, and when there were obstacles or cars in the visiting route, etc.

Q5: It was easy to navigate the location-based story using narrative navigation

In the response to the question “It was easy to navigate the location-based story using narrative navigation” shown in Figure 7.21, the majority of participants chose “Agree”.

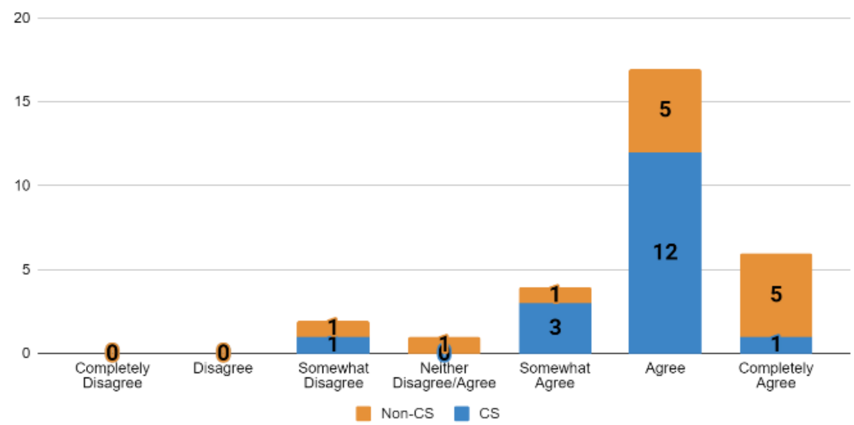


Figure 7. 21 Q5 (It was easy to navigate the location-based story using narrative navigation) of the participants.

In the responses to question Q5, 6 of the 30 participants chose “Completely Agree”, and 17 of the 30 participants chose “Agree”. Figure 7.21 shows 17.6% of participants with CS backgrounds chose “Somewhat Agree”, 7.6% of participants with non-CS backgrounds chose “Somewhat Agree”. One of 13 participants without a CS background chose “Neither Disagree/Agree”. More specifically, 1 participant with a CS background and 1 participant with non-CS background chose “Somewhat Disagree”.

Here are the details of choosing “Somewhat Agree” participants talked about.

Table 7. 6 Overview of answers for Q5.

Participant	Likert Scale				Feedback	Translated	CS/ Non CS	Positive/ Negative
	Neither Disagree /Agree (4)	Somewhat Agree (5)	Agree (6)	Completely Agree (7)				
1			6		"It leads us from one point to another point and narrows down the path so then it's easy to navigate and faster."	N	Y	Positive
2				7	"Numbers with distance displayed direction and distance to the destination." (translated from Mandarin)	Y	N	Positive
3			6		"The navigation doesn't have a route." (translated from Mandarin)	Y	Y	Positive
4			6		"GPS should be more accuracy."	N	Y	Positive
5				7	"No specific detail, just the same as the prior answer." (translated from Mandarin)	Y	Y	Positive
6		5			"Toward the direction of the red flag." (translated from Mandarin)	Y	Y	Negative
7		5			"You need to keep looking at the screen with your eyes, it is recommended to use the mobile phone to vibrate and prompt, and many times you cannot look at the mobile phone while walking."	N	Y	Negative
8			6		"The overall experience was really good. While you're using the phone, it's hard to detect the direction. should go to guess. Maybe the mobile phone could show the ways that the user should go rather than suggesting they should just try the different directions."	N	N	Positive
9			6		"I am not 100% agree."	N	N	Positive
10			6		"Sometimes I can't see the numbers that mean for the meters, it's hidden from the screen. It's very rare, not always. 90% good, but for 10% that the numbers are hard to find the number means that distance, it's hard to find and out of the screen." (translated from Mandarin)	Y	N	Positive
11		5			"GPS function and coordinates to guide you how to go, it is relatively easy to find." (translated from Mandarin)	Y	Y	Negative
12		5			"You should have given me better instructions. Tell me need to stare at the phone screen for walking or just take the phone and go."	N	Y	Negative
13		5			"There was like some help provided by you just to change the route because if we strictly follow where this is taking us, we might end up on a blocked road or a Hill. You have to take some detours like you have to move from another direction to go exactly in the same position. So, it was not that easy to use for the first thing." (translated from Mandarin)	Y	N	Negative
14				7	"The real-time navigation function is a good App for strangers to visit the school. Need to consider how people with disabilities who cannot use mobile phones use this software." (translated from Mandarin)	Y	N	Positive
15			6		"Don't worry about the order of the story, just follow the instructions of the App directly." (translated from Mandarin)	Y	Y	Positive
16				7	"Narrative navigation is very intuitive on the mobile phone screen, very intuitive to use, know the operation instructions, the interface is clean, simple."	N	N	Positive

Table 7. 6 (Continued).

Participant	Likert Scale				Feedback	Translated	CS/ Non CS	Positive/ Negative
	Neither Disagree /Agree (4)	Somewhat Agree (5)	Agree (6)	Completely Agree (7)				
17			6		"The history of the university was really easy to use."	N	Y	Positive
18			6		"Sometimes it's hard to find the right direction, but at this stage it's perfect." (translated from Mandarin)	Y	N	Positive
19			6		"I don't need to follow the pre-set historical development, I just read a piece of history and I can choose some points to see, where to see where I go, the order of the stories limits the order of visits." (translated from Mandarin)	Y	N	Positive
20		5			1. "GPS deviation." 2. "Sometimes the red arrow on the left (exactly) points to the building entrance and misleads me into the building."	N	N	Negative
21				7	"When I arrive at the POI, the audio tells you which chapter you've reached and explains the order. These points are really good."	N	Y	Positive
22				7	"The narrative navigation is simple, informative, and easy to catch for a person who doesn't like to have too much information, less information, but more informative."	N	N	Positive
23			6		"The flag lets me know how to identify where I am by distance and then it also pops up (historical introduction) speaking 'I'm here', so it shows me my goal." (translated from Mandarin)	Y	N	Positive
24				7	"When the user reaches the POI 5 within meters range, the information is automatically displayed without any operation, which is very easy to use." (translated from Mandarin)	Y	Y	Positive
25	4				1. "Flag jitter, not very good." 2. "The hand keeps holding the phone, the hand is very tired."	N	Y	Negative
26		5			"The narrative provided me with enough information to use it. But I did need a bit too much support from you."	N	N	Negative
27		5			"The timeline is what makes it easier to use, which way to go to the flags, need to go around."	N	Y	Negative
28				7	"I can't control (not familiar with the app)"	N	Y	Positive
29		5			"A virtual path should be added, with some kind of colour or line indication."	N	Y	Negative
30			6		"Pop up on the screen and appear "Next" button."	N	Y	Positive

According to the feedback of all participants for Q5, the proportion of participants that answered "Agree" or "Completely Agree" to Q5 (76.67%) is close to the participants who chose "Agree" or "Completely agree" in Q4 (73.33%). Two participants chose "Somewhat Disagree" with Q5 compared to the previous Q3 and Q4 questions.

We analysed the details of the participants' choices of "Somewhat Agree", "Neither Disagree/Agree" and found that their negative comments were mostly focused on UI design, use of prototypes, and GPS deviation. For example, increasing the vibration of the mobile phone, according to the virtual route instructions on the ground, no need to keep looking at the mobile phone.

In summary, 24 of the 30 participants answered “Agree” and “Completely Agree” to Q3 (“It was enjoyable to use narrative navigation for the story”), 22 of the 30 participants answered “Agree” and “Completely Agree” to Q4 (“The narrative navigation for the story was easy to use”) and 23 of the 30 participants answered “Agree” and “Completely Agree” to Q5 (“It was easy to navigate the location-based story using narrative navigation”).

7.2.3 Further Suggestions

The following questions Q6 to Q7 enabled each participant to make further suggestions.

Q6 & Q7: Suggestions to improve/ other comments or questions

Twenty-nine 29 of the 30 participants answered Q6 (What suggestions do you have to improve the App?) and Q7 (Any other comments or questions?), while only 1 participant had no ideas for Q6 and Q7. We categorised the participants' answers, and divided them into eight categories. Table 7.7 shows each category, and each participant chose the result.

Table 7. 7 Categories of responses of participants to Q6 and Q7.

Participant ID	Suggestions	Add path	GPS signal jitter	UI re-design	Introduction related	Add arrow direction	Visit order	Safe	Other	Translated	CS/ Non CS
1	"Add an AR path on the road."	√								N	Y
2	"More details about the introduction." (translated from Mandarin)				√					Y	N
3	1. "Red flags should not disappear." 2. "Introduction should not occupy more space." 3. "GPS jitter." (translated from Mandarin)		√	√	√					Y	Y
4	"Add navigation route" (translated from Mandarin).	√								N	Y
5	1. "Don't take the phone every time." 2. "Chapter 4 has no clear direction."		√						√	Y	Y
6	1. "Customized visit order." 2. "Add an introduction to walking." 3. "Cost of data usage." (translated from Mandarin)				√		√		√	Y	Y
7	"Information windows are too large, put at the bottom. (translated from Mandarin)"			√						N	Y
8	1. "Add four directions." 2. "Customized visit order."					√	√			N	N
9	"To broaden the view."			√						N	N
10	1. "Distance number display problem." 2. "Introduction on and off." 3. "Sometimes two chapters suddenly disappear, other 3 chapters are fine."		√							Y	N
11	"No suggestions and comments." (translated from Mandarin)									Y	Y
12	1. "UI Improved." 2. "Red arrows misunderstanding." (translated from Mandarin)			√					√	N	Y
13	1. "5M notice." 2. "Add path." 3. "Detect the obstacle."	√	√						√	Y	N
14	1. "Don't want to hold the phone." 2. "Tourism easily to use." (translated from Mandarin)								√	Y	N
15	"Add more direction arrow." (translated from Mandarin)					√				Y	Y

Table 7. 7 (Continued).

Participant ID	Suggestions	Add path	GPS signal jitter	UI re-design	Introduction related	Add arrow direction	Visit order	Safe	Other	Translated	CS/ Non CS
16	"Add more information for participants." (translated from Mandarin)				√					N	N
17	"Red bubble on the ground (the trigger zone)."	√								N	Y
18	"Move the screen to find the red flag."			√						Y	N
19	"Following distance order." (translated from Mandarin)						√			Y	N
20	1. "Customized visit building." 2. "Use straight or curved arrows." 3. "Safe problem." (translated from Mandarin)					√	√	√		N	N
21	"Move the phone to find a flag."			√						N	Y
22	"Add more instructions."				√					N	N
23	1. "Applied to a museum." 2. "Change one flag to arrow pointing."			√					√	Y	N
24	1. "Add diverse elements, add bubble dialogues and virtual avatars." 2. "Add more POI and more history to enrich the story line." (translated from Mandarin)			√	√					Y	Y
25	1. "The UI is very simple." 2. "AR View is the same as using a digital video, except for more arrows and flags" (translated from Mandarin)			√						N	Y
26	1. More instruction. 2. Expand more history.				√					N	N
27	Follow the distance from near to far, use different orders.						√			N	Y
28	1. Not familiar with app. 2. Safety while looking mobile.							√	√	N	Y
29	1. Having a sort of pathway. 2. Certain names pop up.	√		√						N	Y
30	1. A little tag pop. 2. Show a path on the ground. 3. Don't like flags disappearing while 45 degrees.	√		√						N	Y
Total		6	4	11	7	3	5	2	7		

Each participant gives one or more one answer, the total answers are 45. Figure 7.22 shows all chosen categories of participants based on CS background and Non-CS background.

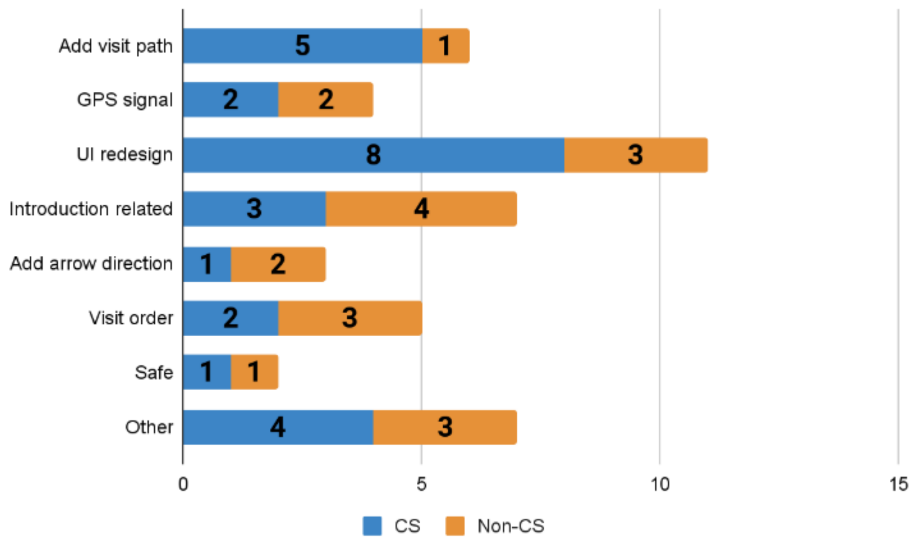


Figure 7. 22 The categories of responses to Q6 and Q7.

The most feedback is about UI design, 11 of the 45 responses proposed that the prototype should be improved "UI design", for instance, the intro dialog should not take up much space, or put the intro at the bottom on the screen, etc.

The second most feedback (7 of the 45 responses) was "introduction related" and "Other", such as participants wishing to introduce as they walk when story chapters have a lot to cover. Participants also hoped that the connection between AR and storytelling needs to be made stronger. Participants wish for more AR views or effects in the Finial Prototype.

Six responses from participants mentioned a desire to add visual paths to guide participants to each destination, and 5 feedback suggested that the story visit order be a random visit story order rather than a fixed order of visit.

Four responses from participants regarding GPS signal drift, we analysed that the reason for GPS signal drift is that the user-study area is close to a 3-story building, which leads to deviations in GPS signal accuracy. The Final Prototype initializes a new scene at the beginning of each story chapter visit, and the GPS signal is continuously corrected in the first 15 seconds of the scene running, causing the flag to shake and move quickly.

Three responses included the desire to add more arrow directions or that curved arrows allow the participant to walk more easily.

Two responses from participants regarding walking safety. There is a vehicle lane in some user-study areas, and the mobile phone screen needs to be viewed by the participant at all times in the user-study area during the user-study, as some participants are concerned about the safety of the user-study.

7.2.4 Participant Movement Track Map Analysis

After each participant finished the interview, we exported the XML file of the test mobile phone to a computer that runs the programme in order to generate the participant's movement track map. See Appendix D.2 for the 30 participants' movement maps. The statistics from the 30 participants' trails are summarised in Table 7.8.

The visiting time for each story chapter has been divided into three parts: navigation time of each story chapter, chapter story introduction time and story chapter scene jump time. The total time for the entire story is the sum of these elements of time of all the five story chapters. In Table 7.8, each story chapter is the sum of navigation time and introduction reading time, with the total time being the time of the entire story time. The time format is MM:SS (minutes and seconds). The distance is the actual walking distance, the unit used is a linear meter.

In each participant movement map, the different coloured triangles with the mobile phone icons indicate a combination of three pieces of information: the colour represents the gyroscope pitch angle, the direction represents the top of the triangle, which points at the angle between the camera and true north, and the mobile phone icon represents the mobile phone's landscape or portrait orientation. In Table 7.8, the first, second, and others predominantly used gyroscope pitch angles for each participant are listed, and the percentage of all pitch angles for each category is given. To highlight the different gyroscope pitch angles, we used the same colour as the gyroscope pitch angles in the map.

Table 7.8 shows the background of the participants, the navigation time (abbreviated as NT in the figure, MM:SS in minutes and seconds format) and distance (abbreviated as D in the figure, meters) for each story chapter, and the story visit time (abbreviated as T in the figure, MM:SS format), total walking distance (meters), gyroscope pitch angle (degrees) for the whole story.

Table 7. 8 Movement tracks summary of the 30 participants (Time: mm:ss, Distance: meters, Triangle: gyroscope pitch, %: percentage of all triangles of this type).

