Establishing Design Principles for Augmented Reality for Older Adults

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ABSTRACT

Augmented Reality (AR) is growing rapidly and becoming a more mature and robust technology, which combines virtual information with the real environment in real-time. This becomes significant in ensuring the acceptance and success of Augmented Reality systems. With the growing number of older mobile phone users, evidence shows the possible trends associated with using AR systems to support older adults in terms of transportation, home activities, rehabilitation training and entertainment. However, there is a lack of research on a theoretical framework or AR design principles that could support designers when developing suitable AR applications for specific groups (e.g. older adults). This PhD research mainly focuses on the possibility of developing and applying AR design principles to provide various possible design alternatives in order to address the relevant AR-related issues focusing on older adults. This research firstly identified the architecture of Augmented Reality to understand the definition of AR using a range of previous AR examples. Secondly, AR design principles (version 1) were identified after describing the AR features and analysing the AR design recommendations. Thirdly, this research refined the AR design principles (version 2) by conducting two half-day focus groups with AR prototypes and related scenarios for older adults. The final version of the AR design principles (version 3) for older adults was established. These are: Instantaneous Augmentation, Layer-focus Augmentation, Modality-focus Augmentation, Accurate Augmentation and Hidden Reality. Ultimately, all of these design principles were applied to AR applications and examined in practice using two focus groups. Additionally, as part of the process of AR principle development, a number of AR issues were identified and categorised in terms of User, Device, Augmentation, Real Content, Interaction and Physical World, based on the pre-established AR architecture. These AR issues and design principles may help AR designers to explore quality design alternatives, which could potentially benefit older adults.

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PUBLICATIONS

A number of publications have been completed by the author during the period of PhD research. These are listed below:

Liang, S., (2016) 'Design Principles of Augmented Reality focusing on the Ageing Population', In Proceedings of the 30th International BCS Human Computer Interaction Conference (HCI 2016), Bournemouth University, Poole, UK, 11 - 15 July 2016

Liang, S., (2015) 'Research Proposal on reviewing Augmented Reality Applications for supporting Ageing Population', in Applied Human Factors and Ergonomics 2015

Liang, S. and Roast, C., (2014) 'Five Features for modelling Augmented Reality' In: Kurosu, M, (ed.) Human-Computer Interaction application and Services: 16th International Conference, HCI international 2014 Proceedings, Springer

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CHAPTER 1 – INTRODUCTION

This chapter introduces the background to the research presented in this thesis and the general reasons for developing Augmented Reality design principles for older adults in **Section 0**. The research questions and objectives driving this thesis are then introduced in **Section 1.2**. Several important terms that are used throughout this thesis are defined in **Section 1.3**. A description of the overall structure of this research is presented in **Section 1.4**. This shows how each component of the research fits together to contribute to the whole PhD research and promotes the development of Augmented Reality design principles for older adults.

1.1 MOTIVATION

Augmented reality (AR), as a technological enabler, is a visualisation technique that synthesises various types of multimedia information (N. Chung, Han, & Joun, 2015). AR applications are found in various fields, such as education (Yilmaz, 2016), health sciences (Moro, Štromberga, Raikos, & Stirling, 2017), tourism (L. Lee, Ng, Tan, Shaharuddin, & Wan-Busrah, 2018) and navigation (Chen et al., 2015). Due to the development and adoption of mobile devices, AR is growing rapidly and becoming more mature and robust on mobile platforms. The AR research priorities have shifted from software and hardware development towards the design of effective, easy-to-use applications (Endsley et al., 2017; Scholz & Smith, 2016). The implementation of design guidelines or principles may improve the acceptance and success of future AR systems.

With the growth of older mobile phone users, a trend in the use of AR systems among older people has been observed (Malik, Abdullah, Mahmud, & Azuddin, 2013). Peleg-Adler et al. (2018) highlighted the

potential of AR technology as a possible aid to help older adults to manage everyday tasks, such as navigation and planning. Therefore, it has become important to design suitable AR applications that may benefit older adults in certain areas. There have been several attempts to realise the potential of AR in order to bring benefits to this group (Lera, Rodríguez, Rodríguez, & Matellán, 2014; Okuno, Ito, Suzuki, & Tani, 2017; Quintana & Favela, 2013; Yamamoto et al., 2015). However, the investigation into principles or guidelines for designing appropriate AR applications for older adults has been fairly limited (Malik et al., 2013). There appear to be two main reasons for this:

- Designing AR applications for older adults presents some intrinsic challenges because AR is still technically immature in some respects; for example, registration and tracking problems still exist (Kalalahti, 2015).
- Technology-driven AR has caused the development of AR applications to become disconnected from older adults and their usage contexts. Thus, the user requirements, the usability of the applications and the design criteria have been insufficiently considered.

1.2 AIMS AND OBJECTIVES OF THIS RESEARCH

The general research question for this thesis is:

Is it possible to establish a set of principles for AR design for older adults?

The aim of this research is to establish a set of design principles to support AR designers in formulating design solutions or exploring the quality of the design alternatives that could potentially benefit older adults.

To achieve this aim, this research has five specific objectives:

1) to clarify the terminology of Augmented Reality, including its definition, elements, features and other related concepts.

This will be achieved by reviewing the literature on AR-related concepts (**Chapter 2**) and producing a conceptual AR architecture (**Chapter 2**) and AR features (**0**) as the fundamental work of this thesis in order to establish the AR-related design principles.

2) to identify a set of first version Augmented Reality design principles.

This will be achieved by analysing the contemporary research and developments in the field of Augmented Reality and highlighting the most relevant design recommendations related to AR in order initially to formalise the first version design principles associated with AR (**0**).

3) to characterise and specify the design-related issues of older adults that might be addressed by AR.

This objective has three subsections:

3.1) to clarify the definition and characteristics of older adults.

This research will review the existing literature in order to investigate older adults' definition and characteristics (**Chapter 2**).

3.2) to develop AR applications for older adults based on a user-centred design process.

This research will review the existing AR applications for older adults in terms of *transportation*, *home activities*, *rehabilitation training* and *entertainment* (**Chapter 2**). Two AR applications will be developed, followed by a systematic design process, including establishing the requirements for older adults by focusing on home activities and designing and prototyping AR alternatives including AR Pillbox and AR Reminder (**Chapter 1**).

3.3) to evaluate AR applications for older adults in order to specify the AR-related issues by conducting focus groups.

Two design focus groups will be conducted in the first empirical stage in order to explore the requirements of older adults (**Chapter 5**), AR design issues (**Chapter 5**) and usability issues for older adults (**Chapter 5**) by employing qualitative data analysis techniques.

4) to assess the relevance between AR design principles and design-related issues for older adults.

This research, in the first empirical stage (**Chapter 5**), will assess the connection between the first version design principles of AR and different design-related issues for older adults (e.g. tackle design issues, raise design issues, etc.) and also between the second version of AR design principles and usability issues for older adults.

5) to reflect on the assessment of the principles and iteratively develop the third version of AR design principles for older adults.

This research, in the first empirical stage, will produce a second, revised version of AR design principles for older adults, based on the participants' feedback (**Chapter 5**), then iteratively create a third version after analgising the data obtained from the participants' feedback (**Chapter 6**).

6) to evaluate the third AR design principles for designing AR applications for older adults.

This research, in the second empirical stage (**Chapter 7**), will allow the target users (older adults) to evaluate a set of AR prototypes imbedded with third version design principles. By analysing the participants' feedback in terms of the ease of use of the AR prototypes, the evaluation of these principles will be discussed.

1.3 IMPORTANT TERMS AND DEFINITIONS

The following chapter of this thesis will use specific terms. These terms are used in a variety of areas and can lead to misunderstandings. For this reason, these important terms are defined here. For the purpose of

this research, the following definitions will be used throughout this thesis:

- **Augmented Reality** - *An array of processes designed to present virtual content*, *deriving information by the server from real content based on the physical world and to enrich the interaction between users and virtual content or devices.*
- **Virtual Content** - *the additionally computer-generated information displayed on the AR device via an array of processes based on real-content counterparts. In this thesis, one word - Augmentation - has been used to express the same meaning as 'virtual content'.*
- **Server** - *a source of data and processing that is not located on the device.*
- **Real Content** - *the presented data taken directly from the physical world context of use.*
- **Physical world** - *the material world including geographic location, physical objects and real-world environment.*
- **Interaction** - *the communication between the AR user and AR device or virtual content in some way.*
- **User** - *an individual who manipulates and controls an AR system and who is the immediate intended beneficiary of an AR system.*
- **Device** - *the sensors, processors or displays which capture the physical world image and provide information to the AR users.*
- **Older adults** - *individuals who are 65 years of age and above.*
- **design principles** - *The high-level, fundamental, reusable, widely applicable and structured resources used to orient designers towards considering aspects of design, including: capturing, communicating and accessing knowledge and expertise.*

1.4 ORGANISATION OF THIS THESIS

Below is a brief introduction of each chapter:

Chapter 1 explains the motivation of this research and the aims of the research, followed by a summary of how these aims will be achieved. Additionally, the definitions used throughout this thesis are identified.

Chapter 2 reviews the existing literature related to the main concepts of this research, in terms of the meaning of AR, AR conceptual architecture, AR design principles, older adults, older adults' needs, older adults' requirements, design challenges and the existing AR applications for older adults; and also explains the reasons why this research focuses on AR design principles for older adults.

0 covers the methodology for achieving the aims of the research, including the philosophical paradigm, research approach, research strategies, research choice, time horizon, detailed data collection techniques and data analysis procedures.