	CS/NON CS	Visited Time and Distance Walked												Location marker	Gyroscope Pitch					
		Story chapter 1		Story chapter 2		Story chapter 3		Story chapter 4		Story chapter 5		Total			1st		2nd		Other	
		NT	D	NT	D	NT	D	NT	D	NT	D	T	D		Angle	%	Angle	%	Angle	%
P1	Y	1:01	42.6	0:50	28.5	0:38	27.0	0:43	27.6	1:08	39.8	4:47	165.5	169	yellow ▲	88.2	orange ▲	8.98	green ▲	3.0
P2	N	0:55	36.6	1:06	36.9	1:24	21.0	0:52	33.2	0:46	28.9	7:13	156.6	148	yellow ▲	81.4	green ▲	18.6		
P3	Y	1:06	46.6	2:14	29.8	0:36	16.2	0:42	38.8	1:04	47.9	7:08	179.2	215	yellow ▲	97.7	green ▲	2.3		
P4	Y	0:28	43.8	0:42	28.0	0:45	29.5	1:00	32.0	1:00	49.0	5:02	182.3	156	yellow ▲	94.9	green ▲	5.1		
P5	Y	1:35	42.6	0:58	30.2	0:28	25.5	1:12	32.0	1:57	31.5	7:02	161.8	138	yellow ▲	73.2	green ▲	26.8		
P6	Y	1:13	45.6	0:42	28.7	0:45	27.2	0:49	30.8	1:15	38.8	6:16	171.1	172	yellow ▲	70.3	green ▲	29.7		
P7	Y	0:53	42.1	0:48	26.9	0:41	28.3	0:46	31.6	0:51	33.6	5:10	160.4	150	yellow ▲	94.7	green ▲	5.3		
P8	N	2:04	40.8	0:59	38.7	0:46	25.7	1:03	39.2	1:46	31.8	8:32	176.2	179	yellow ▲	87.2	green ▲	11.7	blue ▲	1.1
P9	N	0:58	37.8	0:34	27.9	1:13	29.8	0:42	29.2	1:06	31.4	5:26	156.0	149	yellow ▲	98.0	green ▲	2.0		
P10	N	0:50	76.5	0:47	29.5	1:47	28.2	0:52	31.4	1:35	42.4	8:00	208.1	170	yellow ▲	95.9	green ▲	4.1		
P11	Y	1:05	33.1	0:51	32.6	0:42	23.0	0:54	29.8	1:04	43.4	5:33	161.9	169	yellow ▲	86.4	green ▲	13.6		
P12	Y	1:39	47.8	0:57	26.9	0:56	28.3	1:52	36.0	1:07	47.2	8:43	186.2	230	yellow ▲	88.7	green ▲	11.3		
P13	N	1:10	37.9	1:37	31.8	1:00	26.9	0:44	26.6	1:15	30.8	8:01	153.9	162	yellow ▲	92.6	green ▲	7.4		
P14	N	0:58	45.0	1:05	29.5	0:37	19.0	0:55	34.0	1:34	32.3	7:11	159.9	163	yellow ▲	92.0	green ▲	8.0		
P15	Y	1:31	24.2	0:43	31.8	0:24	27.0	1:05	28.5	0:33	30.8	5:18	142.1	157	yellow ▲	82.2	green ▲	15.9	blue ▲	1.9
P16	N	1:09	51.9	0:44	25.1	0:37	20.1	1:00	29.3	1:14	38.5	6:30	165.0	159	yellow ▲	97.5	green ▲	2.5		
P17	Y	3:17	53.8	0:35	30.4	0:38	28.2	0:31	30.3	0:39	32.6	7:20	175.4	147	green ▲	72.8	yellow ▲	20.4	orange ▲ blue ▲	1.4 5.4
P18	N	0:34	44.3	0:32	38.0	0:34	29.0	1:06	30.3	0:50	46.3	5:02	187.8	153	yellow ▲	98.0	green ▲	2.0		
P19	N	0:55	37.8	0:42	31.4	0:21	25.5	1:15	29.4	0:34	56.3	4:51	180.3	137	yellow ▲	92.7	green ▲	5.8	orange ▲	1.5
P20	N	1:58	35.5	0:58	26.9	0:23	25.5	1:33	35.0	1:21	45.5	8:36	168.4	174	yellow ▲	82.2	green ▲	17.8		
P21	Y	1:52	20.2	1:02	32.8	0:40	25.6	0:38	29.5	0:49	34.8	7:20	142.9	182	yellow ▲	53.8	green ▲	45.1	orange ▲ blue ▲	0.5 0.5
P22	N	1:40	44.8	1:03	31.9	1:20	29.1	0:48	29.1	1:17	35.7	8:16	170.6	181	yellow ▲	100				
P23	N	0:57	37.4	0:47	29.2	0:45	25.5	0:36	27.6	0:31	29.0	4:56	148.7	143	yellow ▲	86.7	green ▲	13.3		
P24	Y	0:48	41.6	1:19	26.0	0:52	35.0	0:30	28.5	0:58	30.5	7:58	161.6	151	yellow ▲	93.4	green ▲	6.6		
P25	Y	1:24	47.0	0:46	25.7	0:44	33.6	0:44	28.8	0:35	37.6	5:43	172.6	159	yellow ▲	66.8	green ▲	30.2	blue ▲	5.0
P26	N	1:05	38.0	1:26	34.9	2:07	22.9	1:09	31.3	0:52	30.5	8:47	157.6	187	yellow ▲	76.5	green ▲	23.5		
P27	Y	1:49	41.1	0:58	35.2	0:38	27.0	0:47	29.5	0:52	31.1	5:55	163.8	174	yellow ▲	95.4	green ▲	4.6		
P28	Y	2:15	46.6	0:52	27.3	0:53	29.5	1:03	30.9	1:37	37.6	8:55	171.8	191	yellow ▲	94.8	green ▲	5.2		
P29	Y	0:41	41.5	1:11	31.8	0:50	30.9	0:41	30.3	1:00	28.7	6:38	163.2	137	yellow ▲	86.9	green ▲	13.1		
P30	Y	0:55	42.3	0:44	25.6	0:27	26.8	0:36	27.3	0:31	32.0	5:55	154.0	132	yellow ▲	75.8	green ▲	24.2		

Gyroscope pitch: twenty-nine of the 30 participants predominantly used the gyroscope pitch angles 67.5° - 112.5° (straight ahead on horizontal plane), however one participant with a CS background (P17) predominantly used the camera angles 22.5° - 67.5° (slightly downward camera angle). Three participants with a CS background (P1, P15, P25) and two participants with Non-CS backgrounds (P8, P19) used three kinds of gyroscope pitch angles (including to slight upward or toward the ground), and two participants with CS backgrounds (P17, P21) used four kinds of gyroscope pitch angles (including pointing slightly upwards and towards the ground).

When the camera was facing the sky or the ground, no POIs were displayed. This is mainly caused by two situations. One is related to the environment. For example, story chapters 4 and 5 are visited in the construction area of The Pā, and the route is close to a wall and the route of the visit is a slow uphill climb. On the movement track map of P1, the mobile phone camera was pointed to the ground many times during the walk. Another situation is the usage behaviour of the participants. At the beginning of the Final Prototype, the participants had to point their mobiles towards the sky or the ground to find the POIs.

Phone orientation: twenty-five of the 30 participants always tested the Final Prototype by using the landscape left-orientation of the test mobile phone. Five participants (P8, P19, P20, P25 and P26) changed the orientation of their mobile phone while using the digital prototype. For example, out of 189 story navigation and chapter story visits by participant P26, 176 used the phone to navigate and read the story with landscape left orientation, 11 with portrait orientation, and two with portrait upside down orientation. Only one of five participants is from a CS background, while the other four participants have Non-CS backgrounds.

Table 7. 9 Mobile phone orientation of the remaining 5 participants.

	CS / Non-CS	Location Marker	Landscape Left	Landscape Right	Portrait	Portrait Upside Down
P8	N	179	176 (98.3%)		3 (1.7%)	
P19	N	137	99 (72.3)		38(27.3%)	
P20	N	174	173 (99.4%)		1 (0.6%)	
P25	Y	159	154 ((96.9%)		3 (1.9%)	2 (1.2%)
P26	N	187	174 (93.0%)		11 (5.9%)	2 (1.1%)

Time spent in story chapter: refers to the sum of the story chapter navigation time and the chapter story introduction time, as shown in Table 7.8. Participant P28 with the longest visit time was 8:55, participant P1 with the shortest visit time was 4:47, and the average visit time was 6:44. We found that among the 15 participants whose interview time was lower than the average visit time, participants with CS background accounted for 66.7% (10 out of 15), and among the 15 participants whose interview time was higher than the average visit time, participants with CS background accounting for 46.7% (7 out of 15), participants with CS background had less visit time than participants with Non-CS background. The reason might be that participants with a CS background are more proficient in using the test mobile phone than participants with the Non-CS background.

We analysed the participants who spent a longer time in each story chapter, P8 (story chapter 1), P3 (story chapter 2), P26 (story chapter 3), P20 (story chapter 4) and P5 (story chapter 5), and found two reasons for the longer visit time spent in a story chapter, One of these reasons is GPS drift, which causes story chapter introductions not to be displayed accurately at the location on the visiting route. It is necessary for participants to tilt or pan to find POIs. The second is that the participants are interested in the commemorative plaques of story chapter 3, and reading the commemorative plaques at the scene increases the visiting time.

Time spent in story chapter introduction: the time that each participant spent reading the story chapter introduction, starting with the pop-up that provided the campus history introduction dialogue box and ending with the participant clicking a button to prompt departure for the next story chapter.

In Figure 7.23 and Figure 7.24, two pie charts are shown of the 30 participants who read the most and least amount of story chapter introduction time, respectively. Figure 7.23 shows that 10 out of the 30 people spend the most time reading the introduction to story chapter 2. Figure 7.24 shows that 11 out of the 30 participants spent the least time reading the introduction to story chapter 4.

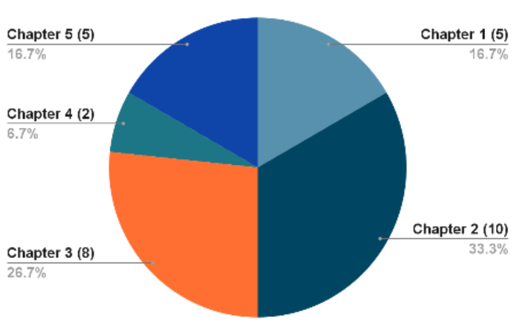


Figure 7. 23 The longest visited story chapter introduction.

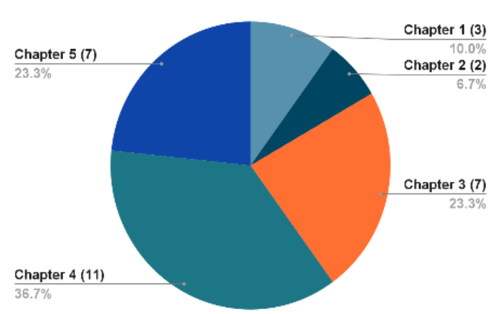


Figure 7. 24 The shortest visited story chapter introduction.

Participant Track

Here, we have chosen the movement track of participant P8 and participant P17 in parallel as examples when analysing participant behaviours, (see Figure 7.25).

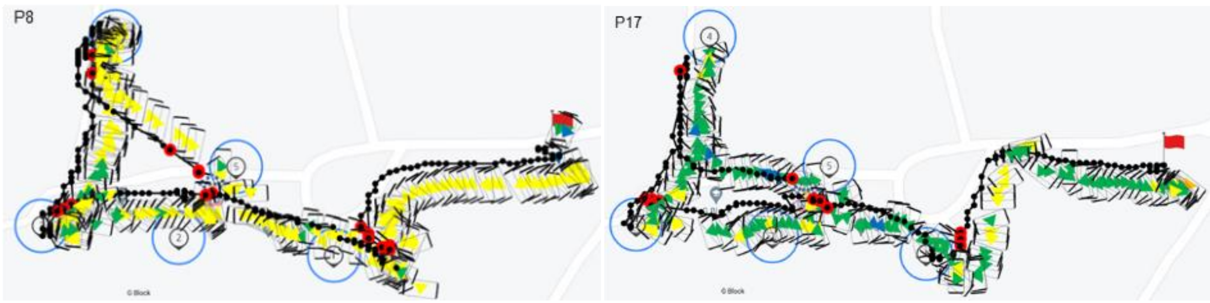


Figure 7. 25 The movement track map of the participant P8 (left) and Participant P17 (right).

Participant P8 spent 8 minutes and 32 seconds visiting the entire story and walked 176.2 meters, while participant P17 took 7 minutes and 20 seconds to visit the whole story and walked 175.40 meters.

During the visit, the P8 walked a total of 179 location markers, 156 location markers using the 67.5 - 112.5° gyro pitch angle (straight ahead), and 21 location markers using the 112.5° - 157.5° gyro pitch angle (slightly downward camera angle), 2 location markers using 157.5° - 202.5° (towards the ground). The participant used 176 times landscape orientation and 3 times portrait orientation to visit all POIs.

The P17 walked a total of 147 location markers, 107 location markers using the 112.5° - 157.5° gyro pitch angle (slightly downward camera angle), and 30 location markers using the 67.5 - 112.5° gyro pitch angle (straight ahead), 2 location markers using 22.5° - 67.5° gyro pitch angle to view POIs (slightly upward camera angle), and 8 location markers using 157.5° - 202.5° (towards the ground). The participant used landscape orientation to visit all POIs.

As can be seen from the comparison of the movement tracks of the two participants in Figure 7.25, P8 and P17 had close to opposite behaviours regarding Gyroscope Pitch Angle. However, they used the same camera orientation (landscape) to visit all story chapters.

To analyse the detailed behaviour of the participants, we divided the movement track map of each participant in Figure 7.25 into five figures to visit the detailed description of each story chapter. Figure 7.26 shows how P8 and P17 moved from the starting point to story chapter 1.

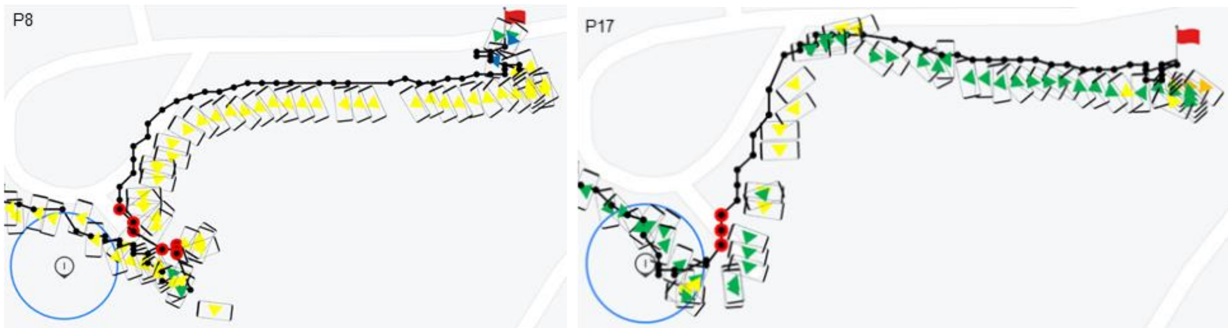


Figure 7. 26 The movement track of participant P8 with visiting story chapter 1 of (left) and the movement track of participant P17 with visiting the story chapter 1 (right).

The two green triangles and two blue triangles in the upper right corner of Figure 7.26 (left) indicate that at the beginning of the visit to story chapter 1, participant P8 pointed the camera slightly downward and toward the ground. We are assuming that, at this moment, participant P8 was familiarizing him/herself with the use of the Final Prototype.

Participant P8 then navigated to the story chapter 1 location using the gyroscope angle of straight lines on the horizontal plane, while the camera was also oriented towards story chapter 1. Figure 7.27 provides two screenshots, made by participant P8, with a slightly downward view and a horizontal plane view at the beginning of story chapter 1. In the figure, you can see that the position of the red flag on the screen is the direction of story chapter 1.

Figure 7. 27 The slightly downward view (left) and horizontal plane view (right) of participant P8.

In Figure 7.26 (right), the green triangles from the starting point indicate that the participant P17 tilted the phone downward to visit. Similarly, in the case of participant P8's behaviour, the top of the triangles points to the location of story chapter 1 in the lower left corner of Figure 7.26, and the mobile phone is in landscape operation mode. In addition, as participant P17 walks towards the lower left, the location marker density becomes sparse, indicating that the participant speeds up and that the distance between each location-marker becomes larger. The three location markers with red circles indicated that the participant had stopped to observe the story during the storytelling in story chapter 1.

The P17 participant spent 3 minutes and 17 seconds visiting story chapter 1, because the P17 observed the POI from different angles when initiating him/her use of the prototype. The P17 could not see the POI on the movement track map when he/she did not move, and the phone action was tilted or panned. As such, only the first action at this location is shown on the map. We discovered this situation by analysing the raw XML data. Table 7.10 shows that at the same location (-37.78876877, 175.3185577) the P17 did 10 camera pan and tilt movements, but the movement track maps only show the first one (see the first row), and the remaining 9 movements (see the other 9 rows).

Table 7. 10 Details of participant P17's camera pans and tilt movements in story chapter 1 at the location.

No.	Time	Latitude	Longitude	Camera Angle	Pitch Angle	Pitch Description	Figure
1	03/11/2022 11:18:33	-37.78876877	175.3185577	217.266922	61.09	Slightly upward	7.28
2	03/11/2022 11:18:34	-37.78876877	175.3185577	207.8611145	66.54	Slightly upward	
3	03/11/2022 11:18:35	-37.78876877	175.3185577	266.2402039	160.01	Towards the ground	7.29
4	03/11/2022 11:18:36	-37.78876877	175.3185577	238.0592957	135	Slightly downward	7.30
5	03/11/2022 11:18:37	-37.78876877	175.3185577	237.1948242	131.19	Slightly downward	
6	03/11/2022 11:18:38	-37.78876877	175.3185577	179.1962891	134.71	Slightly downward	
7	03/11/2022 11:18:39	-37.78876877	175.3185577	239.6897278	108.33	Straight ahead on horizontal plane	7.31
8	03/11/2022 11:18:40	-37.78876877	175.3185577	250.2329712	95.71	Straight ahead on horizontal plane	
9	03/11/2022 11:18:41	-37.78876877	175.3185577	265.7795105	95.71	Straight ahead on horizontal plane	
10	03/11/2022 11:18:42	-37.78876877	175.3185577	195.2279053	122.0	Slightly downward	7.32

To explain this situation, Figures 7.28 to 7.32 show a series of screenshots of the behaviour of P17 tilting the camera at location (-37.78876877, 175.3185577).

Figure 7. 28 The slightly upward view of P17.

Figure 7. 29 The toward the ground view of P17.

Figure 7. 30 The slightly downward view of P17.

Figure 7. 31 The horizontal plane view of P17.

Figure 7. 32 The slightly downward view of P17.

It can be observed in Table 7.10 and Figures 7.28 to 7.32 that participant P17 frequently manipulated the camera pan and tilt at the same location, but that in Figure 7.26, only the first camera angle and pitch angle were shown. This issue will be discussed later.

After visiting story chapter 1, the participants P8 and P17 visited story chapter 2. Figure 7.33 shows P8's (top) and P17's (bottom) movement track when moving from story chapter 1 to story chapter 2.

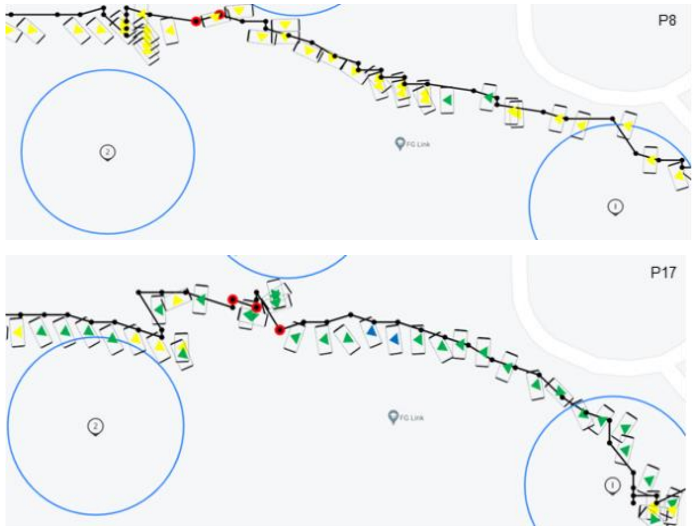


Figure 7. 33 Participant P8's (top) and participant P17's (bottom) movement track when visiting story chapter 2.

The mobile phone landscape icon in Figure 7.33 represents the pan angle of the participant holding the mobile phone camera towards story chapter 2.

Participant P8 visited story chapter 2 using the gyroscope angle with a slightly upwards facing camera, with the exception of two slightly downwards gyroscope angles.

During P17's visit to story chapter 2, the two blue triangles in Figure 7.33 (bottom) represented the participant's behaviour of holding the phone pointed towards the ground. The large number of mobile phone landscape icons with coloured triangles in Figure 7.33 represented the panning angle of the participant's hand-held mobile phone camera towards story chapter 2.

As can be seen from Figure 7.33, the number of mobile phone icons between story chapter 1 and story chapter 2 for P17 is significantly less than the number of mobile phone icons between story chapter 1 and story chapter 2 for P8.

Figure 7.34 shows the movement track of the participant P8 and P17 from story chapters 2 to 3.

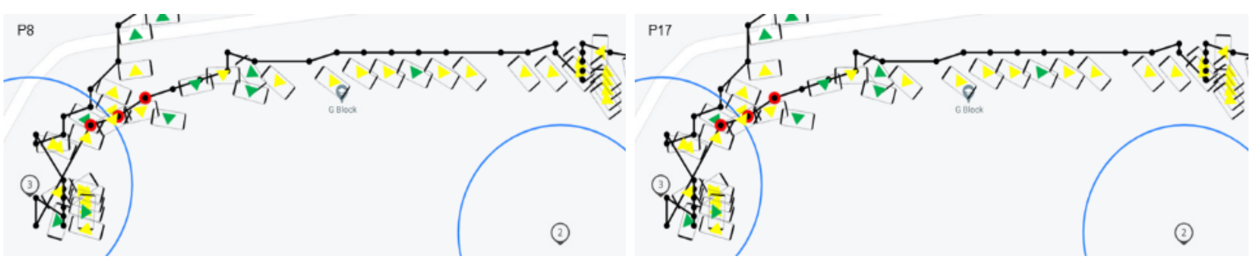


Figure 7. 34 The movement track of participant P8 (left) and participant P17 (right) when visiting story chapter 3.

Story chapter 3 is the commemorative plaque of the first internet connection point in New Zealand. After reading the story in the App, the participants approached the commemorative plaque. It can be seen in Figure 7.34 that the visit route of P8 and P17 overlaps with the location of story chapter 3.

Compared with participant P17, participant P8 passed through more location markers when visiting the commemorative plaque. According to the movement tracking map of P17, when participant P17 reached story chapter 3, the tracking data was lost for 10 seconds for unknown reasons. Figure 7.35 shows the movement track of participants P8 and P17 when moving from story chapters 3 to 4.

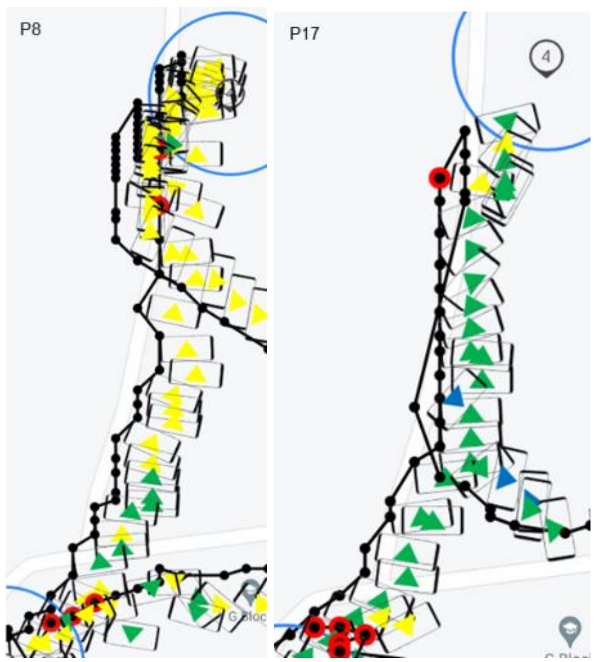


Figure 7. 35 The movement track of participant P8 (left) and participant P17 (right) when visiting story chapter 4.

Both participants walked from story chapter 3 to story chapter 4 using the phone in landscape mode. Participant P17's visit to story chapter 4 was shorter than participant P8's to the same story chapter, because only a black dot with a red circle is shown near story chapter 4 in Figure 7.35 (right). Figure 7.36 shows a screenshot recorded by P17 when tilting the phone down to the path on which they were walking.

Figure 7. 36 The downward pointing view recorded by P17 when visiting story chapter 4.

Next, Figure 7.37 shows the movement track of participants P8 and P17 when moving from story chapter 4 to story chapter 5.

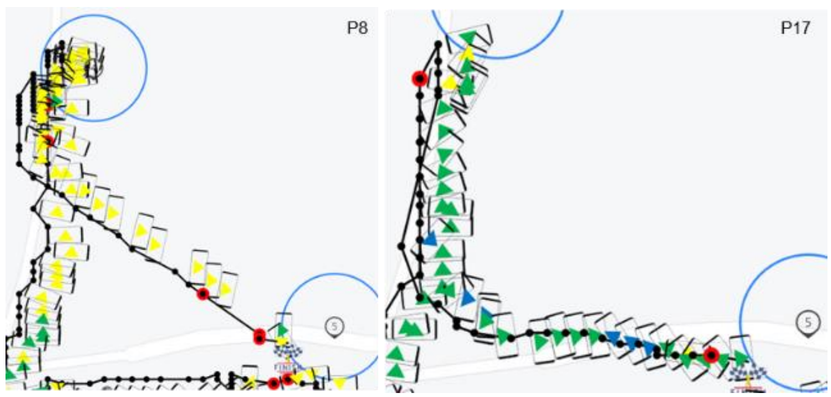


Figure 7. 37 The movement track of participant P8 (left) and participant P17 (right) when visiting story chapter 5.

In Figure 7.37, the visit route of participant P8 took the shortest path to story chapter 5, while participant P17 moved along the sidewalk to visit story chapter 5. When participant P17 visited story chapter 5, they tilted the phone slightly downwards. Six times they titled the camera towards the ground causing the phone to not display any POI. Figure 7.38 records a screenshot of P17 tilting the camera towards the ground on the first occasion out of 6.

Figure 7. 38 The recorded image of participant P17 titling their phone towards the ground.

The behaviour of P8 has the characteristics of the behaviour seen in most of the participants, while the behaviour of P17 has the obvious characteristics of someone who is more individual.

After analysing the movement tracks of the 30 participants, we have observed the following details.

Time and distance walked: All participants used the prototype in less than 9 minutes and walked less than 200 meters. The average visit time was 6 minutes and 44 seconds. The shortest time was 4 minutes and 47 seconds, and the longest time was 8 minutes and 55 seconds.

Participant P28 was the participant who watched the POI the longest. Furthermore, they spent the longest time navigating with the POI at the beginning of the prototype, and when visiting story chapter 3, they carefully read the text on the commemorative plaque at the scene, which led to this participant's visit which of course added further to the time spent using the prototype. Participant P1 who took the shortest time was familiar with the campus history, and this participant clicked on the “Next” button without reading the story chapter introduction, resulting in a very short participant visit time.

Camera Angle: The camera angle refers to the panning view of the participant's Augmented Reality view. In each participant’s movement track map, the top of each triangle, in the map, can be clearly seen pointing. When the top of the triangle points in the direction of the next POI location, it means that the participant pointed the camera of the test phone in the direction of the next POI location (POIs displayed on the phone screen) while navigating on foot.

For example: When the P17 turns, the orientation of the mobile phone also changes accordingly. Figure 7.39 shows the change in the direction of the triangles of the seven-walking location-markers in the middle part and the three lookout location markers at the bottom of participant P17’s movement track.

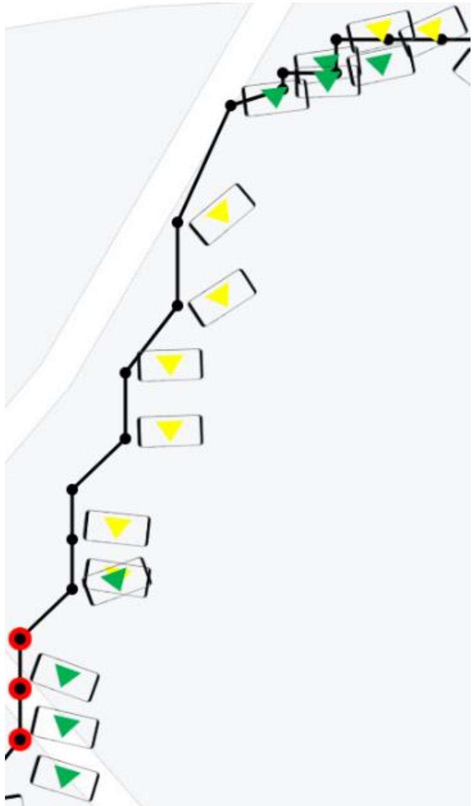


Figure 7. 39 Example of changes in camera angles during P17’s visit to story chapter 1.

Direction: Direction represents the direction in which the visitor is walking. In each movement track map, similar to the case mentioned for the camera angle, sideways pans were used to look for POIs when the participant turned during the visit. Figure 7.33 shows the direction that P17’s camera points when searching for the next story chapter address, for example when participant P17 moves forward, the mobile phone shows movement of panning from left to right.

Gyroscope Pitch Angle: The gyroscope pitch angle represents the tilt view of the participant's AR view. The following table 7.11 shows the number distribution of the ratio of the camera tilt angle of the 30 participants' location markers to the camera tilt angle of all their location markers.

Table 7. 11 Number of participants with the ratio range of camera tilt angles.

Pitch Description	Triangle	Gyroscope Pitch Angle	under 1%	1-9%	10-19%	20-29%	30-39%	40-49%	50-59 %	60-69%	70-79%	80-89%	90-100 %
Slightly upward camera angle		22.5°-67.5°	1	3									
Straight ahead on horizontal plane		67.5°-112.5°			1				1	1	4	9	14
Slightly downward camera angle		112.5°-157.5°		14	8	4	1	1			1		
Towards the ground		157.5°-202.5°	1	4									

As can be seen in Table 7.10, moving straight ahead on a horizontal plane was the most preferred tilt angle used by participants. While participants rarely looked up slightly or towards the ground, participant P22 only used straight ahead on the horizontal plane.

Twenty-nine of the 30 participants interviewed moved with a slightly downward camera angle. We selected for analysis 7 participants whose location markers approached and exceeded 30% of the location markers using a slightly downward camera angle, see Table 7.12.

Table 7. 12 Slightly down more than 20% of the total location markers of each story chapter.

Participant	Slightly down more than 20% of the total location markers	Slightly down more than 20% of the total location markers of each chapter				
		Story chapter 1	Story chapter 2	Story chapter 3	Story chapter 4	Story chapter 5
P5	37(26.4%)	8	8	5	14	2
P6	51(29.7%)	15	7	12	11	6
P17	107(72.3%)	33	22	14	22	16
P21	82(45.1%)	23	16	8	23	12
P25	48(30.2%)	4	2	6	21	15
P26	44(23.5%)	3	5	14	20	2
P30	32(24.2%)	12	2	7	6	5

From Table 7.12, the number of location markers visited by the 7 participants using each story chapter using a slightly downward angle can be divided into two situations, one is story chapter 3, story chapter 4 and story chapter 5 have the most times, such as 3 participants (P5, P25, P26). Another situation is that the first story chapter has the most times, such as 4 participants (P6, P17. P21, P30).

According to the analysis, in the first case, the participants visiting story chapter 3, story chapter 4 and story chapter 5, there was only one flag (red flag) at the bottom of the screen of the Final Prototype. However, in the first two story chapters, participants can see more than two flags on the screen.

Another situation is where the participants in story chapter 1 just started using the prototype and tried different tilt angles in order to gain familiarity in using the Final Prototype.