0 formulates the first version of the AR design principles by highlighting the most relevant AR features and correlating these with AR design recommendations based upon the existing literature.

Chapter 1 discusses the two initial AR applications for older adults developed in this research based on the design lifecycle, including establishing requirements, designing alternatives and prototyping.

Chapter 5 discusses the first empirical stage - two AR design focus groups in order to assess the first and second version design principles by evaluating the two initial AR applications for older adults and analysing the connection between AR usability issues and design principles, based on the participants' feedback.

Chapter 6 formalises the third version of AR design principles for older adults, which is synthesised based on the previous focus groups.

Chapter 7 describes the second empirical stage, which aims to evaluate the third version of AR design principles for older adults by applying them to AR applications using focus groups.

Chapter 8 describes the possibilities related to applying the final version of design principles to various AR designs for older adults, presents the contributions of this research and offers recommendations for further work.

CHAPTER 2 - LITERATURE REVIEW

This chapter reviews the current literature relevant to the theme of this thesis. Firstly, this chapter discusses AR-related concepts (**Section 0**) and summarises seven key components of AR, including *user, interaction, device, server, virtual content, real content* and *physical world* in an AR architecture (**Section 2.2**). Secondly, this chapter reviews the existing design principles of AR, identifies different definitions of design principles and chooses the most appropriate one for this research (**Section 2.3**). Thirdly, the definition and characteristics of older adults and their design challenges are discussed (**Section 2.4**). Fourthly, the user-centre design process is reviewed in order to develop AR applications for older adults (**Section 2.5**). Finally, the existing AR applications for older adults are classified into different categories in terms of transportation, home activities, rehabilitation training and entertainment (**Section 2.6**).

2.1 THE CONCEPTS OF AUGMENTED REALITY

Gartner's (2017) Hype Cycle illustrates the maturity and adoption of different technologies and applications, and how these offer the potential to solve problems and exploit new opportunities. **Figure 2.1** shows that AR is in the tough of expectation and the experiments and implementation are fail to deliver. However, the upside and potential of AR are enormous compared with other technology (e.g. virtual reality). The theoretical concepts drawn from the real experience, accumulated during the first peak period of expectation, may make the AR applied to the enterprise more crystallised and widely accepted by people. As a result, opportunities for designers and researchers to design and establish new AR design principles are emerging.

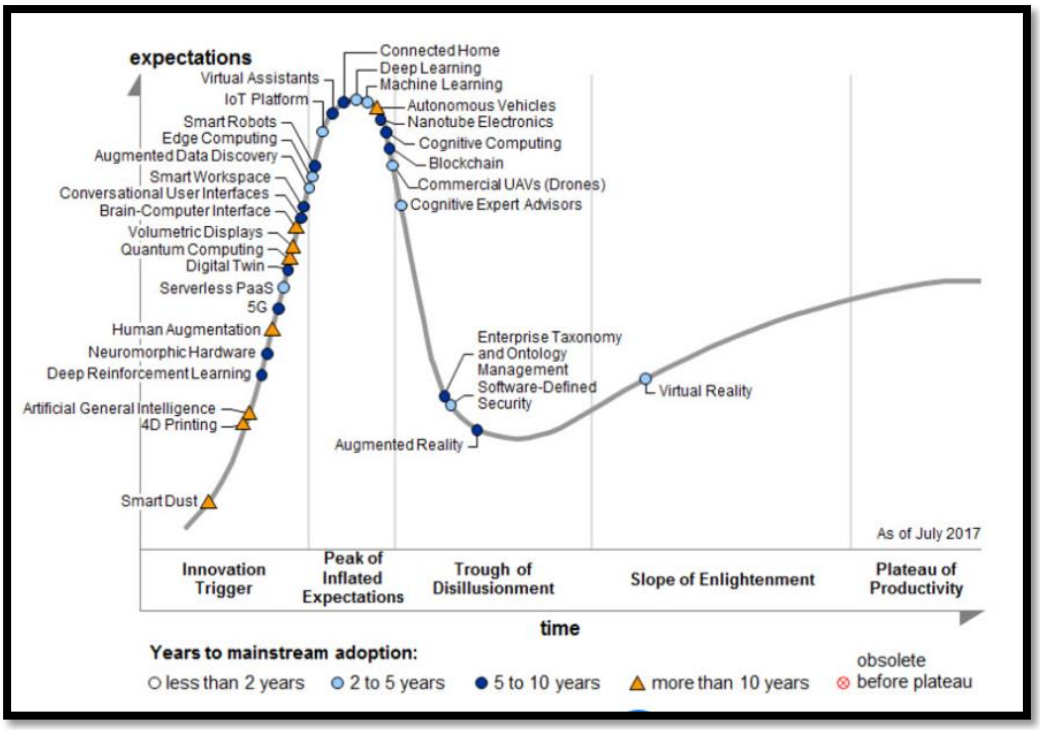


Figure 2.1: Hype Cycle for Emerging Technologies, 2017, Source from: (Gartner, 2017))

The existing definitions are many and wide ranging (Azuma, 1997; Caudell & Mizell, 1992; Craig, 2013; Liarokapis & De Freitas, 2010). The term – Augmented Reality was first defined by Caudell and Mizell (1992) as an enabling technology *'used to augment the visual field of the user with information necessary in the performance of the current task'*.

Milgram and Kishino (1994) used a diagram to distinguish the concept of AR and a broader concept of Mixed Reality (MR), as shown in **Figure 2.2**. The real and virtual environments lie at each end of a continuum. Both AR and augmented virtuality are the mediators of this continuum.

Figure 2.2: The reality-virtuality continuum (Milgram & Kishino, 1994)

There might be the possibility of using the augmentation modalities (e.g. audio or vibration), beyond the visual field. Mackay (1996) described AR as a new paradigm for interacting with computers that takes advantage of users' senses and skills. He also classified different AR applications into three categories: '*users*', '*objects*' and '*environment*' (see **Table 2.1**).

Augment	Approach	Technology	Applications
Users	Devices worn on the body	VR helmets; Goggles; Data gloves	Medicine; Field service; Presentation
Physical objects	Embedded devices within objects	Intelligent bricks; Sensors; GPS	Education; Office facilities; Positioning
Environment surrounding objects and users	Project images and remote recording	Video cameras: Graphics tablets; Bar code readers; Scanners; Video Projectors	Office work; Film-making; Construction; Architecture

Table 2.1: Examples of Augmented Reality Approaches with relevant technologies and applications (Mackay, 1996)

In order to avoid limiting AR to specific technologies, Azuma (1997) defined AR as a system that has the three following characteristics:

1) It combines a real environment with virtual objects.

2) It is interactive in real time.

3) It is registered in 3D.

These three characteristics are not restricted to particular display technologies, such as a head-mounted display (HMD). In addition, they are not limited to our sense of sight but could potentially apply to any of our senses, including hearing, touch or smell (Bederson, 1995; Novotný, Lacko, & Samuelčík, 2013). Researchers can speculate further as to whether tools, such as memory aids, represent augmentations to other human capabilities (like cognition). Liarokapis and De Freitas (2010) offered a more general definition of AR:

'technology that combines virtual information onto the real environment in real-time performance'.

The main criticism of this definition is the extent to which virtual information and the real environment are the only elements of AR. Are they simply combined or do any other relationships exist between the elements? Craig's book (2013), *'Understanding Augmented Reality Concepts and Applications*', investigated several fundamental concepts and elements of AR, such as *user*, *interaction* and *device.* He produced a more robust definition of AR:

'*Augmented Reality is a medium in which digital information is overlaid on the physical world that is in both spatial and temporal registration with the physical world and that is interactive in real time*'.

The understanding of AR in this research is based on Craig's (2013) definition, which presents the virtual information derived from real objects to enrich the users' interactions. The conceptual architecture of AR is further explored in the next section.

2.2 A CONCEPTUAL ARCHITECTURE OF AR

This section collects some of the existing literature and explores the conceptual architecture of AR, which aims to ascertain the relationship between the various elements available in the design of AR systems and understand the real meaning of AR. This AR architecture (**Figure 2.3**) is the reflection and abstraction of existing AR experiences and characteristics.

The term AR *user*, in the architecture, means an individual who can manipulate and control the AR system. The arrow beneath the term *interaction* represents the relationship between the user and AR *device* (e.g. adjusting the device's physical position) or *virtual content* (e.g. clicking on a virtual bubble). An AR *device* (e.g. smart phone, IPad, etc.) can load the information by connecting with a *server* or address the data processing based on the *device* itself. *Virtual content* refers to the additionally computer-generated information displayed on the AR *device*. *Real content* is the original digital information presented on the

AR *device* without any intrinsic change. *Physical world* refers to material objects and the environment.

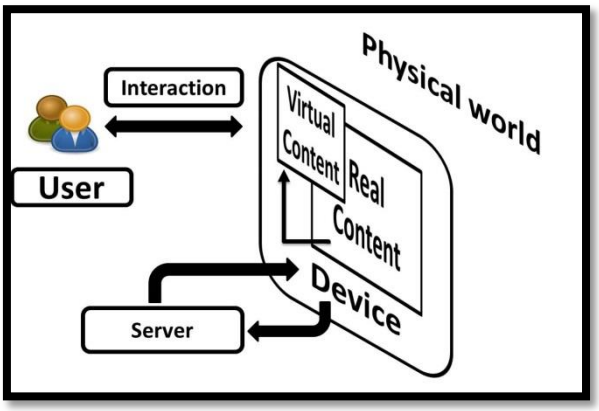


Figure 2.3: Generic Augmented Reality Conceptual Architecture

The following sections (**2.2.1-2.2.7**) discuss each element of the above conceptual architecture by reviewing the existing AR literature and systems in order to identify the definition of Augmented Reality. Because these elements will be used throughout this research, each term is briefly defined, and relevant features and examples are presented. The definition of AR and these elements are summarised at the end of this section.