Orientation: Twenty-five of the 30 participants completed the test of the Final Prototype using only the landscape left orientation of the test mobile phone. Among the remaining five participants (P8, P19, P20, P25, P26), they overwhelmingly used the landscape left orientation, and rarely used the portrait and portrait down orientations. An average of 7.48% of participants used portrait, two out of the five participants used portrait upside-down, only four times in total. For example, participant P19 visited the POIs in portrait mode throughout their visit to story chapter 1, and only switched to landscape mode when he started reading the introduction to story chapter 1. Figure 7.40 shows the portrait orientation when participant P19 visited story chapter 1.

Figure 7. 40 Example of portrait orientation during P19's visit of story chapter 1.

GPS signal accuracy: Pedestrian navigation requires accurate GPS positioning, but GPS has accuracy errors, which lead to the problem of location drift during use.

We identified two aspects of the positioning error, one is the positioning error of the participants when walking, for example, in the beginning of the Final Prototype, participants P3, P6, P8, P17, and P20 wandered at the starting point of story chapter 1. The other position error occurs when there is an issue in targeting the story chapter. For example, when participant P12, P24 and P27 were close to story chapter 2, their GPS drift caused the introduction of the story chapter to be read too far away from the story chapter (the introduction will be displayed within 5 meters). These two aspects cause some users to experience different effects in the user-study. Others included a restart of the prototype due to a program crash (for example, when participant P15 visited story chapter 3), and an inability to acquire about 10 seconds of data in XML format due to a loss of GPS signal (Occurred during P5, P20 and P29 visited story chapter 5). Table 7.13 shows the data of GPS signal drift for eleven participants.

Table 7. 13 Situation classification due to GPS signal drift.

Participant	Wandering at starting point of story chapter 1	Inaccurate positioning in story chapter 2	Prototype restart in story chapter3	Lost 10 seconds of data in story chapter 5
P3	√			
P5				√
P6	√			
P8	√			
P12		√		
P15			√	
P17	√			
P20	√			√
P24		√		
P27		√		
P29				√

More detailed comments of each participant trail were presented in Appendix D2.

In this section, we analysed the movement track data of all participants, including participants' visit time, gyroscope pitch, phone orientation, and track map. And we selected the track and on-site screenshots of the two participants, P8 and P17, to compare their behavioural characteristics. Finally, a summary was discussed on the time and distance walked, Camera Angle, Direction, Gyroscope Pitch Angle, Orientation of all participants, and the limitation of the Finial Prototype (GPS signal accuracy).

7.3 Discussion

The evaluation of the Final Prototype included a questionnaire, the use of a digital prototype and the participant's movement track map. We here discuss the insights gained.

User-study Result Insights

Similar to the participants in our studies for Initial Digital Prototype (see Chapter 3) and Paper Prototype (see Chapter 5), the participants had previously used map navigation, but a high percentage of them had never or rarely used Augmented Reality navigation.

The overall feedback showed that twenty-four of the 30 participants enjoyed using the narrative navigation (see Q3 in Section 7.2.2), twenty-two participants found the Augmented Reality narrative navigation easy to use (see Q4 in Section 7.2.2), and twenty-three participants agreed that it was easy to navigate the location-based story using narrative navigation (see Q5 in Section 7.2.2). Among the participants who gave positive reviews, the proportion of participants with CS backgrounds and Non-CS backgrounds is very close. For example, in Q3, 12 participants with

CS backgrounds and 12 participants with Non-CS backgrounds gave positive comments; in Q4, 12 participants with CS backgrounds and 10 participants with Non-CS backgrounds gave positive comments; in Q5, 13 participants with CS backgrounds and 10 participants with Non-CS backgrounds gave positive comments.

However, six of the 30 in Q3, eight of the 30 in Q4 and seven of the 30 in Q5 (see discussion of Q3, Q4 and Q5 in Section 7.2.2) gave negative feedback regarding GPS deviation and UI design. GPS drift leads to poor navigation accuracy. We observed that each participant visited the location where the story introduction automatically pops up for each story chapter is different, which means that the participants did not arrive or must have passed the correct location to see the story introduction for this story chapter. After summarising the participants' who gave negative responses to Q3, Q4, and Q5, we found that there were twice as many participants with CS backgrounds (five in Q3, 5 in Q4, 4 in Q5) as those without CS backgrounds (one in Q3, three in Q4, three in Q5).

In answering Q6 (What suggestions do you have to improve the App?) and Q7 (Any other comments or questions?), some participants suggested that Narrative Navigation should use more gaming features that would be similar to what one would find in Pokémon Go. Their feedback mainly focused on the UI design, for example: *"Introduction should not occupy more space", and "Information windows too large."* (see Table 7.7). Two participants strongly recommended that we redesign the prototype such that it functions as a game-based digital prototype. Participant P7 said "*Information windows are too large, put the bottom" [like RPG game dialogues]*, while participant P24 said, "*add bubble dialogues and virtual avatars.*" (see Table 7.7).

In those comments, we observe that location-based Augmented Reality is mainly known in the context of mobile gaming and that location-based books and Augmented Reality use for narration is in its infancy.

Although some participants complained about the prototype's usability and UI design, most participants still considered the *Narrative Navigation* concept to be a successful concept for location-based stories.

Prototype using Observation Insights

All participants successfully navigated the five story chapters and visited the information in the correct order. We observed from their location tracking that many participants did not become proficient in using the prototype until they visited story chapter 3. This is because they asked me some prototype usage questions during the first two story chapter-visits while they hardly had any questions during the last three-story chapter visits.

We found that training and guiding before using the prototype improved participants' understanding of the overall story during use of the prototype. Participant P26 said that "more instructions" are needed, especially for participants with Non-CS backgrounds who are not familiar with similar Apps, and they need more training.

Participants from outside the campus were more interested in the story of the visits than those from the campus, who were more familiar with the campus history than participants from outside the campus.

Sometimes under strong sunlight test conditions, when the sun was shining directly onto the mobile phone screen, the participants needed to block the sun to see the mobile phone screen. Similar to most wearable computer systems, the long-term high-brightness use of the mobile phone screen leads to the management of mobile phone power requires attention. In addition, participants need to pay attention to the safety issues when walking during the use of the prototype.

The insights gained during the use of the prototype walk-through can guide the development of further prototypes, and commercial application of more location-based services.

Movement Track Insights

The participant tracking (visualised here as a map) provided relevant insights about the participant's behaviour. Collecting mobile phone motion sensor data and camera angle data made it easier to analyse participant behaviour than it was to analyse visual observations or video recordings of participant movements.

When analysing the track recordings, we noticed that 25 of the 30 participants never rotated the mobile phone and 22 of the 30 participants only tilted their mobile phone straight ahead and slightly downwards camera angle.

The visual map of movement track is very helpful for analysing participants' behavioural data and provides guidance for prototype UI design, walk-through route planning and location-based story chapter narrative.

Limitations

We observed a series of issues occurring with the user study, considering participants walk safe, GPS signal drift, data visualisation displays in participant movement track map.

A number of issues limited the effectiveness and clarity of the user study:

Covid-19 restriction: The interviews were conducted during the ongoing Covid-19 pandemic, which had a huge impact on recruiting 30 participants for 'face-to-face' interviews. In particular, recruiting people of different ages, with different professional backgrounds, and with different cultural backgrounds, made quantitative analysis to a certain extent infeasible In addition, the prototype test requires on-site testing on campus. However, the university strictly prohibited unvaccinated students and off-campus persons from entering campus, so there were many difficulties in recruiting participants.

Limitations in viewing multiple behaviours at the same location: The participant movement tracking map is currently using a location-based 2D map. When a participant performs multiple actions at the same location, only the first one can be displayed on the map. This makes it necessary to work out how to perform multiple actions at the same location. A solution might be to add at each location a zoomed-in continuous movement submap for that location.

GPS signal drift: In the narrative navigation prototype user-study, there was GPS signal drift during the participant interview, which caused the participants to provide feedback that was contrary to what was expected. We suspected GPS drift is happening quite frequently due to the proximity to three-storey buildings when visiting story chapter 2, but there is no time to further investigate this question.

In Chapter 7, we mentioned that some of the data exceptions in the figures of participants' movement track maps were caused by GPS signal drift. Our user study is based on outdoor navigation, and GPS positioning is the only positioning method in this user study. Therefore, limited by GPS signal drift, drift and loss occurred many times during the user study process (see Section 7.2.4). According to the data analysed by the participants' movement track map, we think it will inevitably have some errors.

Movement Track visualisation: The participant movement track map is a two-dimensional map, which cannot use more space to mark other information at the same location. Although it shows multiple combined information for a location, it fails to show both spatial and temporal information on the map of participant behaviour. One possible solution is to generate a 3D movement track map of the participant.

Overall, Narrative Navigation was a successful idea, with an average of 23 out of the 30 participants giving positive feedback to Q3, Q4, and Q5 in the questionnaire, and as such established a new approach to storytelling based on location.

7.4 Summary

In this chapter, we evaluated our Final Prototype. Section 7.1 described the user study material, questionnaire, study procedure and user observation study. The story of Final Prototype was about the history of the University of Waikato, introducing buildings of the campus and memorable events. We invited 30 participants (see Appendix D1.1 for details) to participate in the walk-through, asked the questions on the questionnaire, and made an observational summary of the walk-through process.

Section 7.2 explored the results of the user study and further analysis. The answers to each question were summarized and analysed; the answers to Q3, Q4, and Q5 were classified using a Likert scale, and statistics were made based on the CS and Non-CS background of the participants and whether the feedback was positive or negative. Answers to improvement suggestions/other comments or questions in Q6 and Q7 were divided into 8 subcategories for summary analysis. Appendix D.2 shows each participant's movement map of 30 participants, and Table 7.8 of subsection 7.2.4 listed in detail the background of each participant, the time spent visiting each chapter, the number of location markers and the most used gyroscope pitch. We selected Participants P8 and P17 as examples to compare and analyse the behavioural characteristics of the study participants.

Section 7.3 discussed the results and analysis of the Final Prototype evaluation, we found the insights related to user-study results, observation and movement Track, and discussed the limitations that limited the effectiveness and clarity of the user study.

In this chapter, we answered the question we posed in chapter 1 "*How can we visualise location-based stories in a mobile AR application beyond POI approaches?".* We found that despite some limitations of the study, the majority of participants enjoyed using narrative navigation to narrative stories. They identified narrative navigation as a useful new way to storytelling based on location. This is also evidenced by the positive feedback on the answers to Q6 and Q7 in Section 7.2.3.

Chapter 8 Summary and Conclusions

This thesis explored visualisation of location-based information in the context of location-based stories. In particular, we explored how to navigate to the location of a story event. We call our novel AR-navigation concept *Narrative Navigation*.

This final chapter is divided into four sections. In Section 8.1 we describe the key characteristics of the four prototypes that were developed and evaluated as part of our investigation. In Section 8.2 we explain the significance of our findings. Recommendations for future work are outlined in Section 8.3. Finally, Section 8.4 presents the conclusions and insights of our research into the development of the concept of narrative navigation using augmented reality.

8.1 Summary of four Prototypes

This thesis proposes the concept of narrative navigation in the context of location-based storytelling. We have shown that location-based narrative navigation can be visualised using augmented reality. In our research we answered the research question, *how to use Augmented Reality to visualise location-based information for navigation in a storytelling context?*

We examined the above question through a number of studies, in each case exploring a particular prototype (four overall), and in which each prototype was designed to achieve a specific set of goals. Table 8.1 lists the details, goals and characteristics of each prototype. In our research, we developed three digital prototypes and one paper prototype, and evaluated two of the digital prototypes and the paper prototype. The findings from those investigations provided insights into participants' preferences and difficulties when interacting with augmented reality stories and using the concept of narrative navigation. The Final Prototype included a movement tracking map which enabled easier tracking of participants' movements. The preliminary evaluation of participants' movements indicated that it was easy to know how participants behave, as it was to analyse their favourite gyroscope pitch angle, mobile phone orientation, etc.

Table 8. 1 Comparison of the main characteristics of the four prototypes.

	Initial Digital Prototype	**Paper Prototype**	**Narrative Navigation Prototype**	**Final Prototype**
Overview				
Investigations	Version A or Version B to navigate to correct next location	Order by distance or by story order	Prototype functional walk-through	Easy to navigate the location-based story using narrative navigation
Achieved goal	POI shape	Determine story order	Fully functional prototype	Storytelling data visualisation
Storytelling	No story	No story	Tree's introduction	History of University od Waikato
Story chapter Content	Local trees	Local trees	Local trees	University landmarks
Viewing Point	One observation point	Two observation point	Two observation point	One starting point
Visit each POI	Y	Observation point only	Y	Y
POI				
POI Avatar	Sphere, Tree, 3D Flag, 2D Flag	2D Flag	2D Flag	2D Flag
POI display height display on mobile screen	Flags height intervals are not equal	Flags height intervals are equal	Flags height intervals are equal	Flags height intervals are equal
POI introduction	N	N	Tree story and event commemoration	Building and Plaque introduction and history of the University of Waikato
POI order	Distance Low Distance High	Near-Low (Distance) Near-High (Distance) Next-Low (Story) Next-High (Story)	Near-Low (Distance) Next-Low (Story)	Next-Low (Story)
POI order number	white, magenta, green, red, and yellow	N/A	Numbers 1,2,3,4,5	Numbers 1,2,3,4,5
POI background colour	Black	Next story chapter: red Another story chapter: blue	Next story chapter: red Another story chapter: blue	Next story chapter: red Another story chapter: blue
AR navigation				
AR implementation	POIs (flags)		POIs (flags) Story chapter Introduction	POIs (flags) Story chapter Introduction Fish bone indicators
Navigation indicates	Flag, distance	N/A	Flag, distance, red arrow	Flag, distance, red arrow
Evaluation				
Internal user tracking Data Visualization	N	N	N	Y (Movement tracking map)
Interview participants	15	30	N/A	30
Interview questions	2 background questions and 4 opening questions	2 background questions, 4 choice questions and 3 opening questions	N/A	2 background questions + 5 choice and opening questions

Table 8.1 provides an overview of the four prototypes, POI details and prototype evaluation. During user-research of the four prototypes, the research question was addressed in a number of ways. A review of the literature on augmented reality and navigation studies, provided in Chapter 3, indicated how to visualise location-based information in location-based stories context. A new conceptual design that emerged from our prototype studies of POI visualisations in the AR view is that AR information displays should be designed in a cascading sequence when the goal is to guide participants in a purposeful narrative navigation journey. The story navigated by users within the Final Prototype only introduces part of the tour of campus history and events, however, this has been adequate to demonstrate the concept of narrative navigation.

8.2 Contributions of this Thesis

This section summarises the contributions of this thesis to work related to the visualisation of location-based information using augmented reality. The research focused on related work to narrative navigation in location-based linear stories.

We first review the contributions of each chapter to understand the methodology, prototypes, results and evaluation of the thesis.

Chapter 1 describes the thesis research questions, research focus and research background. Our research question was: *How to use Augmented Reality to visualise location-based information for navigation in a storytelling context?* and research background that investigates location-based services (LBS), storytelling and augmented reality. The investigation of two use case studies (*POP-UP China* and *Hong Kong: A Centennial of Change*) found a lack of interactivity in location-based stories as a result. The first use case study (*POP-UP China*) was a pop-up picture book that included storytelling with location landmarks, while the second use case study (*Hong Kong: A Centennial of Change*) was related to location-based data and augmented reality visualisation. Both of these cases lacked on-site interaction with geolocation.

In Chapter 2, we examined the work related to augmented reality and navigation. For AR-related work, we investigated augmented picture books, augmented maps/atlas, location-based augmentation and AR-supported data visualisation to analyse augmented reality interactive and reactive locations and visualisation types. For navigation-related work, we examined car navigation, wayfinding, indoor navigation, navigation interfaces, and the display of POI in the AR view, and studied the methods and ways of POI information display.

In Chapter 3, we researched the visual design of POIs, exploring which shape of POI avatar in 3D (sphere, tree, and flag) and 2D (flag) would be more suitable for the Initial Digital Prototype. We chose a two-dimensional flag with a black background as the POI avatar, and used different colours to distinguish different POIs. Each POI avatar included a number to indicate the distance from the POI to the participant's location. In the end, we developed two versions of the Initial Digital Prototype that included two kinds of story-orders.

In Chapter 4, we describe how we invited 15 participants to evaluate this Initial Digital Prototype. All participants provided feedback, after which we further analysed and explored the findings. We observed that the participants had difficulty grasping the concept of narrative navigation (navigating to the next location in the story). Participants' feedback indicated that they liked the display of the next story location at the bottom of the mobile phone screen rather than at the top of the mobile phone screen. We also observed that many participants preferred to be shown the locations ordered by distance to the users' location, which reflects their experience with digital map navigation.