2.2.1 User

Craig (2013, pp. 67) stated that '*all of the magic of an AR experience takes place in the mind of one or more*' users. AR technology provides artificial stimuli that cause the users '*to believe that something is occurring that really is not*'. For the purposes of this research, a *user* can be defined as an individual who manipulates and controls an AR system and who is the immediate intended beneficiary such system. Take the personal health AR assistant prototype (Gutiérrez, Cardoso, & Verbert, 2017) as an example; the purpose of this application is to provide users with an awareness of similar product recommendations, product information and health impact predictions. As another example, surgeons can use Augmented Reality as a visualisation aid and possibly collect 3-D images of a patient in real-time during surgery (Nguyen et al., 2017). In this case, the AR system brings benefits for

doctors, nurses and patients. However, the direct AR user would be the surgeon, who watches and controls the AR system. AR users could also be tourists (Han, tom Dieck, & Jung, 2018), students (Dinis, Guimarães, Carvalho, & Martins, 2017; Squires, 2017) and maintenance operators (Palmarini, Erkoyuncu, Roy, & Torabmostaedi, 2018), because of the different uses of AR applications. Other AR applications have been developed for children with autism to enhance their social skills (Chung & Chen, 2017; Sahin, Keshav, Salisbury, & Vahabzadeh, 2017). However, to date, the research on designing AR applications for older users is limited (Peleg-Adler et al., 2018), possibly because several critical issues have still not been addressed; for example, what are the potential benefits for AR to older users and how accessible is this new technology to this population? In addition, older users might be '*unable to enjoy them fully because they feel discouraged or intimidated by modern devices'* (Saracchini, 2015).

2.2.2 Interaction

After looking at the user independently, this research considers the communication between users and the AR system – interaction (Dix, 2009). Craig (2013) defines *'interaction'* by splitting the term into: *'inter'* and *'action'*. '*Action'* means that '*something is done*' while 'Inter' means '*between in a reciprocal way*'. Thus, an interaction is something that is done between two things. Craig (2013) states that *'interaction'* occurs when:

'One entity does something and the other entity responds in some way'.

'*Entity*' is a general word that aims to express an independent existence. This research mainly concentrates on the interaction which can occur between one entity (the AR user) and another (the AR *device* or *user* and *virtual content*); for example, if users try to use the ARshop app (Wang et al., 2017) to find the location of a specific shop, they may adjust the position of their mobile device (e.g. IPhone or IPad) to see the overlaid virtual annotation. On screen, the action of adjusting the AR device's physical position can be described as the

interaction **between the user and the AR device**. This action results in the response of identifying the virtual target shop on the device. Then, if users wish to obtain further information about a specific shop (e.g. opening times, location, or contact number), they can click on a virtual icon that visually indicates this information. After that, further overlaid information can be presented in another pop-up frame. The action of clicking on the virtual annotation represents **the user and virtual content interaction**. The response of the new pop-up images implies that the interaction is completed. Therefore, this research refers to interaction as **the communication between an AR user and AR device and virtual content in some way**.

2.2.3 Device

Schall et al. (2009) state that there are three hardware functions for all AR devices, including '*sensors'* (Yu, Ong, & Nee, 2016)*, 'processors'* (Wagner & Schmalstieg, 2003) and *'displays'* (Zhou, Duh, & Billinghurst, 2008). Sensors recognise the state of the physical world which the AR system needs to deploy; for example, a camera can capture the physical world image and provide information to the AR users. GPS and compass sub-systems can help to identify the location and orientation of the device (and so, indirectly, its user). Sensor information is processed to generate an output on the display (or other output mechanism, such as the audio speaker or vibration). A display will normally show a combination of *physical world* and *real content*. Frequently, the AR system relies on the processor of not only the device but also that of a wirelessly accessed server as well. Hence, it is important to note that the processing is distributed between the device and the server.

2.2.4 Server

This is an element of many AR systems that is relevant to analyse since it is a source of data and processing that is not located on the device. In order to overcome the limitation of the device's storage capability, it is helpful to link the device to a server. This can be

achieve by using a wired or wireless connection (Fenu & Pittarello, 2018). Data transmission between a device and a server is not this research's priority.

2.2.5 Virtual Content (Augmentation)

Without compelling virtual content, Augmented Reality becomes nothing more than a technological novelty (Azuma, 2017; Lee et al., 2018). For the purpose of this research, *virtual content* is defined as computer-generated information that is displayed on an AR device. Returning to the ARshop app (Wang et al., 2017), when users use the app and move around, one or many shop annotations pop up automatically. The position of these bubbles indicates the direction of the real-world shop. When a user clicks on a virtual annotation, more information about a particular shop is presented, such as the opening times (text), photos of the shop or website information. Based on the different human senses (sight, sound, smell, touch, taste), different modalities of virtual content can be categorised, including visual, audio and haptic, with the most common being visual and audio content.

2.2.6 Real Content

Real content in this research refers to the presented information (virtual content) taken directly from the physical world without changing or adding any original objects. Taking the AR Thai-Malay translator app (Pu, Abd Majid, & Idrus, 2017) as an example, the virtually translated words (*virtual content*) are generated based upon the original words when users begin to use this application. Other related information (*real content*) like the menu's colour or images could be captured by the mobile device and observed by users without any intrinsic change. Both virtual content and real content are digital information, but the former involves extra information while the latter retains the intrinsic physical objects (like a camera).

2.2.7 Physical World

Physical world refers to the material world, including geographic location, physical objects and a real-world environment. In an AR

system, it will be more significant to generate the virtual content associated with the physical world, like an AR translator (Pu et al., 2017). The difference between real content and real-world information is that the former is digital information presented by the AR device while the latter should be material-world phenomena which people can touch or see in reality.

Therefore, in summary, the working definition of **Augmented Reality** used throughout this thesis is defined as:

*An array of processes for presenting **virtual content**, deriving information through the **server** from **real content** based on the **physical world** to enrich the **interaction** between **users** and **virtual content** or **devices**.* The relevant definitions in the context of an Augmented Reality system used for the research purposes are shown in **Section 1.3**.

From an AR design perspective, in this research, the critical aspect is the process of understanding the relationship between virtual content, real content and the physical world. AR users are not very concerned about the types of devices that they are using, but could be attracted by different types of virtual content (Craig, 2013). Azuma (2017) states that digital users often express great curiosity about what virtual content can be provided but rarely any interest in the device itself. The AR architecture presented in **Figure 2.3** provides a more explicit basis on which to articulate the AR elements and the intended design principles of AR systems addressed in this research.

2.3 DESIGN PRINCIPLES FOR AUGMENTED REALITY

The existing research suggests that AR could be used to amass an enormous amount of profit in the fields of tourism, education, medicine, etc., as its use becomes increasingly feasible and popular (Chen et al., 2015; Lee et al., 2018; Moro et al., 2017; Yilmaz, 2016). Kourouthanassis et al. (2013) stated the challenge for AR designers:

'How can we associate, organise, and present information into a dynamically changing real world in a way that protects users from cognitive overloads resulting from the massive amount of available information?' However, a review of the literature reveals few guidelines or design principles listed as being in use in the AR area. Although several reports on AR design can be found (Balcisoy, Kallmann, Fua, & Thalmann, 2000; Barrie, Komninos, & Mandrychenko, 2009; Dunleavy, 2014; Huang, Alem, & Livingston, 2012; Karlsson & Li, 2010; Lee et al., 2009; Wu, Hwang, Yang, & Chen, 2018), most of these refer to highly complex settings and infrastructures intended for highly specific purposes. Studies on design or from a user-centred perspective are scare, which motivates and justifies further research with a specific focus on AR system design principles. This section reviews the general design principles related to Human-Computer Interaction (see **Section 2.3.1**) and discusses why this research focuses on design principles rather than other kinds of design guidance (see **Section 2.3.2**). After that, some of the existing AR design principles are introduced (**Section 2.3.3**) and the formats for formalising them are discussed in detail (**Section 2.3.4**).

2.3.1 Design Principles in Human-Computer Interaction

Design principles tend to be more fundamental, widely applicable and enduring than guidelines, which are narrowly focused (Shneiderman, 1992). In Human-Computer Interaction (HCI), design principles start from a broad range (Stone, Jarrett, Woodroffe, & Minocha, 2005) and narrow down to specific divisions, including usability, accessibility, etc. (Benyon, Turner, & Turner, 2005; Nielsen, 2005). Simply speaking, the aim of applying design principles is to help designers to explain and improve their designs (Thimbleby, 1990). Additionally, Rogers et al. (2011) state that design principles are high-level concepts, which are not intended to specify how to design an actual interface. They also define design principles as the ‘generalisable abstractions intended to orient designers towards thinking about different aspects of their designs'.

Design principles represent one of a number of different design resources used in HCI to capture knowledge and expertise in a form that allows its re-use and adoption by others. The rationale is that a guideline prescribing what to do can be used without a designer having to replicate an empirical study to answer a question. How to capture, represent and communicate such knowledge have been recurring issues within HCI. There are questions related to: the level of expression (abstract to concrete); the formatting of the knowledge; access (how easy it is to find the right knowledge); and application (how design principles can be applied with a specific design).

This definition of **design principles** (**Section 1.3**) not only states the level of abstraction and scope of application but also points to the functionality of the design principles. However, a full understanding of the interaction design principles should be put into context with other forms of HCI design recommendations, such as usability principles (usability heuristics), design guidelines and design patterns. The following section will discuss these in detail.

2.3.2 Characteristics of Design Principles over Other Forms

2.3.2.1 A Comparison between Design Principles and Usability principles (heuristics):

Usability principles (Nielsen, 2005) involve inspecting human computer interaction, whereby evaluator aim to identify (both major and minor problems) usability problems (Akçayır & Akçayır, 2017). They are applied both to identify and analyse problems in the design context and focus on the functionality of a system interface with the purpose of improving the end-user experience (Muñoz, Barcelos, & Chalegre, 2011). Quiñones and Rusu (2017) defined the term *'usability principles'* as *'usability heuristics',* which are broad rules of thumb and general checklists.

One major difference between design principles and usability principles is, therefore, the stage during which they are used. Experts normally evaluate functional products or high-fidelity prototypes using usability principles or heuristics at the end of the design process (Camburn et al., 2017). Design principles are intended to be used early in the design process, aiming to consider more design alternatives and make an appropriate design decision. The contents of usability principles are more prescriptive and measurable in nature, while design principles are more descriptive and lack metrics.

2.3.2.2 A Comparison between Design Principles and Design Guidelines

Cowley and Wesson (2005) stated that *'design guidelines are a commonly used and generally accepted aid for physical design*'. They are normally ill-suited to solving the variety of design problems but useful in ensuring consistency within a brand, company or user group (Olga, 2014). In addition, the technical jargon often included in the guidelines excludes potential users from actively participating in the design of a product (Griffiths & Pemberton, 2005). Compared with design principles, design guidelines rarely address large scale issues and usually depend on contextual rules for designers to follow. Design principles are context-free rules and address larger scale issues than guidelines.

2.3.2.3 A Comparison between Design Principles and Design Patterns

Design patterns are solutions to a problem (Leitão, 2013), which is well-proven through being tested by others and safe to follow. Applying design patterns aims to identify the low-level implementation for a specific area. In a comparison between design principles and patterns, the former provides high-level solutions and supports designers to consider different design alternatives. The latter focuses on a low level of solutions with full assessment. The design principles might not be fully examined, but this might work to broaden the designers' design space and make the final design decision more efficiently.

2.3.2.4 Characteristics of Design Principles

This research summarises three main characteristics of design principles as follows:

- They broaden the design space for designers or enhance the communication between them during the early stage of the design process.
- They address large scale issues.
- They formulate high level design solutions or alternatives.

These characteristics are helpful in deriving the appropriate design principles for AR. In the next section, some of the existing design principles for Augmented Reality are reviewed.

2.3.3 Design Principles for Augmented Reality

No.	Name	Description in AR
1.	Affordance	An affordance of AR applications is direct object manipulation in a three dimensional space, so interaction devices which are registered in 3D should be preferred.
2.	Reducing cognitive overhead	The cognitive effort of the user required to interact with an AR system could serve as a distraction.
3.	Low physical effort	The user should be able to accomplish tasks without unnecessary interaction steps or fatigue. Fatigue may be caused by parts of the system (e.g. data helmets) that are heavy or uncomfortable for users to wear. Simulator sickness may also occur in the case of AR.
4.	Learnability	Learning to use the system should be easy. AR applications allow the realisation of novel interaction techniques which need to be learnt before the user can use the system. effectively.
5.	Satisfaction	Subjective user perceptions when interacting with the application are also important for usability, not just objective measurements. Physical and virtual elements should be matched in such a way that the real context is integrated with the AR experience.
6.	Flexibility	User interface with AR applications should be designed to suit different users' preferences and abilities.
7.	Responsiveness	Slow tracking performance can cause lag and problems with the current AR systems, which should improve with the evolution of technology.
8.	Error tolerance	Systems should be robust and error tolerant. Many AR systems are still prone to instability due to the early development stage, and tracking stability remains a major problem. Combining different algorithms (e.g. hybrid tracking) (Rizzo, Kim et al. 2005) and identifying and resolving error scenarios can improve the robustness of the system and reduce user frustration.

Table 2.2: Design Principles of AR, from Dünser et al. (2007)

Dünser et al. (2007) applied eight well-known general HCI principles (see **Table 2.2**) to AR systems in order to explore how these principles may be related to the emerging domain of AR application design.

These eight principles were collected from a large number of general HCI design principles and usability heuristics (Isaacs & Walendowski, 2002; Nielsen & Molich, 1990; Quesenbery, 2003; Shneiderman, 1992; Stone et al., 2005). Dünser et al. (2007) aimed to find out how they can apply these to an AR system. However, it is a matter of debate whether such design principles are transferable to AR systems (Endsley et al., 2017). Several fundamental differences exist between the traditional graphical user interfaces (GUIs) and AR-based ones. Additionally, they only discussed the possibility of applying these traditional principles to the AR context, without any validation. An alternative approach is discussed by Kourouthanassis et al. (2013). Firstly, they provided a formal definition of AR and highlighted its various elements then, secondly, reviewed the existing usability and design principles of AR. Thirdly, they selected several important items which could address the requirements of the interaction design of mobile AR travel applications. Fourthly, they putted these principles practically into an AR application. Finally, they performed a field study involving 33 tourists in order to evaluate whether their design choices, based on the design principles, effectively led to enhanced satisfaction and improved overall user experience. They produced five AR design principles, presented in **Table 2.3**.

One of the advantages of Kourouthanassis et al. (2013)'s principles is that they strengthen the connection between the principles and the AR design issues. For example, they recommended that designers should *'Use the context for providing content'* design principle to '*minimize cognitive and information overload*'. If we compare these two sets of design principles, we find that some of them overlap (Dünser et al., 2007; Kourouthanassis et al., 2013); for example, design principle No. 5 of Kourouthanassis et al. (2013) seems to be relevant to the **Affordance** principle of Dünser et al. (2007) (in **Table 2.3**). In addition,

Feedback principle (No. 4 in **Table 2.3**) is similar to design principle No. 7 in **Table 2.2** – **Responsiveness**.

No.	Design Principles	Definition
1.	Use the context to provide content.	Employ sensor and marker technology to collect contextual information (i.e. user location, user orientation, object in-focus properties, current task) in order to augment real-world objects with contextual information.
2.	Deliver relevant-to-the-task content.	Filter (or personalise) interactive content based on multiple contextual criteria.
3.	Inform about content privacy.	Design the functionality around different privacy spheres (i.e. public versus private content).
4.	Provide feedback about the infrastructure's behaviour.	The application should inform users regarding its current state and also any changes in its state.
5.	Support procedural and semantic memory.	Employ familiar icons and/or interaction metaphors to communicate the application's intended functionality and ensure smooth user interactions.

Table 2.3: Design Principles of AR from Kourouthanassis et al. (2013)

However, these five design principles of AR possess some limitations. It is inconsistent to use some of the words that feature in the definitions; for example, Kourouthanassis et al. (2013) failed to define the different *'contextual criteria'* or *'contextual information'* when they recommended *'Use the context for providing content'* and *'Deliver relevant-to-the-task content'* (**Table 2.3**). Also, there is a lack of discussion about the scope for applying these principles and what type of design issues or challenges can be addressed. In addition, there is no formal validation of the application of these AR design principles, so their application is likely to depend upon the designers' own instincts, experience and rule of thumb. However, what experienced designers may consider easy and obvious may not be so for users or novice designers. Therefore, it seems important to question whether these AR design principles are valid, including: being valued and adopted by designers; being understood by designers; and ensuring a particular quality in any resulting system. Each of these points suggests an alternative view of design principles and different criteria for validity.

2.3.4 The Structure for formalising AR Design Principles

There are various ways in which prior knowledge or expertise has been made available to others and one common technique is to employ a common structure. Hence, in order to formulate a set of AR design principles, it is important to articulate design principles, in a format that supports the communication and consistency of describing knowledge. Several proposed structures for formalising design principles (Blackwell et al., 2001; Green & Blackwell, 1998; Saenz-Otero, 2005) were reviewed.

Green and Blackwell (1998) structured the cognitive dimensions, including: definition, thumbnail illustrations, explanations, cognitive relevance, cost implications, types and examples, workarounds, remedies and trade-offs. Additionally, Blackwell et al. (2001) produced another format for structuring cognitive dimensions, including: the criteria for acceptance, orthogonality, granularity, object of description, effect of manipulation, applicability and origin. These two structures were used to describe the design principles related to cognitive-related technology, which is a relatively mature domain compared with Augmented Reality. Therefore, it is inapplicable to use this structure, including all of the elements, in this research.

Saenz-Otero's (2005) doctoral thesis presents his design principles based on the following structure:

1) '*Principle name'.*
2) *'Descriptive version of the principle'* - presents the principle with the basic characteristics of a design.
3) *'Prescriptive version of the principle'* - presents the principle so that it can be used as a guideline when creating design goals or requirements.
4) *'Basis of the principle'* - relates the principle to the previous literature to explain the basis upon which it was derived.
5) *'Explanation'* - describes the principle in full.