In Chapter 5, guided by the result of the Initial Digital Prototype, we created a Paper Prototype that focused on story order. Thirty participants tested prototypes ordered by both distance and ordered by story narrative (NL-D, NH-D, NL-S, NH-S), and responded to our interview questions. A key finding was that the number of participants who liked order by story or order by distance was almost the same. Most participants chose Near-High (Distance) and Next-Low (Story), with the participants from Non-CS backgrounds choosing to order by distance more than those with CS backgrounds.

In Chapter 6, we found four issues during the walk-through, which include the ideal POI size, the quantity of POI, the spacing of POIs, the camera positioning of the mobile phone, and the need for navigation hints. We experimentally revised the POI design. A tracking map of participant behaviour was developed in preparation for the evaluation of the Final Prototype.

In Chapter 7, we report on the results of our evaluation of the Final Prototype using 30 participants. Most participants gave positive feedback. We then focused on analysing and summarising the movement track map of the participants in the user-study, Insights and limitations, including movement tracking, participant observations and GPS drift, were identified and discussed.

In the beginning of the thesis, we described combining AR technology with GPS information to guide users to visit POI while reading a story. We used the GPS coordinates of each POI as unique identification to increase a series of visual superimposed information to each chapter of a story.

The concept of narrative navigation using augmented reality is a key finding that has emerged from this research, and a novel concept developed in this thesis. In other approaches (see Section 2.2.2), the POI display on mobile phones was found to be too small and position inaccurate, with too much location-based information displayed on the screen. Following the POI design evaluation of the four prototypes, we introduced narrative navigation to address these issues. The success of our approach has been shown in the evaluation presented in Chapter 7.

As outlined in Chapters 3 and 6, most studies focused on the effect of AR for display and interaction, whereas our study aimed to investigate the display and design of POIs, and the ordering of POIs information in an AR-location-based mobile application. An aim of our study was to allow participants to get the information they need more quickly, rather than be distracted by irrelevant information. Therefore, one of the key outcomes of our research is how to display AR information in a linear story order to guide the story readers.

The key contributions of our research are significant in the following ways:

1. POIs as the core element of location-based AR display on mobile devices, can be delivered to participants with more guidance so that they can enjoy the narrative navigation of the story.
2. Identifying the next location in the story order and removing visited story chapters will result in a more intuitive narrative navigation for the participants.
3. Directional settings that enable participants to navigate to each chapter of the story.

8.2.1 Key Finding: POI as the Core element of Location-based AR Display

Our analysis of the related work on POI shown in AR view (see Table 2.7) provided insight in indicating the direction and navigation within the storytelling context. In Chapter 4, we used the concept of POIs layered display and 3D objects projected to 2D, through narrative navigation to realise the intuitive understanding of participants and storytelling with narrative navigation. A valuable outcome of our findings described in Chapter 8 was that the participants enjoyed using narrative navigation in the story.

The cascading of 2D POI displays as the POI avatar to guide the development of the story, the 2D POI avoids the visual distraction of 3D POI, and the layered structure guidance simplifies the navigation information while considering the safety of walking in a storytelling context environment, so that participants gave positive comments on the easy of navigating the location-based story when using narrative navigation.

8.2.2 Key Finding: Identifying the Next Location in the Story Order

In the prototypes described earlier and summarised in Table 8.1, we designed and tested a range of indicators for the story visit navigation, which were provided through a combination of text, colour, screen position, and arrows. We describe here our recommended narrative navigation interface design based on our findings. A Flag is used to indicate the direction of a POI’s location. The distance (e.g., 15m or 49ft) is placed in the middle of each flag to indicate the distance between the participant's location and the POI. Each flag should also contain a story chapter number in the upper left corner to indicate the story order. The ordering of the numbered flags is recommended to begin at the bottom of the screen with ordering from bottom to top based on the story order of the POIs. A red flag at the bottom of the mobile phone screen indicates the next location (next story chapter) to be visited. Directional arrows are displayed on the left and right of the screen to indicate which direction to pan the mobile phone to assist with locating the POI flags that may be outside the view of the mobile phone at each present point in time. In particular, a single fishbone arrow or a double fishbone arrow that is displayed on the left or right side of the mobile phone not only indicates which side of the mobile phone that the POI is on, but also shows the approximate distance the user will need to pan the phone to locate the POI. This UI design of simple and rich information enabled participants to quickly master the use of the prototype and navigate to the objects that need to be visited. Positive feedback from participants indicated that they appreciated many of the intuitive features of this design (see Chapter 7).

8.2.3 Key Finding: Directional Settings of Story Navigation

An important contribution to emerge from our research is the design of POI navigation based on story ordering as opposed to traditional distance and direction-based navigation. For narrative navigation, story order is important. As noted in Section 8.2.2 the design of POIs ordering is recommended to begin at the bottom of the mobile phone screen with ordering from bottom to top based on the story order of the POIs. A red flag at the bottom of the phone screen indicates the next location (next story chapter) to be visited (see Chapters 3 and 4). The indication of distance but with the addition of story order numbering and ordering was important when assisting users to understand the context of the story or narrative in the linear fashion typical of most stories. The design ensuring identification of the next location in the story order allows participants to locate the target to be visited, especially if the participant does not know which story chapter will be visited in advance (see Chapters 4 and 5).

8.3 Future Research

These studies largely took place during the COVID pandemic. The events during the pandemic impacted on our research in a number of significant ways. There were campus closures, and restrictions to in-person meetings and user-research limiting the scope of the research methods, participant recruitment methods, and available stories for use in App prototyping. For example, we noted restrictions in possible participant background diversity, and limited rapid prototyping and user research methods and thus future research could address a number of these limitations.

Future studies will focus on user-friendly design and navigation destination accuracy. There are a number of possible future research directions, detailed below, that could be taken if narrative improvements and technical improvements are made.

8.3.1 Narrative Improvement

The major research occurred in COVID-19 terms, considering COVID-19 limitations, contactless interview and campus closure lead to research interruptions. So, a number of interesting evaluations had to be left for future work. The narrative improvements that could be explored through future work include the use of more complex story narratives, with additional story chapters or narrative POIs, as well as the exploration of some contemporary AR navigation interface design features that may enhance the narrative navigation user-experience.

Location-based story

A further user-study with a strong narrative requirement is suggested to address the observed story order issues for narrative navigation. Our current examples have a linear order but not a strong narrative requirement that other examples might have (e.g., detective stories with clearer dependencies between chapters). We suggest exploring such stories further.

Secondly, while we currently use linear stories in our evaluations, we suggest further exploring non-linear options of narrative navigation as well.

Examples are adventure type stories (i.e., stories including reader decision options), or supporting events held at specific locations on campus, such as the annual University Engineering Design, allowing participants to read up-to-date information about the event (i.e., with loose narrative structure).

Studies with wider range of location

Studies should explore the impact of additional locations within the story and may expand from outdoor locations to indoor locations. It would also be valuable to investigate an expanded diversity of locations, for example, buildings, statues, events, and other available objects marked with latitude and longitude.

8.3.2 Technical Improvement

The technical improvements that could be explored in future research includes improved navigation accuracy, the display of virtual paths and POI displays.

Improve narrative navigation accuracy

Further research could be done to integrate ARCore with a series of other technologies that include Visual Positioning Systems (VPS) and SLAM (Simultaneous localization and mapping). Visual Positioning Systems creates a map and builds a fast search index based on key visual features of pre-captured images of known locations, enabling the comparison of the image features captured in the field with the features in the index, to identify where the user is standing. Simultaneous localization and mapping are also a vision technology that uses feature points to understand the environment. For example, SLAM is used to identify floors, walls, etc., and to construct feature point maps, which are used for indoor and outdoor navigation in order to achieve accurate navigation.

So, the introduction of VPS, SLAM and ARCore integration can improve the accuracy of narrative navigation. We plan to use unity3D to integrate ARCore, VPS and SLAM in our future research.

Virtual path displayed on the screen

More research is needed to better understand how to add a virtual path superimposed on the actual road of the navigation, in order to guide the user to walk quickly to the destination, especially if the user is standing in the right location but not knowing the right direction.

POI display on AR view

Future research should concentrate on improving the AR immersion experience starting with avoiding UI controls and information that clutter the mobile phone screen. Second, visual cues and animations may assist first-time users. Finally, investigation of the display of important information through interactive contextual instructions or prompts may further enhance the usability of this unique AR tool.

Future work will also include expanding our digital prototype to experiment with POI markers that change shape as a user approaches a location, and using directional markers.

8.4 Concluding Remarks

In this thesis, we introduced and demonstrated the concept of narrative navigation as a means of using augmented reality to guide readers through a location-based story.

The thesis began with two use-cases to explore how storytelling and location information could be integrated. In the related work on augmented reality and navigation, a research gap was found, with no scholars appearing to have paid any attention to the use of augmented reality for narrative navigation in the context of a story. Our exploration of the Final Prototype found that narrative navigation for location-based stories was easy to use, and furthermore that it was easy to navigate to each of the location-based story chapters. The main contributions of the research were discussed in Section 8.2, in which we learned that:

- Two-dimensional POI avatars are suitable for narrative navigation scenarios, through a cascade order of POIs displays, providing a way for readers to interact with stories by walking on sidewalks in outdoor environments to access location-based stories.
- Identifying the next location in the story order in a location-based story in the AR view provides more guidance to the reader and enhances the cohesion and coherence of the context of the story chapters.
- The combination of directional navigation instructions and story exploration, as well as the movement track map of the participants, provided participants with a wonderful story-telling journey. In the Final Prototype evaluation, the participants gave positive comments, and suggested that a virtual path to the next location should be added to the App in the future.

The key contribution of this research centres on the visualisation of location-based information using augmented reality to explore the concept of narrative navigation.

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Appendix A Material for Initial Digital Prototype (Chapter 4)

The appendix includes the related material of the interview study with 15 participants in Chapter 4:

- Ethical approval letter from the Human Research Ethics Committee of the School of Computing and Mathematical Sciences at the University of Waikato, dated 15 January 2020;
- The participant information sheet, which outlines the title, purpose, procedure, and participant's rights;
- Research Consent Form, which each participant signed before the participant agreed to participate in our research;
- Research questions notes, which includes interview questions.

School of Computing and Mathematical Sciences
Rorohiko me ngā Pūtaiao Pāngarau
The University of Waikato
Private Bag 3105
Hamilton, New Zealand

Phone: +64 7 838 4322
Website: www.cms.waikato.ac.nz
Email: cms@waikato.ac.nz

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

15 January 2020

Alex Zhang
c/- Department of Computer Science
THE UNIVERSITY OF WAIKATO

Dear Alex

Request for approval to conduct a user study with human participants

On the basis of the information you have provided on the SCMS Preliminary Ethics Application Form relating to your research "User perceptions of directionality in mobile AR interfaces", the committee has given you approval to proceed with your proposed study. The approval number is CMS-19-45, which you should include on the Participant Information Sheet.

We wish you well with your research.

Mark Apperley
CMS Ethics Committee Convenor
School of Computing and Mathematical Sciences

Figure A.1 Study Ethics approval

Participant Information Sheet

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Ethics Committee, School of Computing and Mathematical Sciences

Project Title
User Perceptions of Directionality in Mobile AR Interfaces

Purpose
This research is being carried out as a part of the research for my PhD in Computer Science at the University of Waikato, to investigate the User's Perceptions of Directionality in Mobile AR Interfaces.

What is this research project about?
This research is to investigate user perceptions of the information presented in an Augmented Reality mobile interface that aims to give users directional information.

What will you have to do and how long will it take?
You will be invited to interact with three mobile interfaces on a supplied mobile phone at the University of Waikato. You will then be asked to answer a small number of questions about each interface. This should take no longer than 30 minutes. The interview may be recorded. You will be asked to give consent prior to the interview.

What will happen to the information collected?
The information collected will be used by the researcher to write a research report for the credit of a specific paper. It is possible that articles and presentations may be the outcome of the research. Only the researcher and supervisor will be privy to the notes, documents, recordings and the paper written. Afterwards, notes, documents will be destroyed and recordings erased. The researcher will keep transcriptions of the recordings and a copy of the paper but will treat them with the strictest confidentiality. No participants will be named in the publications and every effort will be made to disguise their identity.

Declaration to participants
If you take part in the study, you have the right to:

- Refuse to answer any particular question, and to withdraw from the study before analysis has commenced on the data.
- Ask any further questions about the study that occurs to you during your participation.
- Be given access to a summary of findings from the study when it is concluded.

Who's responsible?
If you have any questions or concerns about the project, either now or in the future, please feel free to contact either:

Researcher:
Qimo Zhang
qz116@students.waikato.ac.nz
021 0892 8717

Supervisor:
Associate Professor Annika Hinze
hinze@waikato.ac.nz
07 838 4052

Dr Nicholas Vanderschantz
vtwoz@waikato.ac.nz
07 838 4652

Figure A.2 Principals Information Sheet

Research Consent Form

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

Ethics Committee, School of Computing and Mathematical Sciences

User Perceptions of Directionality in Mobile AR Interfaces

Consent Form for Participants

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study or to decline to answer any particular questions in the study. I understand I can withdraw any information I have provided up until the researcher has commenced analysis on my data. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ______________________________

Name: ______________________________

Date: ______________________________

Additional Consent as Required

I agree / do not agree to my responses to be tape recorded.

Signed: ______________________________

Name: ______________________________

Date: ______________________________

Researcher's Name and contact information:
Qimo Zhang
qz116@students.waikato.ac.nz
021 0892 8717

Supervisor's Name and contact information:
Associate Professor Annika Hinze
hinze@waikato.ac.nz
07 838 4052

Dr Nicholas Vanderschantz
vtwoz@waikato.ac.nz
07 838 4652

Figure A.3 Research Consent Form

Research Questionnaire

THE UNIVERSITY OF WAIKATO

User Perceptions of Directionality in Mobile AR Interfaces

I have read the **Participant Information Sheet** for this study and I understand the details of the study. My questions about the study have been answered to my satisfaction, and I understand that I may ask further question at any time.

I also understand that by completing and returning this questionnaire that I give my consent for the researcher to use all data completed for questions I have chosen to answer.

Questionnaire

Q1. Do you have experience using map for navigation?

□ Never □ Rarely □ Occasionally □ Often

Q2. Do you have experience using location-based augmented reality?

□ Never □ Rarely □ Occasionally □ Often

Version A

Q3-1. It was easy to navigation to the correct next location in the story?

□ completely agree □ somewhat agree □ neutral □ somewhat disagree

□ completely disagree

Version B

Q3-2. It was easy to navigation to the correct next location in the story?

□ completely agree □ somewhat agree □ nature □ somewhat disagree

□ completely disagree

Q4. Do you prefer version A or version B and Why or Why not?

□ Version A □ Version B

Q5. For your preferred version:

If you would change two things, what would there be?

Q6. Any other comments & question?

<<Name>>

Figure A.4 Research Questions Notes - Page 1

Appendix B Materials for Paper Prototype (Chapter 5)

The appendix includes the dataset, ethic application form and ethic approval letter.

- Ethical approval letters from the Human Research Ethics Committee of the School of Computing and Mathematical Sciences at the University of Waikato, dated 28 August 2020;
- The participant information sheets, which outline the title, purpose, procedure, and participant's rights;
- Research Consent Forms, which were signed by each participant prior to participate in our research;
- Research questions notes, which include interview questions.

The University of Waikato
Private Bag 3105
Hamilton, New Zealand, 3240
0800 WAIKATO (924 528)

HECS Human Ethics Committee
Brett Langley
Telephone +64 77 838 4060
Hecs-ethics@waikato.ac.nz

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

28 August 2020

Qimo Zhang
Supervisors: Annika Hinze and Nicholas Vanderschantz

Re: HECS Ethics Approval of Application HREC(HECS)2020#33 "User Perceptions of Directionality in Mobile AR Interfaces"

Dear Qimo:

Thank you for submitting your amended application HREC(HECS)2020#33 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

• Your application concerns users' perceptions of information presented in an augmented reality interface designed to give directional information.
• Users will interact with four different paper prototype applications, and will then be required to answer a number of questions relating to their experience.

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

B Langley

Brett Langley, PhD
Chairperson
HECS Human Ethics Committee
University of Waikato

Figure B.1 Study Ethics approval

Participant Information Sheet

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Ethics Committee, School of Computing and Mathematical Sciences

Project Title
User Perceptions of Directionality in Mobile AR Interfaces

Purpose
This research is being carried out as a part of the research for my PhD in Computer Science at the University of Waikato, to investigate the User's Perceptions of Directionality in Mobile AR Interfaces.

What is this research project about?
This research is to investigate user perceptions of the information presented in an Augmented Reality mobile interface that aims to give users directional information.

What will you have to do and how long will it take?
You will be invited to interact with a set of four paper prototypes of mobile interfaces at the University of Waikato. You will then be asked to answer a few questions about each mobile interface of the questionnaire. This should take no longer than 30 minutes. The interview may be recorded. You will be asked to give consent prior to the interview.

What will happen to the information collected?
The information collected will be used by the researcher to write a research report for the credit of a specific paper. It is possible that articles and presentations may be the outcome of the research. Only the researcher and supervisor will be privy to the notes, documents, recordings and the paper written. Afterwards, notes, documents will be destroyed and recordings erased. The researcher will keep transcriptions of the recordings and a copy of the questionnaire but will treat them with the strictest confidentiality. No participants will be named in the publications and every effort will be made to disguise their identity.

Declaration to participants
If you take part in the study, you have the right to:

- Refuse to answer any particular question, and to withdraw from the study before analysis has commenced on the data.
- Ask any further questions about the study that occurs to you during your participation.
- Be given access to a summary of findings from the study when it is concluded.

Who's responsible?
If you have any questions or concerns about the project, either now or in the future, please feel free to contact either:

Researcher:
Qimo Zhang
qz116@students.waikato.ac.nz
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Supervisor:
Associate Professor Annika Hinze
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Figure B.2 Principals Information Sheet

Research Consent Form

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Ethics Committee, School of Computing and Mathematical Sciences

User Perceptions of Directionality in Mobile AR Interfaces

Consent Form for Participants

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study or to decline to answer any particular questions in the study. I understand I can withdraw any information I have provided up until the researcher has commenced analysis on my data. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ____________________

Name: ____________________

Date: ____________________

Additional Consent as Required

I agree / do not agree to my responses to be tape recorded.

Signed: ____________________

Name: ____________________

Date: ____________________

Participant ID:

Researcher's Name and contact information:
Qimo Zhang
qz116@students.waikato.ac.nz
021 0892 8717

Supervisor's Name and contact information:
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Dr Nicholas Vanderschantz
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Figure B.3 Research Consent Form

Researchers Interview Notes Sheet

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Project Title

User Perceptions of directionality in Mobile AR Interfaces

Gender M / F **Age**....... **Work/Occupation**..................... **Students/Faculty**....................

Participant ID:

My questions relate to navigating a location-based story using augmented reality. The story is told in 5 ordered locations; visiting these five locations one after the other allows a user to experience the story. During the study, you will be shown mobile app screens with five location flags presented on the screen. These represent your AR view at this location. Each flag represents one story location for you to navigate to. I will ask you to imagine that you are navigating to these story locations. We will use your feedback to identify the best way to display the AR story locations to a user.

General Questions

1) Do you have experience using map for navigation?

[1] Never [2] Rarely [3] Occasionally [4] Often

2) Do you have experience using location-based augmented reality?

[1] Never [2] Rarely [3] Occasionally [4] Often

Here are two AR camera views in two different locations. Five flags are displayed on the screen of each tablet. Each flag represents a location in the story. The red flag is the next location to visit.

First Set of Questions

Version

[DH] Each flag has a different height. Height shows distance. The distance flow is increasing from the bottom flag to the top flag.

[DL] Each flag has a different height. Height shows distance. The distance flow is increasing from the top flag to the bottom flag.

[SH] Each flag has a different height. Height shows story flow. The story flow is increasing from the top flag to the bottom flag.

[SL] Each flag has a different height. Height shows story flow. The story flow is increasing from the bottom flag to the top flag.

3a) which location should you visit next?

3b) in which order should you visit the five locations?

3c) How much do you agree with the following statement? I am confident that I can identify the next location in the story?

Researchers Interview Notes Sheet - Page 1

Figure B.4 Research Questions Notes - Page 1

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

3d) How much do you agree with the following statement? It is easy to navigate the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

3e) How much do you agree with the following statement? I am confident that I can identify the order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

3f) How much do you agree with the following statement? It is easy to navigate the correct order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Second Set of Questions

Version

[DH] Each flag has a different height. Height shows distance. The distance flow is increasing from the bottom flag to the top flag.

[DL] Each flag has a different height. Height shows distance. The distance flow is increasing from the top flag to the bottom flag.

[SH] Each flag has a different height. Height shows story flow. The story flow is increasing from the top flag to the bottom flag.

[SL] Each flag has a different height. Height shows story flow. The story flow is increasing from the bottom flag to the top flag.

4a) which location should you visit next?

4b) in which order should you visit the five locations?

4c) How much do you agree with the following statement? I am confident that I can identify the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Researchers Interview Notes Sheet - Page 2

Figure B.5 Research Questions Notes - Page 2

4d) how much do you agree with the following statement? It is easy to navigate the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

4e) How much do you agree with the following statement? I am confident that I can identify the order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

4f) How much do you agree with the following statement? It is easy to navigate the correct order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Third Set of Questions

Version

[DH] Each flag has a different height. Height shows distance. The distance flow is increasing from the bottom flag to the top flag.

[DL] Each flag has a different height. Height shows distance. The distance flow is increasing from the top flag to the bottom flag.

[SH] Each flag has a different height. Height shows story flow. The story flow is increasing from the top flag to the bottom flag.

[SL] Each flag has a different height. Height shows story flow. The story flow is increasing from the bottom flag to the top flag.

5a) which location should you visit next?

5b) in which order should you visit the five locations?

5c) How much do you agree with the following statement? I am confident that I can identify the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

5d) how much do you agree with the following statement? It is easy to navigate the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Researchers Interview Notes Sheet - Page 3

Figure B.6 Research Questions Notes - Page 3

5e) How much do you agree with the following statement? I am confident that I can identify the order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

5f) How much do you agree with the following statement? It is easy to navigate the correct order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Fourth Set of Questions

Version

[DH] Each flag has a different height. Height shows distance. The distance flow is increasing from the bottom flag to the top flag.

[DL] Each flag has a different height. Height shows distance. The distance flow is increasing from the top flag to the bottom flag.

[SH] Each flag has a different height. Height shows story flow. The story flow is increasing from the top flag to the bottom flag.

[SL] Each flag has a different height. Height shows story flow. The story flow is increasing from the bottom flag to the top flag.

6a) which location should you visit next?

6b) in which order should you visit the five locations?

6c) How much do you agree with the following statement? I am confident that I can identify the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

6d) how much do you agree with the following statement? It is easy to navigate the next location in the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

6e) How much do you agree with the following statement? I am confident that I can identify the order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

Researchers Interview Notes Sheet - Page 4

Figure B.7 Research Questions Notes - Page 4

[5] Somewhat Agree [6] Agree [7] Completely Agree

6f) How much do you agree with the following statement? It is easy to navigate the correct order of the story?

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Final Questions

Now that we have completed four sets of questions, I would like to summarise your answers and begin to do pairwise comparisons for the best results.

First, we will compare order by distance, please you look at the four photos. The distance of these two photos are increasing from the bottom flag to the top flag, and the distance of another two photos are increasing from the top flag to the bottom flag.

7) Which version do you prefer in order by distance?

[1] DH Version [2] DL Version

Why: ....

Next, we will compare order by story flow, please you look at the four photos. The story flow of these two photos are increasing from the top flag to the bottom flag, and the story flow of another two photos are increasing from the bottom flag to the top flag.

8) Which version do you prefer in order by story flow?

[1] SH Version [2] SL Version

Why: ....

Finally, we will compare the four photos that you chose.

9) Which one of the two sets of photos do you like?

[1] D? Version (Q7) [2] S? Version (Q8)

Why: ....

Thank you for participating in my research.

Researchers Interview Notes Sheet - Page 5

Figure B.8 Research Questions Notes - Page 5

Appendix C Material for Narrative Navigation Prototype (Chapter 6)

The appendix includes the screenshots of walk-through of Narrative Navigation Prototype, and a world space to screen space background for the design exploration of showing POIs in AR view.

Section C1 describes the improved Walk-through screenshots of the Narrative Navigation Prototype feature. Section C2 introduces the world space system of Unity 3D. This content demonstrates how to convert the spatial location of a physical object to the screen position of a virtual object on the phone screen.

C1 Screenshots of Walk-through

The section introduces the detailed walk-through of Narrative Navigation Prototype. The walk-through started at overview position A, walked along the sidewalk to the first story part, and the participant can see through the AR view that as the participant moves, the avatar of each story part on the user study phone screen moves left and right. After visiting story part 1, participants would walk to overview location B to see the remaining story parts that should be visited, and then visited story part 2, story part 3, story part 4, and story part 5 in order. The details of the walk-through will be described below.

Overview A

We started at the starting point (overview A), and then visited each part of the story according to story order. The screenshot in Figure C.1 shows the AR scenario of NL-S (high is last / low is next in story) of 'order by story flow' as the participant stands at overview A.

We can see the numbers counting upward from the bottom of the AR view to the top, and thus We can clearly understand which flag is story part 1 of the story (shown in red in Figure C.1). The number in the middle of each flag, shown as 'Xm', is the distance between the location of each part and the overview A (see Figure C.1).

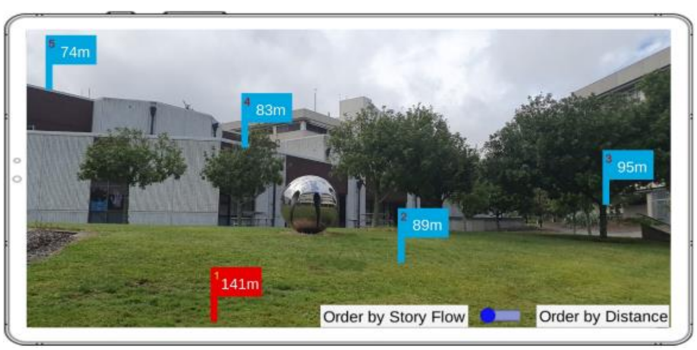

Figure C.1 AR view of orders by story at overview A

Story part 1

We walked along the sidewalk to the story part 1. When we walked within three meters of the story part 1, an information notice would be automatically popped up with audio reading (see Figure C.2).

This information includes arrival notification information, tree name, and a botanical description of the Kahikatea tree that can be viewed here.

Figure C.2 The introduction of story part 1 on the AR view

After visiting the Kahikatea tree, we would walk to overview B.

Overview B

Figure C.3 shows POI shown in AR view and indicating how to navigate to the next part of the story when we stood at overview B location. The red flag at the bottom of the figure shows that the next destination for the visit is story part 2. The location linked with story part 2 is 58 meters away from the user location. Story parts 3, story part 4 and story part 5 are displayed in order from the bottom to the top of the AR view. Next, we walked to story part 3.

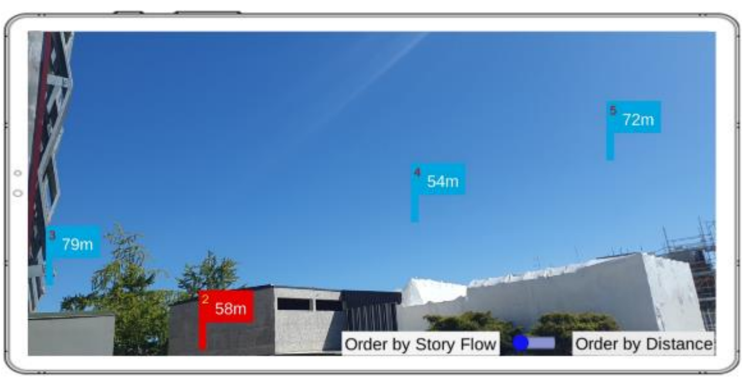

Figure C.3 AR view of order by story at overview B

Story part 2

When we arrived within 3 meters of story part 2, information related to the story part would be automatically presented to me (see Figure C.4). We could click on the yellow bar to display the Norfolk Island pine introduction.

Figure C.4 The introduction of story part 2 on the AR view

Story part 3

Then, after reading the introduction of Norfolk Island pine, we walked to story part 3, The bottom red flag showed the next story part and indicated direction and distance, and story part 3 was 7 meters away from our location (see Figure C.5). Story part 4 and story part 5 displays in order from the bottom to the top on the AR view.

Figure C.5 AR view of after visit story part 2

When we arrived within 3 meters of story part 3, an information related to the story part would be also automatically presented to me (see Figure C.6)

Figure C.6 The introduction of story part 3 on the AR view

Story part 4

Next, after reading the introduction of Totara tree, we walked to story part 4. We walked from story part 3 to story part 4, the bottom red flag showed the next story part and indicated direction and distance, story part 4 was 10 meters away from the location (see Figure C.7). Story part 5 displayed in the order from the bottom to the top on the AR view.

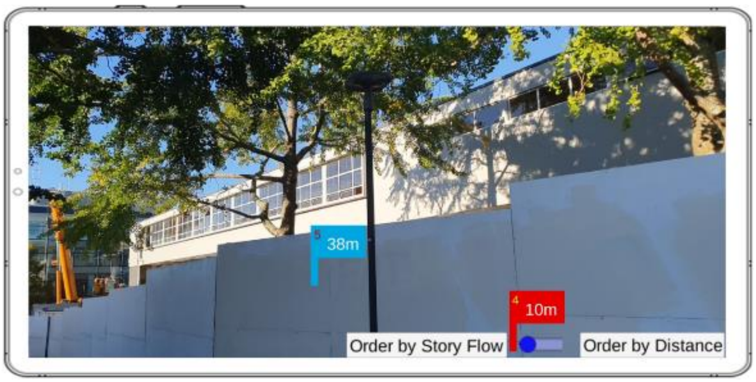

Figure C.7 AR view after visiting story part 3

When we arrived within 3 meters of story part 4, information related to the story part would be automatically presented to the participant (see Figure C.8). The participant could click on the yellow bar to display the Radiata tree introduction.

Figure C.8 The introduction of story part 4 on the AR view

Story part 5

After reading the introduction of Radiata pine tree, we walked to story part 5, the bottom red flag showed the next story part and indicated direction and distance. The story part 5 was 6 meters away from the location (see Figure C.9).

Figure C.9 AR view of after visit story part 4

Finally, when we arrived within 3 meters of story part 5, information related to the story part would be automatically presented to me (see Figure C.10). We could click on the yellow bar to display the Pohutukawa tree introduction.

Figure C.10 Introduction of story part 5 on the AR view

C2 Coordinate System of Unity 3D

The Section introduced the coordinate system of Unity 3D. First, we demonstrated that different 3D software used the right-handed or the left-handed coordinate system.

All digital prototypes were based on Unity 3D software. Unity 3D used four different coordinate systems: GUI system, Viewport system, Screen system and World space system.

GUI system

The UI buttons created in unity were all in the GUI interface coordinate system, and its origin (0, 0) was in the upper left corner, because the screen width was Screen.width and the height were Screen.height, so the coordinates of the GUI system in the bottom right were: (Screen.width, Screen.height), which was two-dimensional coordinate systems, and the value of coordinate z was 0.

Viewport system

When using multiple cameras to display multiple viewports in the same scene, the viewport coordinate system must be considered.

Screen system

It is often necessary to handle mouse-related events (mouse position, click, double-click events, etc.), touch feedback on the mobile phone, and these raw data were all related to the screen coordinate system.