Saenz-Otero (2005) elaborated the five components of design principles format and the definition of the different components. In order to guide AR designers to design more effectively, this thesis aims to describe the AR design principles based upon Saenz-Otero's format (Saenz-Otero, 2005), with some modification. The structure for formalising the principles in this research (see below) consists of 'name', 'basis' and 'explanation', drawn from Saenz-Otero's structure (2005). The term 'definition' is applied based on the concept of the *'Descriptive version of the principle'* to offer a short statement of principles for designers. This research also adds a 'diagrammatic example' component for structuring the first version of the AR design principles, which aims to produce conceptual diagrams for designers. All of these components for structuring the first version principles are re-defined as follows:

- Name: a short, memorable phrase.
- Definition (What is it?): a brief statement of the meaning of the principles.
- Diagrammatic Example: a diagram summarising the main idea in a graphical way.
- Basis: the content is related to the previous literature to explain how the principle was derived
- Explanation (When and where to use it?): a detailed explanation of the AR principle to explain its scope of application.

2.4 OLDER ADULTS

With the growth in the number older mobile phone users, a trend in the use of AR systems among older adults has been observed (Malik et al., 2013). The following section presents the definition used in this research together with the characteristics of older adults.

Czaja et al. (1990) stated:

'Typically, the "aged" are defined as all persons 65 years old and over, with further distinctions made between the "young-old" (65-74 years old) and the "old-old" (85 years old and over)' (p17).

Craik and Salthouse (2011) stated that anyone over the age of 50 is often referred to as "an older adult" and there is clinical evidence to suggest that age-related decline begins at around this time. However, ageing is continuous and does not start suddenly at the age of 50 or 65. The technological familiarity among people aged 50 years old would be very different from that of those aged 80 years old (Czaja, 1990). For the purposes of this research, Czaja et al.'s (1990) view may be followed, which means that, when referring to older adults, **this thesis refers to people aged over 65 years**, even though age in terms of years is only an indicator of a point on the full continuum of age-related characteristics when referring to the older adults. This group generally shares several characteristics in common (Lindley, Harper, & Sellen, 2008). The characteristics of older adults can be referred to as being fundamental with regard to their interaction with technology.

Term	Definition	Examples
Sensation (visual, audition, haptics, smell, taste)	The awareness of simple properties of stimuli such as colour and the activation of sensation cells.	Seeing the colour red, hearing a high-pitched sound.
Perception	The awareness of complex characteristics of phenomena within the environment; the interpretation of the information that results from this.	Recognising a red object as an apple or determining that a sound is an alarm.
Cognition (Working memory Semantic memory, Prospective memory, Procedural memory, Attention, Spatial cognition, Language comprehension)	Processes whereby the brain takes sensory information from the ears, eyes, etc. and transforms, reduces, stores, recovers, and uses it.	Thinking, problem-solving, reasoning, decision-making.
Movement control	Carrying out an action based on perception or cognition; requires the coordination of the muscles to control motion of some kind.	Steering a car; double clicking on a mouse button; taking an object from a shelf.

Table 2.4: Description of Age-related Characteristics (Fisk et al., 2009)

Fisk et al. (2009) review some of the basic characteristics of age-related changes in terms of sensation, perception, cognition and movement control (see **Table 2.4**). In order to inform the design of Augmented Reality for older adults, it is necessary to understand these characteristics.

2.4.1 Sensation and perception

There is a slowing down of functions with age with regard to sensory modalities including vision, hearing, taste, smell and haptics (Kondo & Kochiyama, 2017). Visual and auditory capabilities are the crucial factors when older adults interact with products. People with visual deterioration are more likely to be classified as having symptoms of depression, impaired mobility, decreased walking speed and difficulty completing everyday tasks, such as climbing stairs. The visual changes associated with ageing are associated with dependency with regard to performing the activities of daily living, reduced physical activity, social isolation and mortality (Andrew, Davis, & Johnson, 2017). Several papers (Al-Khalifa & Al-Khalifa, 2012; C. Lee, Su, & Chen, 2012) focus on image processing algorithms for detecting obstacles and object recognition for older adults with visual deterioration. Older adults could apply AR techniques in order to recognise objects based on their features, such as texture, size or sound. Age-related hearing loss is a common sensory change in older adults (Homans et al., 2017). If auditory information is an important aspect of design, age-related changes in hearing must be considered.

2.4.2 Cognition

Suijkerbuijk et al. (2015) described how cognitive decline includes potential memory deficits, difficulties with language, a lowered capacity to concentrate and trouble with maintaining an overview of tasks. Quintana and Favela (2013) agreed that people with memory loss have difficulty recalling recent information and need to be constantly reminded of tasks that need doing. Specifically, Fisk et al. (2009) state that the working memory (e.g. the ability to hold and manipulate

information) declines with age, while the semantic memory (e.g. acquired knowledge) shows a minimal decline with age, even though the ability to access information may be slower. Therefore, it is important to consider age-related changes in cognition when designing AR for older adults and considering how AR could bring potential benefits for them; for example, taking medication often involves multiple tasks with a high level of working memory demands, which need to be integrated into a regimen (e.g. do not take with food, take twice a day, do not eat grapefruit, etc.). Studies show that at least half of older adults fail to take their medication correctly (McLaughlin, Matalenas, & Coleman, 2018). AR augmentation could provide more information than the label on the tablet bottle, but only what is relevant to that individual user. However, choosing AR augmentation needs to be considered with care in order to avoid overloading the users' working memory.

2.4.3 Movement control

Because older adults have reduced muscle strength and tone due to ageing, their deliberate movement is slower. From the design perspective, the impact of age on mobility makes it difficult for older adults to grip and hold various devices (Farage, Miller, Ajayi, & Hutchins, 2012). In addition, balance instability is an important issue related to movement control. Reducing the risk of falls in a variety of older adults is becoming significant. Previous studies on the use of virtual reality and Augmented Reality for the training of balance, improving gait and reducing fall risk in older adults have shown positive effects on walking speed, stride time, step length, etc. (Giladi, 2017; Mirelman et al., 2013; Okuno et al., 2017).

2.5 DESIGNING AR FOR OLDER ADULTS

Older adults are known as 'digital immigrants' (Malik et al., 2013), which means that '*they are born before the technological age*'. Specifically, Turner et al. (2007) emphasised several factors that play

an important role for older adults who interact with technology, specifically personal computers and the internet. These factors are anxiety, alienation, ageing issues, being too busy to learn and the need for the new tools. In addition, Morris et al. (2007) reported that 60% of older adults were uninterested in using the Internet, and 40% of them were 'feeling too old' to access the internet. On the other hand, Mitzner et al. (2010) stated that older adults underestimate their computer knowledge and should be more confident. People are struggling to use technology because some of the technological products are not centrally designed for them. To minimise the problems that older people encounter when using such products, it is necessary to apply a set of systematic steps to the design process.

2.5.1 User-centred Design

User-centred design (UCD) is a broad term that refers to product development in which the users and their representatives contribute to the design of a product (Hilton, 2008). Vredenburg et al. (2002) define UCD as '*the active involvement of users for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach'*. Fisk et al. (2009) identify four key principles of UCD, including: early focus on the users, empirical measurement, iterative design and final evaluation. These principles are accepted as the basis for the interaction design lifecycle model (Rogers et al., 2011), which consists of four areas: establishing requirements, designing alternatives, prototyping and evaluating.

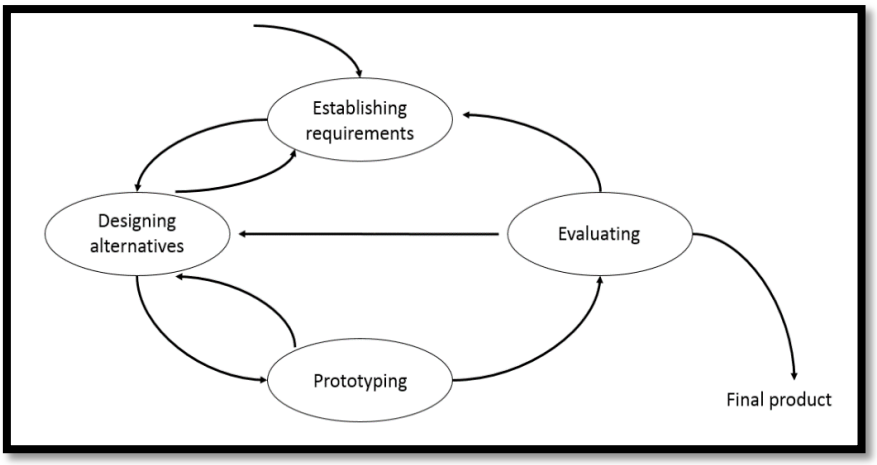


Figure 2.4: A simple interaction design lifecycle model (Rogers et al., 2011)

2.5.2 Establishing Requirements

This activity is fundamental for a user-centred process and very important in Human-Computer Interaction (HCI) (Rogers et al., 2011). Requirements evolve and develop as the stakeholders interact with the design and see what is possible and how certain facilities can help the users. Before Williams et al. (2017) developed an AR tourism app, they established the potential users' requirements through synthesising a domain analysis, tourist observation and semi-structured interviews. Returning to this thesis, the main constraints are why older adults need AR and how AR might benefit them. Therefore, it is important to understand how to include older adults' needs and user requirements when they use AR.

It is not a simple task to ask people 'What do you need?', because they are often unaware of what is possible (Rogers et al., 2011). In addition, people may misrepresent their needs. If a product is a new invention, users are unaware of how it might help them. The system developers should imagine who might wish to use it and what they might wish to do with it (Rogers et al., 2011). User needs refer to the basic wants and experiences of users in order to improve the likelihood of them achieving their goals (Kujala, 2002). Therefore, user needs are affected by the context of use, that includes the users' wants, goals and the experiences during which the product is used. They also form the basis

for the product development and can be seen as the first stage in the requirements gathering cycle.

User requirements are defined as the formal descriptions that state any function, constraint or other property that is needed to satisfy the user needs (Kujala, 2002). These include information about the particular user needs to be satisfied by the future product. User requirements are distinct from technical requirements; the former describes the feature/attributes from the users' perspective while the latter describes how the product is implemented (Courage & Baxter, 2005).

The Ageing Better Project in Sheffield, organised by SYHA (South Yorkshire Housing Association) in 2014, aimed to analyse older adults' requirements and improve their lives in Sheffield. SYHA recruited participants over the age of 50 who felt very lonely and socially isolated. Some of the audio clips have been published online (Audioboom, 2014) and refer to a variety of user issues and requirements identified by over 100 older participants. This research summarised (see **Table 2.5**) the older adults' requirements and classified them into different categories: transport, technology, communication, pet care, home activities, etc.

Category	Content
Transport	Sharing traffic information; transport to community areas where people could participate in quizzes and general chat; having more scooter lanes; route planners; lunch clubs with in-built transport being re-established in the local areas so that people could meet and chat.
Technology	Using assistive software to read documents sent by the Tenants' Association; social media, Skype and Face Time; shopping online without having to leave the house.
Home activities	More assistance with reading and dealing with post; more community members who could help, if they were more aware of the needs at home; others offering help rather than having to ask for it; being reactive is easier than being proactive. One-to-one counselling but also group support; Develop interests.
Communication	Provide older adults with low-cost, free places so that they can meet up for a chat, a meal, and activities. Having places where older adults can look after their pets.

Table 2.5: A summary of older adults' requirements based on the Ageing Better Workshop as part of the the SYHA Project (Audioboom, 2014)

Taking the transport-related requirements of older adults as an example, the current transportation system may present barriers to them and limit their mobility. It is important to provide mobility support and enable older adults to drive. The increased incidence of illness and disability among them may necessitate accommodation that supports their everyday activities. Technological solutions might not meet all of these requirements, but AR offers several possibilities which might benefit and assist older adults. Before reviewing the existing AR applications designed for older adults, some of the related design challenges will be clarified.

2.5.3 Designing alternatives

Traditionally, this activity produces ideas about meeting the requirements, which can be divided into two sub-activities: conceptual design and physical design. The former involves an abstraction including what the product could provide and what users can do. The latter considers the detail of the product, including the colours, sounds, images to use, etc. (Rogers et al., 2011). However, when designers are ready to translate the conceptual design into a physical one, design principles or guidelines are available to enhance the effectiveness and usability of the system (Nielsen, 2008; Wickens, 2004). Going back to this research, the purpose of developing AR design principles is to address or solve usability issues, and support designers in designing high-quality AR alternatives.

2.5.4 Prototyping

The prototypes provide concrete examples to strengthen the participant communication (Rosson & Carroll, 2009) and awareness (Medin & Schaffer, 1978; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976).

Prototypes answer questions and support designers when choosing between alternatives (Rogers et al., 2011). In order to capture and express Augmented Reality technology fully in this research, producing AR prototypes makes it easier for the older adults to judge and invoke their experience. Users have no choice about interacting if they only

have one prototype, which also restricts their thinking. In order to identify a sufficient number of design-related requirements, this research needs to ascertain the appropriate level of prototyping fidelity. Low-fidelity (e.g. paper-based or Wizard of Oz) prototypes are useful because they tend to be simple, cheap and quick to produce (Rogers et al., 2011). However, it is difficult to demonstrate the different features and functions that comprise the application in more detail (Fenu & Pittarello, 2018). A high-fidelity prototype looks far more like the final thing, and can provide the full interactive experience. Additionally, it is very helpful during usability testing and experience evaluation, as it supports interaction and functionality. Nevertheless, despite the clear advantages of developing a high-fidelity prototype, there are also important drawbacks associated with this activity; for example, the user's expectations are raised by higher level prototypes, which require more effort and knowledge to develop (de Sá & Churchill, 2012). A mixed-fidelity prototype provides the best trade-off, as it both helps the stakeholders to understand the design concepts and also makes it possible to detect any usability and design issues. Ventä-Olkkonen et al. (2014) defined the meaning of a mixed-fidelity prototype according to various categories, where the degree of visual and aesthetic fidelity was high but the interactivity remained low. In comparison with high-level fidelity, a mixed-fidelity prototype can offer similar realistic experiences during the early design stage. **Chapter 1** develops two initial AR prototypes with mixed-fidelity.

2.5.5 Evaluation

Traditionally, evaluation is the process of determining the usability and acceptability of a product or design, which is measured in terms of various criteria (Rogers et al., 2011). There are different methods used in evaluation activity. Fenu and Pittarello (2018) evaluated the feasibility of using AR in a literary museum through two pilot studies involving a semi-structured questionnaire (Rogers et al., 2011). Gutiérrez et al. (2017) measured the participants' perceptions of usefulness and ease of use of different health AR assistant systems

using a structured usability questionnaire. Returning to this research, the evaluation of the AR prototypes for older adults aims to identify the AR usability issues, which could be addressed or solved by my AR design principles.

2.5.6 ITERATIVE DEVELOPMENT PROCESS

The development process for AR applications for older adults is based on the interaction design lifecycle model, shown in **Figure 2.4** (Rogers et al., 2011). However, this model aims to develop a product iteratively by understanding the requirements, designing alternatives, prototyping and evaluating. AR applications are developed in this research to assess and develop the AR design principles. The iterative development process of AR applications starts with the initial design principles, formalised in **0**, and ends with the final version of AR design principles, outlined in **Chapter 6**.

2.6 EXISTING AR APPLICATIONS FOR OLDER ADULTS

Despite the fact that very few studies discuss AR applications which address older adults' requirements, 17 publications were found to investigate both AR application design and older adults (**Table 2.6**). These papers can be classified into four main domains: transportation, home activities, entertainment and rehabilitation training. The criteria for this classification were based on two human factors books (Czaja, 1990; Fisk et al., 2009) for older adults. The following definition of each domain was adopted in this research:

Domain	Reference	AR Application
Transportation	Kim and Dey (2009)	AR navigation system
	Fu et al. (2013)	AR indicator
	Rusch et al. (2014)	AR cues I
	Schall et al.'s paper (2013)	AR cues II
	Peleg-Adler, Lanir et al. (2018)	AR Route in public transportation
Home activities	Lera et al. (2014).	AR pillbox
	Wood and Mcrindle (2012)	AR discovery and information system
	Quintana and Favela (2013)	AR annotations
	Saracchini (2014)	AR pico-projector
Rehabilitation Training	Mirelman et al. (2013)	Augmented treadmill
	Yoo and Lee (2013)	AR-based gait training programme
	Schega and Wagenaar (2011)	AR movement guide
	Chang et al. (2017)	AR Perturbation System
Entertainment	McCallum and Boletsis (2013)	3D Angry Birds-like game
	Lin and Chang (2013)	AR table card game
	Fenu and Pittarello (2018)	AR Svevo Tour
	Simão and Bernardino (2017)	AR project game

Table 2.6: A summary of the AR domain for older adults

- Transportation: a means of conveyance, whether walking, driving or using public transport such as buses, tubes, trains or aeroplanes (Fisk et al., 2009).
- Home activities: enabling older adults to maintain independence in their home environment (Fisk et al., 2009).
- Leisure activities: engaging older adults in the physical enjoyment of individual pursuits like sports (Czaja, 1990).
- Rehabilitation Training: a type of therapy that aims to maximise the restoration of an injured person's functional capabilities (Czaja, 1990).
- Entertainment: a form of activity that attracts the attention and interest or gives pleasure and delight (Czaja, 1990; Fisk et al., 2009).

Kim and Dey (2009) developed a prototype using a AR navigation display system overlaid onto a vehicle windscreen for older drivers.

Schall et al. (2013) generated broken yellow lines that comprised a gradually elongating rhombus onto potential roadside hazards to decrease the crash risk caused by cognitive impairment. Fu et al.'s (2013) AR system overlapped the display of time-to-collision with the lead vehicle to improve safety for older drivers. Rusch et al. (2014) created the AR cue system, which showed the virtual no-turn-left sign onto the potential roadside hazards to assist older drivers with gap estimation for left-turns (this research is based on America that drives on the right. However, UK is on the left and left turns are easier than right turns). Peleg-Adler et al. (2018) developed an AR application that added an AR layer to a wall-hung map that included bus time information.

Within the home activities category, Lera et al. (2014) developed a pillbox system by adding virtual graphics to the image captured by a camera. Wood and Mcrindle (2012) and Quintana and Favela (2013) tried to assist people with memory loss and/or who were suffering from Alzheimer's disease (AD). The AR reminder could detect the kettle using an QR code and display a contextual menu with instructions on how to make a hot drink. Saracchini (2014) designed the AR assistive living system and evaluated its impact on the social interaction of older adults as well as its acceptance and usability.

AR for rehabilitation training (Mirelman et al., 2013; Schega, Hamacher, & Wagenaar, 2011; Yoo, Chung, & Lee, 2013) suggested the feasibility and suitability of AR-based training. The AR Perturbation System, developed by Chang, Yang et al. (2017), played an important role in restoring the postural stability of older adults.

In the entertainment domain, McCallum and Boletsis (McCallum & Boletsis, 2013) only proposed a theoretical justification for creating games while Lin et al. (2013) developed an AR-based table card game for older adults. Fenu and Pittarello (2018) focused on cultural heritage, augmented the space of a small museum and explored the feasibility of using AR with both young and older adults. The AR project game

developed by Simão and Bernardino (2017) could be used by older adults to promote exercise.