'Input.mouse position' can got the position coordinates of the mouse on the screen. The origin (0, 0) in the screen coordinate system was in the lower left corner, and the upper right corner was (Screen.width, Screen.height)

The depth values z were all 0. But after the screen coordinates were converted to world coordinates, the z value of the object depended on the camera, so: gameObject.z = camera.z

World Space system

The world space system was defined in global coordinates. It referred to the position of an object in the world or global space.
The Figure C.11 showed the four coordinates system of Unity 3D

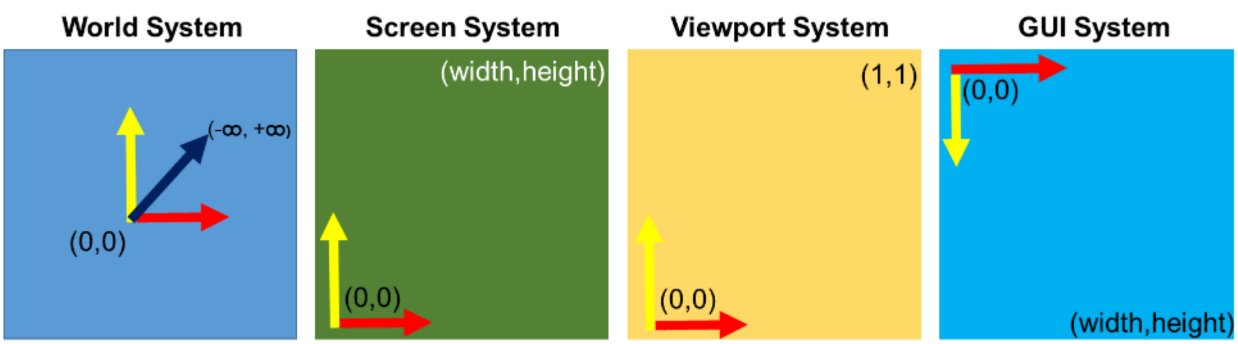

Figure C.11 Unity3D coordinate for different application scene. Photography by Qimo Zhang

Unity 3D provides specific functions to find where the particular point will be in another point system.

When we use the world space point shown on screen, we use the following code to realize the function.

Table C.1 The function of a world space system to screen point system.

```
Camera.main.WorldSpaceToScreenPoint(
    new Vector3(
      gameObject.transform.position.x,
      gameObject.transform.position.y,
      gameObject.transform.position.z
    )
```

Based on the conversion of different coordinate systems, the physical object in the real world can be displayed on the screen system of our digital prototypes.

Section 6.3.1 describes the exploration of POI display in AR views, the coordinate system is an essential element in POI display.

Appendix D Material for Final Prototype

This appendix includes the material of Final Prototype (referred to in Chapter 7), and the screenshots of each participant's movement map of Final Prototype.

Section D1 describes the following details.

- Ethical approval letter from the Human Research Ethics Committee of the School of Computing and Mathematical Sciences at the University of Waikato, dated 1 December 2021.
- The participant information sheet, which outlines the title, purpose, procedure, and participant's rights.
- Research Consent Form, which each participant signed before the participant agreed to participate in our research.
- Research questions notes, which includes interview questions.

Appendix D2 presents the interview drill action diagram for each participant.

D1 Material for Interview Research Questions

The University of Waikato
Private Bag 3105
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0800 WAIKATO (924 528)

HECS Human Ethics Committee
Brett Langley
Telephone +64 77 838 4060
Hecs-ethics@waikato.ac.nz

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

1 December 2021

Qimo Zhang
Annika Hinze
Nicholas Vanderschantz

Re: HECS Ethics Approval of Application HREC(HECS)2021#60 "Narrative navigation using mobile augmented reality location-based story order"

Dear Qimo:

Thank you for submitting your amended application HREC(HECS)2021#60 for ethical approval.

We are pleased to provide formal approval for your project, including the following activities:

- Recruitment of up to 5 participants for an observation study to explore participant reflection of narrative navigation using mobile augmented reality.
- Participants will be subject to a brief preliminary interview and will then be provided with a mobile device and set off following its instructions. On completion of the navigation, they will be interviewed again. Notes may be recorded at these interviews with consent of the participants.

Please contact the committee by email (hecs-ethics@waikato.ac.nz) if you wish to make changes to your project as it unfolds, quoting your application number with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

We wish you all the best with your research.

Kind regards,

Brett Langley, PhD
Chairperson
HECS Human Ethics Committee
University of Waikato

Figure D.1 Study Ethics approval

Participant Information Sheet

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Ethics Committee, School of Computing and Mathematical Sciences

Project Title
Narrative navigation using mobile augmented reality location-based story order

Purpose
This research is being carried out as a part of the research for my PhD in Computer Science at the University of Waikato, to investigate the User's feedback of narrative navigation using mobile augmented reality.

What is this research project about?
This research is to investigate user perceptions of the information presented in an Augmented Reality mobile interface that aims to give users directional information.

What will you have to do and how long will it take?
You will be invited to interact with a digital prototype of a mobile application at the University of Waikato. Before and after the field test, you will be asked to answer a few questions. This should take no longer than 20 minutes. The interview may be recorded. You will be asked to give consent prior to the interview.

What will happen to the information collected?
The information collected will be used by the researcher to write a research report for the credit of a specific paper. It is possible that articles and presentations may be the outcome of the research. Only the researcher and supervisor will be privy to the notes, documents and the paper written. All application data and interview notes will be kept secure during the research process but will be destroyed after the project has been completed. No participants will be named in the publications and every effort will be made to disguise their identity.

Declaration to participants
If you take part in the study, you have the right to:

- Refuse to answer any particular question, and to withdraw from the study before analysis of the data has commenced.
- Ask any further questions about the study that occur to you during your participation.
- Be given access to a summary of findings from the study when it is concluded.

Who's responsible?
If you have any questions or concerns about the project, either now or in the future, please feel free to contact either:

Researcher:
Qimo Zhang
qz116@students.waikato.ac.nz
021 0892 8717

Supervisor:
Associate Professor Annika Hinze
hinze@waikato.ac.nz
07 838 4052

Dr Nicholas Vanderschantz
vtwoz@waikato.ac.nz
07 838 4652

Figure D.2 Study Ethics approval

Research Consent Form

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Ethics Committee, School of Computing and Mathematical Sciences

Narrative navigation using mobile augmented reality location-based story order

Consent Form for Participants

I have read the **Participant Information Sheet** for this study and have had the details of the study explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study or to decline to answer any particular questions in the study. I understand I can withdraw any information I have provided up until the researcher has commenced analysis on my data. I agree to provide information to the researchers under the conditions of confidentiality set out on the **Participant Information Sheet**.

I agree to participate in this study under the conditions set out in the **Participant Information Sheet**.

Signed: ______________________________

Name: ______________________________

Date: ______________________________

Additional Consent as Required

I agree / do not agree to my responses to be tape recorded.

Signed: ______________________________

Name: ______________________________

Date: ______________________________

Participant ID:

Researcher's Name and contact information:
Qimo Zhang
qz116@students.waikato.ac.nz
021 0892 8717

Supervisor's Name and contact information:
Associate Professor Annika Hinze
hinze@waikato.ac.nz
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Dr Nicholas Vanderschantz
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Figure D.3 Research Consent Form

Researchers Interview Notes Sheet

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Project Title

Narrative navigation using mobile augmented reality location-based story order

Gender M / F **Age**___ **Work/Occupation**_________ **Students/Faculty**_________

Participant ID:

This user study relates to the concept of narrative navigation in which you will be using a mobile phone on which augmented reality is used to indicate the order of a location-based story. The story is told in 5 ordered locations. Visiting these five locations one after the other allows you to experience the story. During the study, you will be given a test mobile phone to use the digital prototype on-site. You will follow the five-story locations on the AR view to experience each story part in order. Your feedback will be used to identify the best way to display the AR story locations to a user.

General Questions

1. **Do you have experience using maps for navigation?**

   [1] Never [2] Rarely [3] Occasionally [4] Often

2. **Do you have experience using location-based augmented reality?**

   [1] Never [2] Rarely [3] Occasionally [4] Often

Thank you for answering these questions. We will begin the field test now. Please follow me to the starting point.

Please take the mobile phone running the field test application towards the S block of the university campus. You can see five AR flags shown on the screen of the mobile phone. The red flag is the next flag that you should visit. Please only use this app to navigate the story. During your navigation, you can move the phone around so that it is comfortable for you to use.

After Field Test Questions

3. **Please rate how much you agree with the following sentence:**
   "It was enjoyable to use narrative navigation for the story".

   [1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

   [5] Somewhat Agree [6] Agree [7] Completely Agree

   Please give details.

4. **Please rate how much you agree with the following sentence:**
   "The narrative navigation for the story was easy to use".

   [1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

   [5] Somewhat Agree [6] Agree [7] Completely Agree

   Please give details.

Researchers Interview Notes Sheet - Page 1

Figure D.4 Research Questions Notes - Page 1

5. **Please rate how much you agree with the following sentence:**
"It was easy to navigate the location-based story using narrative navigation".

[1] Completely Disagree [2] Disagree [3] Somewhat Disagree [4] Neither Disagree/Agree

[5] Somewhat Agree [6] Agree [7] Completely Agree

Please give details.

6. **What suggestions do you have to improve the app?**

Note:

7. **Any other comments or questions?**

Note:

Thank you for participating in my research.

Researchers Interview Notes Sheet - Page 2

Figure D.5 Research Questions Notes - Page 2

Table D1.1 The participants' demographic of the interviews

Participant ID	Gender	Age	Occupation	CS background
1	M	30-39	CS PhD Student	√
2	F	20-29	Social Science Bachelor Student	
3	M	30-39	Work	√
4	M	40-49	Work	√
5	F	20-29	CS PhD Student	√
6	M	40-49	Work	√
7	M	30-39	Work	√
8	M	20-29	Work	
9	F	30-39	Work	
10	F	30-39	Social Science PhD Student	
11	M	40-49	Work	√
12	M	20-29	Work	√
13	M	30-39	Engineering PhD Student	
14	M	20-29	Social Science PhD Student	
15	M	20-29	CS Bachelor Graduate	√
16	M	20-29	Management Bachelor Student	
17	M	20-29	Design Master Student	√
18	M	20-29	Management PhD Student	
19	M	30-39	Education PhD Student	
20	F	40-49	Work	
21	F	40-49	CS PhD Student	√
22	M	20-29	Management PhD Student	
23	M	20-29	Work	
24	M	20-29	Design Master Student	√
25	M	20-29	Design Master Student	√
26	F	50-60	Work - teacher	
27	M	20-29	CS PhD Student	√
28	M	40-49	CS PhD Student	√
29	F	20-29	Design Master Student	√
30	M	20-29	Work	√

D2 Maps for each Participant Trail

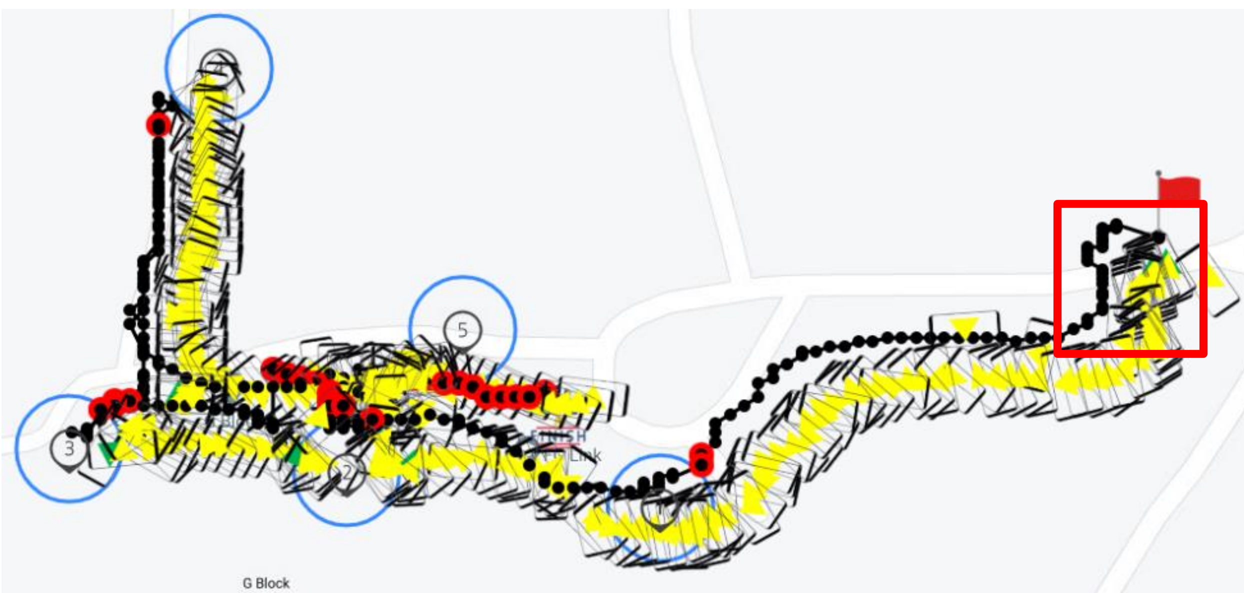
Here was a map of each participant's journey. When the participants finished their user study, the map would be generated by a python program. All legends described Table 6.7 in Section 6.5.1. Each location marker showed the participant movement track and details of the test mobile phone's attributes, such as time, latitude, longitude, camera angle, orientation, gyroscope pitch angle and line angle between two POIs.

There were abnormalities in the maps of P3, P5, P6, P8, P12, P15, P17, P20, P24, P27, and P29, which were caused by GPD signal drift. We described that separately below the participant map. The maps of other participants were not affected by GPS drift and showing better results.

Participant 1

Participant 2

Participant 3



The participant wandered around the starting point of story chapter 1, see the red square. This was caused by GPS signal drift.

Participant 4

Participant 5

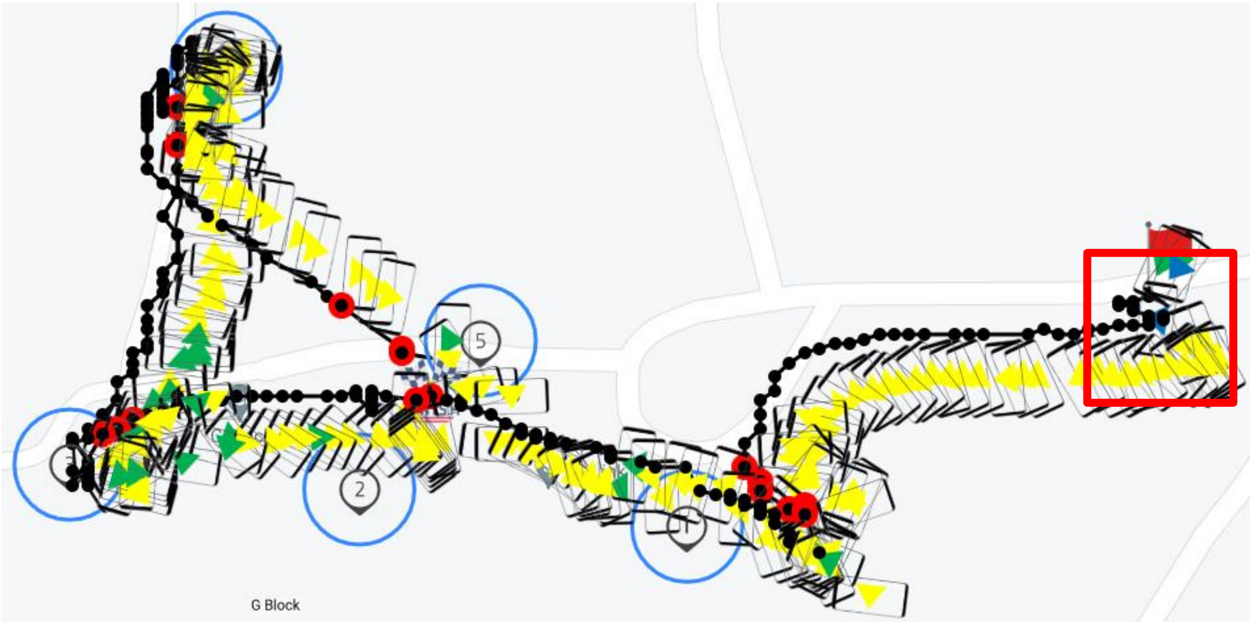
Ten seconds of data lost during the participant visited to story chapter 5, see red rectangle. This was caused by GPS signal drift.

Participant 6

The participant wandered around the starting point of story chapter 1, see the red square. This was caused by GPS signal drift.