In addition, a further three studies (Kurz et al., 2014; Malik et al., 2013; Papegaaij, Morang, & Steenbrink, 2017) mainly focus upon reviewing AR's application rather than developing a specific AR application for older adults. Kurz et al. (2014) discussed the negative feedback related to older adults using handheld AR applications because they were required to hold up the device. Malik et al. (2013) reviewed the design issues for older adults in term of mobile design, cognitive decline, motivational issues and physical impairment. Then, they reviewed related AR applications, like transport systems, voice augmentation and AR radio. Papegaaij et al. (2017) summarised the aspects and efficacy of using virtual and Augmented Reality for balance and gait training.

According to the review of AR applications for older adults, there are several potential ways to use Augmented Reality to address older adults' issues. However, designing AR application for this group is still in the exploratory stage. Firstly, the number of AR applications designed for older adults is limited. Secondly, most of the AR applications remain in the early design process (e.g. in the form of a conceptual design or low-fidelity prototype). Thirdly, there is no AR design guideline or principles specifically focused on this group.

2.7 CHAPTER SUMMARY

In conclusion, this chapter reviewed the related work in terms of Augmented Reality, design principles, older adults, the AR design process and existing AR applications, and identifies the reasons for conducting research in this area.

First of all, after reviewing various AR definitions and concepts, this chapter explores a conceptual AR architecture consisting of seven key elements, including: **User**, **Interaction**, **Device**, **Server, Virtual**

Content, Real Content and **Physical World**, by reviewing the AR-related literature and examples. The meaning of AR and all of these associated elements have been defined.

Secondly, in order to improve the design and development of AR systems, the term **Design Principle** was selected and defined. The characteristics of design principles include: broadening the design space of designers, enhancing the communication in the early design process, addressing large scale issues and formulating high level design solutions or alternatives by comparing the different forms of design recommendations. This chapter also reviewed two representative design principles papers offered by Dünser et al. (2007) and Kourouthanassis et al. (2013). Generally speaking, there are three limitations to the current AR design principles:

- Some of the terms for describing the design principles are inconsistent.
- Most of the AR design principles are based upon traditional HCI principles without considering the fundamental differences between graphical user interfaces (GUIs) and AR-based interfaces.
- These principles have not been formally validated by any designers or developers and have not been applied to a design in practice.

Thirdly, this chapter clarifies the meaning of older adults together with their characteristics, including sensation, perception, cognition and movement control. It is fundamental to identify the potential of using AR to benefit older adults. Additionally, appropriate AR must be selected in order to avoid overloading the working memory of the users.

Fourthly, this chapter reviews the user-centred design development process, which involves four steps: establishing requirements, designing alternatives, prototyping and evaluating. However, the AR applications are developed in this research in order to assess and develop AR design principles rather than create a final AR product.

Fifthly, relevant publications are reviewed that discuss existing AR applications for older adults. These AR applications remain within the early stage of the design process (e.g. taking the form of a conceptual design or low-fidelity prototype). The number of AR applications designed for older adults remains limited and no AR design principles specially focusing on design for this group exist.

Therefore, there are two initial considerations for this research:

Firstly, it is possible to establish new design principles for Augmented Reality.

Secondly, it is possible to apply these principles to support AR design for older adults.

In the next chapter, the research methods will be discussed in order to establish a set of AR design principles.

CHAPTER 3 - RESEARCH METHODOLOGY

Based on the research question and aims presented in **Section 1.2**, this chapter discusses several methods and combinations of methods, which aim to establish a set of design principles for Augmented Reality (AR) especially focusing on older adults. The structure of this chapter is based on the '*Research Onion'* (**Figure 0.1**) (Saunders, 2011), which provides an effective process for designing a research methodology. The methodology in this research mainly concentrates on six different layers drawn from the '*research onion'*: philosophical paradigms, research approaches, research strategies, research choices, time horizons, data collection techniques and data analysis procedures. This chapter discusses these concepts, presents the rationale for choosing a particular method or approach and generally identifies the most appropriate way to apply these methods in this research.

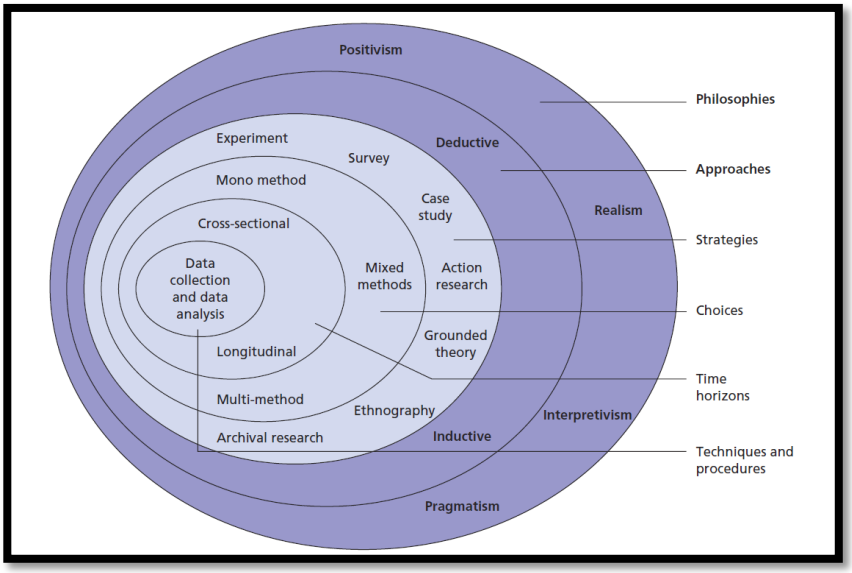


Figure 0.1：Research Onion Diagram, Source: (Saunders, 2011)

3.1 RESEARCH PHILOSOPHICAL PARADIGM

This research's philosophical paradigm (the first layer of the *'Research Onion'* in **Figure 0.1**) establishes the '*set of beliefs and feelings about*

the world and how it should be understood and studied' (Guba, 1990). This subsequently helps to identify the sort of methods required to tackle the research question. There are four widely-accepted research paradigms, which are Positivism, Interpretivism, Realism and Pragmatism. Based on the main research question of this thesis, these are discussed below.

3.1.1 Positivism

Positivism believes that the world is external and assumes that a single, objective reality exists independently of what people perceive (Hudson & Ozanne, 1988). Hence, positivism treats truth and knowledge objectively and universally. This paradigm emphasises approaches to research which presume that the analysed phenomena need to identify objective truths about the world. This paradigm therefore tends to employ research methods that focus on theoretical analysis, quantitative analysis, surveys or experiments. The emphasis is upon establishing singular, unchanging truths.

3.1.2 Interpretivism

Interpretivism emphasises human consciousness, and thus knowledge inevitably depends on the social status of the person (Creswell, 2013). This stresses the subjectivist approaches, which do not presuppose universal truths. Hence, this philosophy gives more import to oriented methodology, such as interviews or observation, which relies upon the subjective relationship between researchers and subjects. Interpretivism does not pre-identify dependent and independent variables but concentrates on the full complexity of human senses. The purpose of this paradigm is to explain the subjective reasons and meanings underlying social action (Kaplan & Maxwell, 2005). The key words related to the interpretative methodologies are participation, collaboration and engagement (Henning, Van Rensburg, & Smit, 2004). Interpretivists should not be separated from their subjects, but act as participant observers who are engaged in the study's activities and recognise the meaning of actions within specific social contexts.

3.1.3 Realism

Realism is similar to positivism and rests on the idea of independence between reality and the human mind (Saunders, 2011). Realism can be divided into two groups: direct realism and critical realism. Direct realism portrays the world through personal human senses, while critical realism believes that humans experience the sensations and images of the real world, which can be deceptive (Novikov & Novikov, 2013).

3.1.4 Pragmatism

Pragmatism argues that both Interpretivism and Positivism are valid research approaches (Saunders, 2011). Pragmatism allows researchers to *'modify their philosophical assumptions over time and move to a new position on the continuum'* (Collis & Hussey, 2013). According to Pragmatism, the research question is the most important determinant of the research philosophy. This is particularly relevant where the research question does not suggest clearly that either a positivist or interpretive philosophy should be adopted as the basis for an inquiry (Ihuah & Eaton, 2013). Pragmatism provides a justification and rationale for combining methods and knowledge to provide tentative answers to research questions (Johnson, Onwuegbuzie, & Turner, 2007).

3.1.5 Choice of Philosophical Paradigm

Returning to the research question (see **Section 1.2**) and two initial assumptions (see **Section 2.7**) of this thesis, the pragmatist paradigm might be an appropriate philosophical paradigm for finding practical solutions for this research. Positivism lacks an in-depth understanding of a context. Researchers cannot capture the full richness of the individuals and environments, which are vital factors when conducting research (Thomas, 2010). Applying the interpretivist paradigm alone would inevitably ignore the significance of the research's objective meaning. The research question of this thesis is related to establishing AR design principles for older adults, and does not suggest

unambiguously that either a positivist or interpretivist philosophy should be adopted. Therefore, it is perfectly possible to work with both philosophies, as suggested by Pragmatism.

More specifically, there are three main advantages associated with adopting a pragmatist paradigm for this research:

1) It provides a more flexible and adaptable way to choose between different research approaches (see **Section 3.2**), depending on the research question.
2) It makes it possible to adopt both objective and subjective perspectives to understand the stakeholder feedback in the process of the data collection and data analysis.
3) It iteratively generates new, effective and practical AR design principles for older adults.