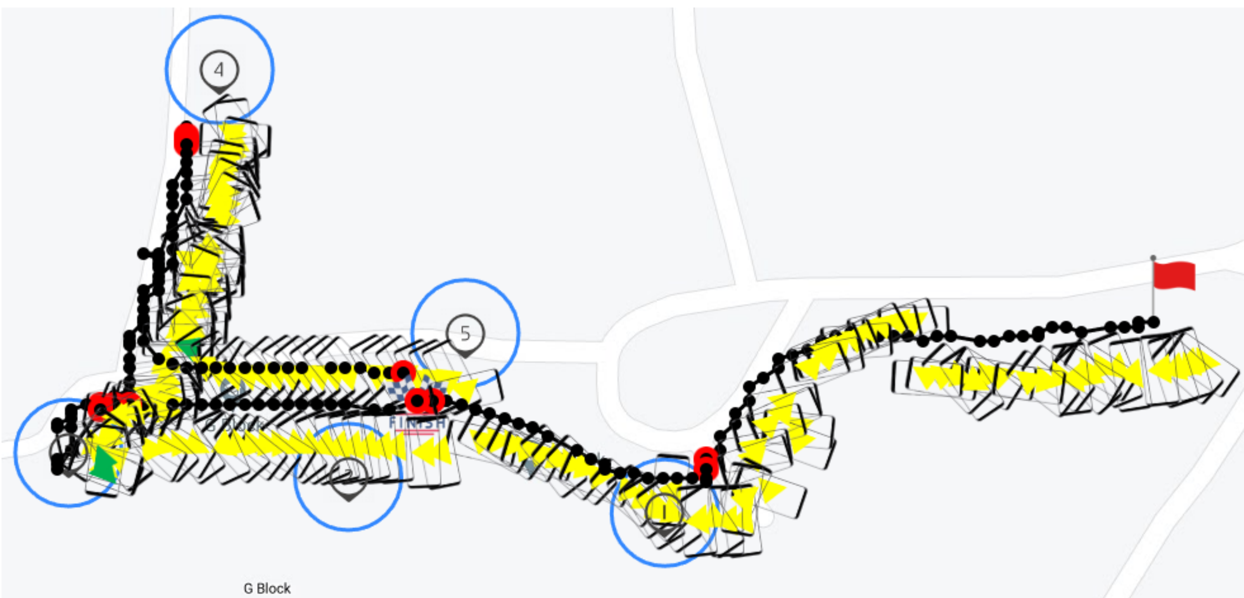
Participant 7

Participant 8



The participant wandered around the starting point of story chapter 1, see the red square. This was caused by GPS signal drift.

Participant 9



Participant 10

Participant 11

Participant 12

Participant 12 experienced inaccurate GPS positioning when the participant was visiting chapter 2 of the story, resulting in intermittent story introductions, and multiple observation-type location markers in chapter 2 of the story showed in blue rectangle. This was caused by GPS signal drift.

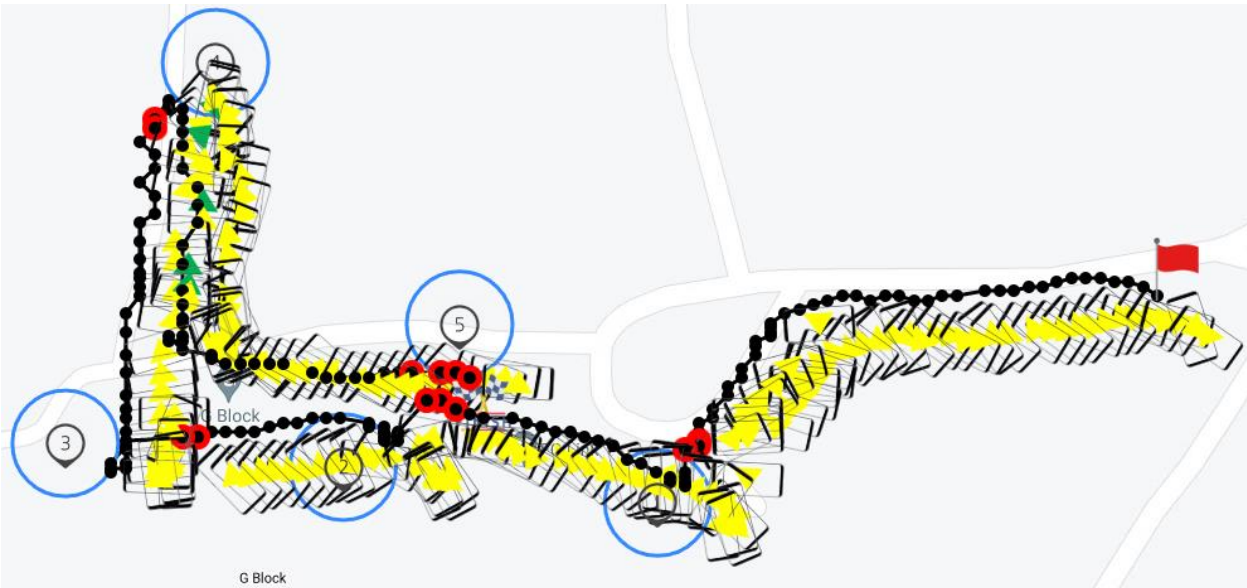
Participant 13

Participant 14

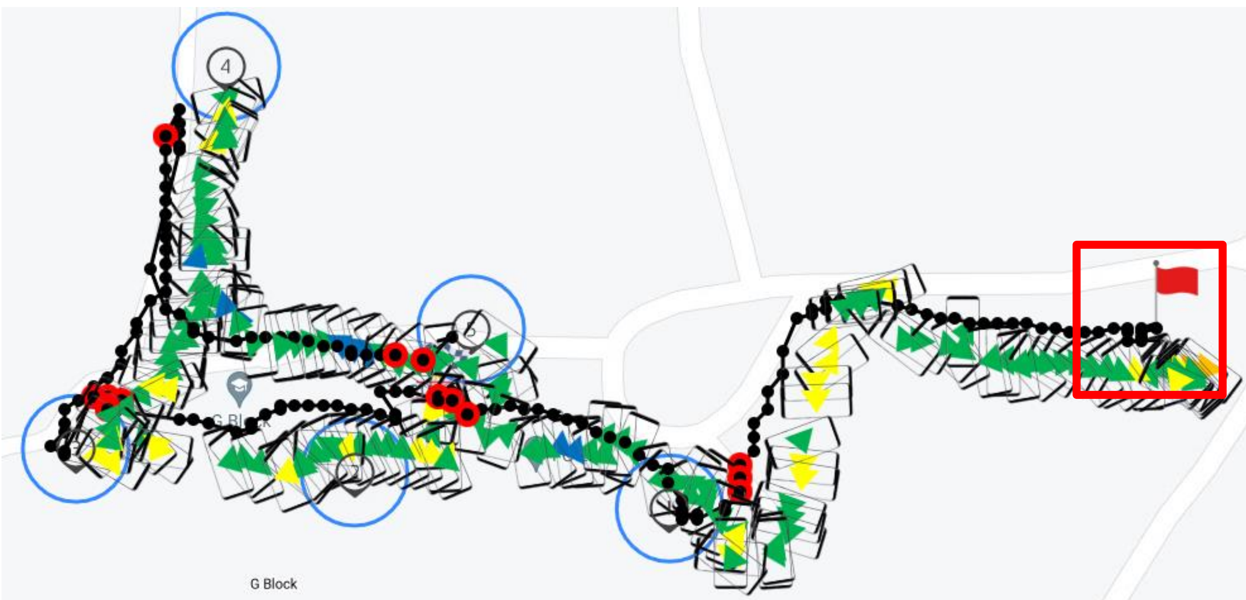
Participant 15

After participant 15 visited the chapter 3 of the story, the prototype suddenly exited. After restarted the prototype, the participant continued to visit the remaining chapters of the story. There were jumps in several location marker visit routes, see the red rectangle, which was caused by the drift of the GPS signal.

Participant 16



Participant 17



Participant 17 spent most of the time observing the avatars of the story chapters using a slightly downward gyro pitch angle (referred to in Section 7.2.4). The participant wandered around the starting point of story chapter 1, see the red square. This was caused by GPS signal drift.

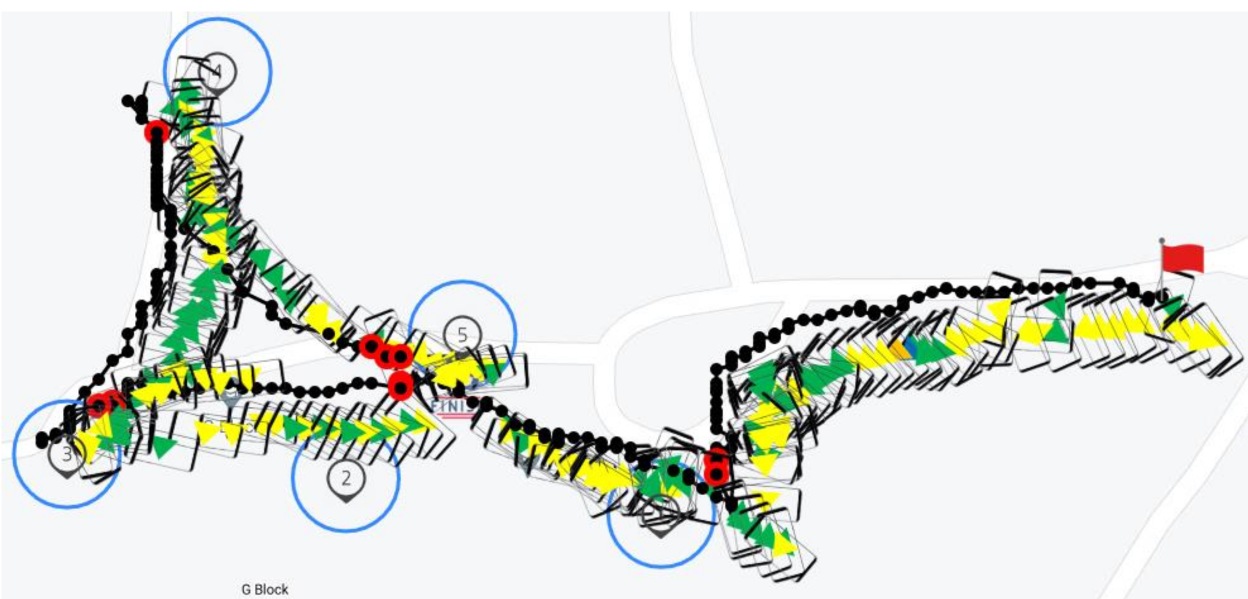
Participant 18

Participant 19

Participant 20

The participant wandered around the starting point of story chapter 1, see the red square. In addition, during the participant's visited to chapter 5 of the story, the GPS signal was lost and reappeared after 10 seconds, resulting in a time interval of no data between the two location markers. There were caused by GPS signal drift.

Participant 21



Participant 22

Participant 23

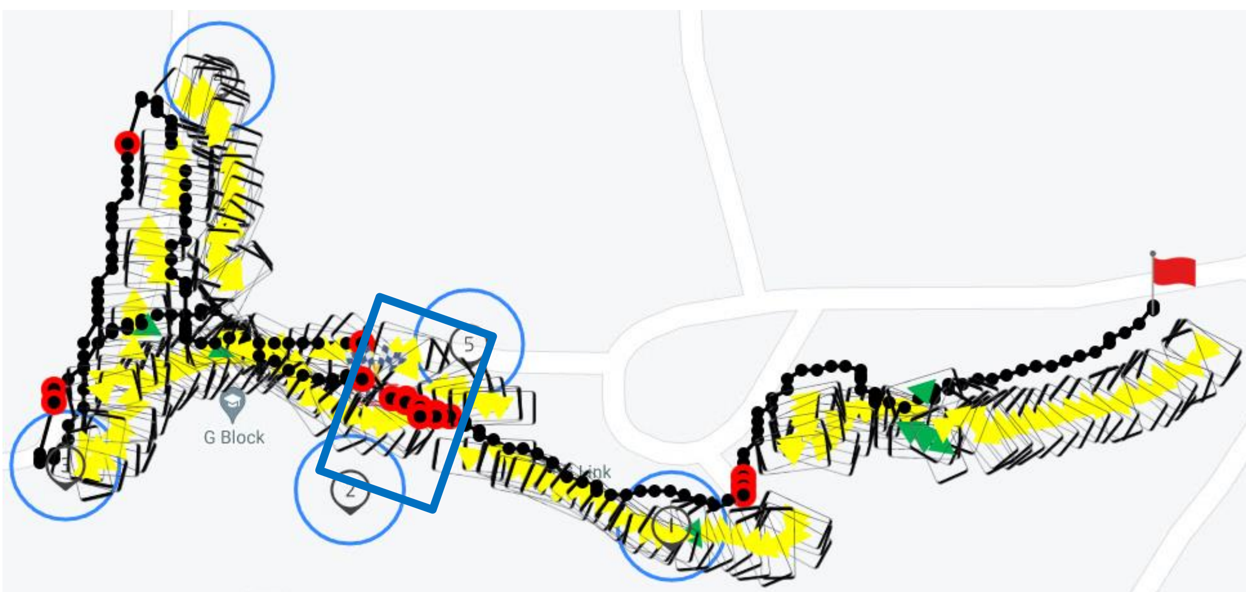
Participant 24

The participant experienced inaccurate GPS positioning when visited chapter 2 of the story, resulting in intermittent story introductions, and multiple observation-type location markers in chapter 2 of the story were shown in blue rectangle. This was caused by GPS signal drift.

Participant 25

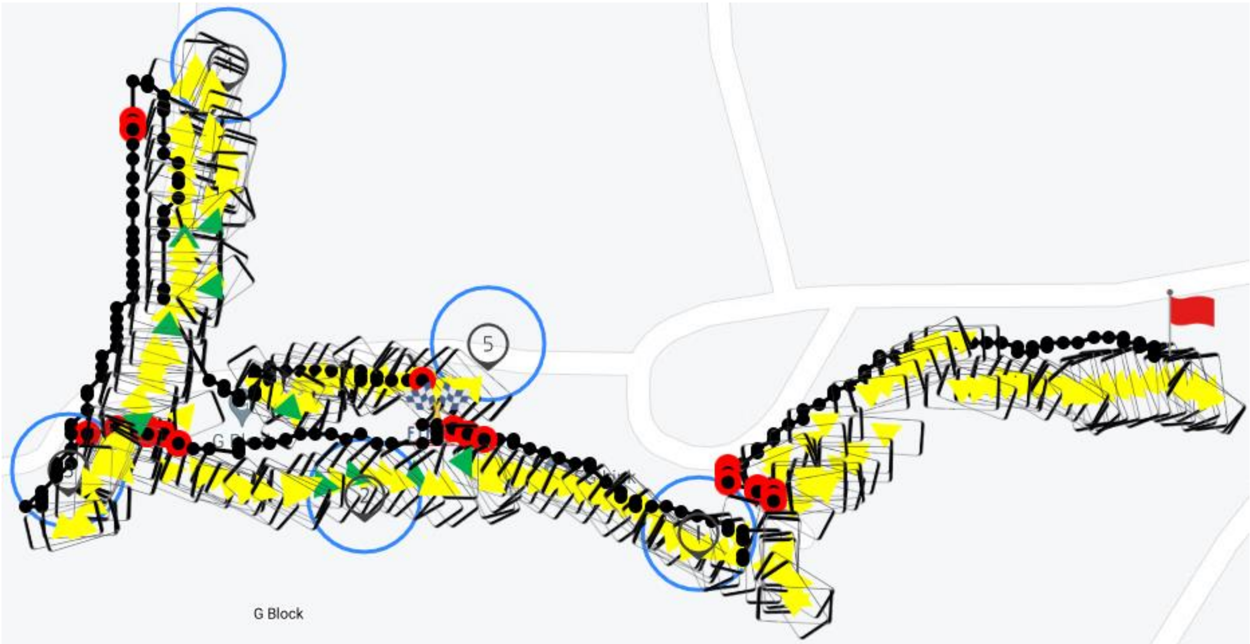
Participant 26

Participant 27



Participant 27 experienced inaccurate GPS positioning when visited chapter 2 of the story, resulting in intermittent story introductions, and multiple observation-type location markers in chapter 2 of the story were shown in blue rectangle. This was caused by GPS signal drift.

Participant 28



Participant 29

During the participant’s visited to chapter 5 of the story, the GPS signal was lost and reappeared after 10 seconds, resulting in a time interval of no data between the two location markers. There were caused by GPS signal drift.

Participant 30