3.2 RESEARCH APPROACH

The next layer in the '*Research Onion*' (see **Figure 0.1**) is the research approach, which includes inductive and deductive research (Saunders, 2011).

3.2.1 Inductive Approach

The inductive approach begins with detailed observations of the world, which then moves towards more abstract generalisations and ideas (Neuman, 2002). Mackay et al. (1997) describe the cycle of inductive research through a series of stages, as depicted in **Figure 0.2**:

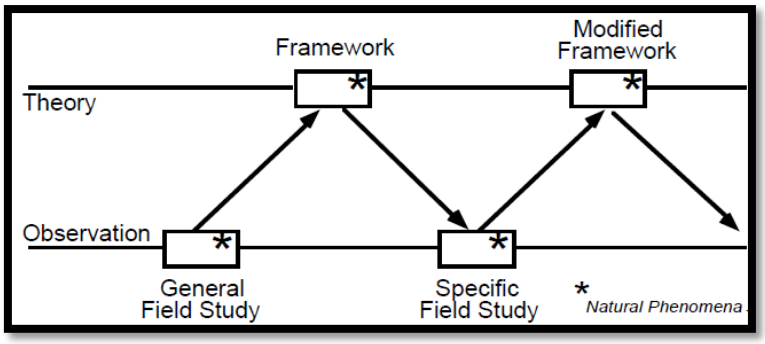


Figure 0.2: Inductive Approach Model, Source: (Mackay & Fayard, 1997)

The stages for conducting inductive research are:

1) Phenomena in the real world are observed without a preconceived target.
2) Attempts are made to describe the phenomenon in a framework or model.
3) Based on the emerging questions, further specific observations are made to evaluate the validity of the original framework.
4) Based on the results, a modified framework is developed.

The inductive approach normally starts with data collection and moves towards building a theory. However, the starting point of this research is the general existing theory on AR design principles, which is irrelevant with the inductive approach.

3.2.2 Deductive Approach

Deduction is the dominant research approach in the natural sciences, which involves the development of a theory that is subjected to rigorous testing (Saunders, 2011). Mackay et al. (Mackay & Fayard, 1997) also describe the cycle of deductive research through a series of stages, as depicted in **Figure 0.3**:

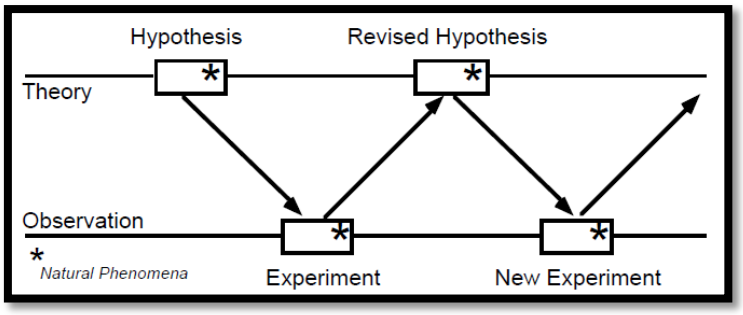


Figure 0.3: Deductive Approach Model, Source: (Mackay & Fayard, 1997)

These stages (**Figure 0.3**) are described as follows:

1) A specific prediction about the behaviour of a phenomenon is generated in the form of a hypothesis.
2) Experiments are conducted, usually in laboratories, to test the hypothesis by manipulating a set of independent variables, whilst eliminating or systematically varying other factors under control conditions.
3) Measurements are taken and the results analysed in order to revise the hypothesis.
4) More precise and controlled experiments are conducted to test the revised hypothesis.

It can be seen that the deductive and inductive approaches follow similar overall patterns but from different starting points and with different views of the conclusions (building a theory or testing a theory).

3.2.3 Choice of Research Approach

A deductive approach is adopted in this research. While it is possible to utilise the alternative research approach (inductive) for the Pragmatist philosophy, this research does not start with data collection. This research moves from existing theory, formulating the research question, to collecting the data and then rejecting or confirming the research question. Specifically, there are two reasons for choosing a deductive approach in this research.

- The starting point of this research is the general existing theory of AR design principles, which follows the beginning process of deduction.
- Design principles are deduced rather than induced and data should be collected to determine whether the hypothesis is confirmed or rejected, which matches the rationale of the deductive approach.

Having outlined the overall research approach, the following sections will describe the strategies, techniques and procedures used to facilitate this approach.

3.3 RESEARCH STRATEGY

The third layer of the '*Research Onion*' (**Figure 0.1**) - research strategy - refers to the logical or master plan regarding how the research can be conducted and how all of the elements of the research can work together to address the research questions (Saunders, 2011). This strategy can include a number of different methods, such as experimental research, action research, case study, grounded theory, surveys, or a systematic literature review (Saunders, 2011).

3.3.1 The Existing Research Strategy for Establishing AR Design Principles

There is no evidence of a formal research strategy which has been used to establish AR design principles for older adults (or even without a focus on a specific group). Dünser et al. (2007) merely described the traditional design principles of graphical user interfaces (GUIs) in the AR context, without considering the methods for establishing them. Mackay et al. (2013) used an unsystematic, informal methodology to investigate AR design principles. They reviewed seven AR-related design papers and highlighted five important design principles, before assessing whether these principles were mentioned in relation to the eight existing AR applications.

However, there is some related literature which discusses the experience of establishing the usability heuristics of AR. Ko et al. (2013) divided the research strategy of establishing AR usability heuristics into two parts: development and validation. In the development stage, they collected 61 AR usability heuristics directly, selected 22 of these during an expert meeting and classified them into five different categories. In the validation stage, they first conducted the usability heuristics evaluation (Wickens, 2004) of three different AR applications with the classified usability heuristics in order to identify the usability issues, the seriousness of these issues, the reasons for these issues, what the related usability heuristics are and how to improve the current AR applications. Based on the experts' feedback, they re-designed one of the AR applications and conducted a usability test using questionnaires to explore the significant difference in usability principles between the different AR applications. Kalalahti (2015) established a series of usability principles for AR using Ruru et al. (2011)'s research strategy, which includes **six** steps: Exploratory, Descriptive, Correlational, Explicative, Experimental validation and Refinement (see **Table 0.1**).

Stage	Description
Step 1: Exploratory	Compiling a bibliography regarding a specific topic of study, including general or related features (if any).
Step 2: Descriptive	Highlighting the most relevant characteristics of the previously collected information, in order to formalise the main concepts associated with the topic of study.
Step 3: Correlational	Identifying the characteristics that heuristics for specific applications should possess, taking into account the traditional heuristics and analysis of cases of study.
Step 4: Explicative	Formally specifying the set of heuristics, using a standard template.
Step 5: Experimental validation	Checking new heuristics against traditional (Nielsen's) heuristics through experiments.
Step 6: Refinement	Refining the heuristics in light of the feedback obtained in the validation stage.

Table 0.1: Research Strategy for establishing Usability Principles, Source: (Ruru et al. 2011)

Both design principles and usability principles (heuristics) are statements that support designers and developers to make more effective design decisions. They can also be applied to identify design issues or usability issues, moving from the general to the specific. Although design principles are broader statements than usability principles (on the difference between design principles and usability principles, see **Section 2.3.2.1**), there are two main reasons for applying Ruru et al. (2011)'s work as the fundamental strategy in this research:

- Ruru et al.'s research strategy provides a set of systematic steps for conducting organised work.
- Ruru et al.'s research strategy makes a significant contribution that is used in practice in different areas.

Jiménez et al. (2012) conduced an experiment involving researchers who had employed Ruru et al. (2011a)'s research strategy. Some of the researchers stated that this research strategy contained relatively complete, step-by-step advice on how to document the usability principles. In addition, there has been little discussion of the research strategy for exploring AR design principles in the literature, but Ruru et al. (2011) developed a similar, closely-connected guide for establishing usability principles for specific kinds of applications, including Grid Computing applications (Rusu et al., 2011), interactive digital television (Collazos, Rusu, Arciniegas, & Roncagliolo, 2009), touchscreen-based mobile devices (Carvajal, 2012) and a virtual environment (Muñoz et al., 2011). Compared with these other four applications, Jiménez et al. (2012) stated that researchers who employed Ruru et al. (2011)'s research strategy to establish principles for the virtual environment found it easier to use.

However, it is inappropriate to apply Ruru et al. (2011)'s research strategy fully in order to establish AR design principles for older adults in this research. Firstly, Ruru et al. (2011)'s research strategy did not mention how to assess new principles for a specific group of people

(e.g. older adults). Secondly, the Experimental Validation Stage (Step 5) simply required comparing new principles with other, existing principles through experiments, without considering any empirical methods, which aim to observe and record the reactions and perceptions of the participants (Rogers et al., 2011). Additionally, the strategy is not iterative in nature. Therefore, returning to this thesis, this research strategy modified Ruru et al. (2011)'s research strategy and added some ideas to the interaction design lifecycle model (Rogers et al., 2011) (**Section 2.5**). Steps one and two are applied in full. Step 3 in this research used the term "Analytical stage", which is a similar but more general term than Ruru et al. (2011)'s third step – the Correlational Stage. In terms of step 4, the Formative stage is used to formalise the first version of AR design principles as the fundamental work. Experimental Validation (step five) is divided into two empirical stages in this research and the Refinement stage is separated into three stage in order to establish iteratively the AR design principles (**Figure 0.4**). The following section describes these steps and clarifies the purpose of each stage.

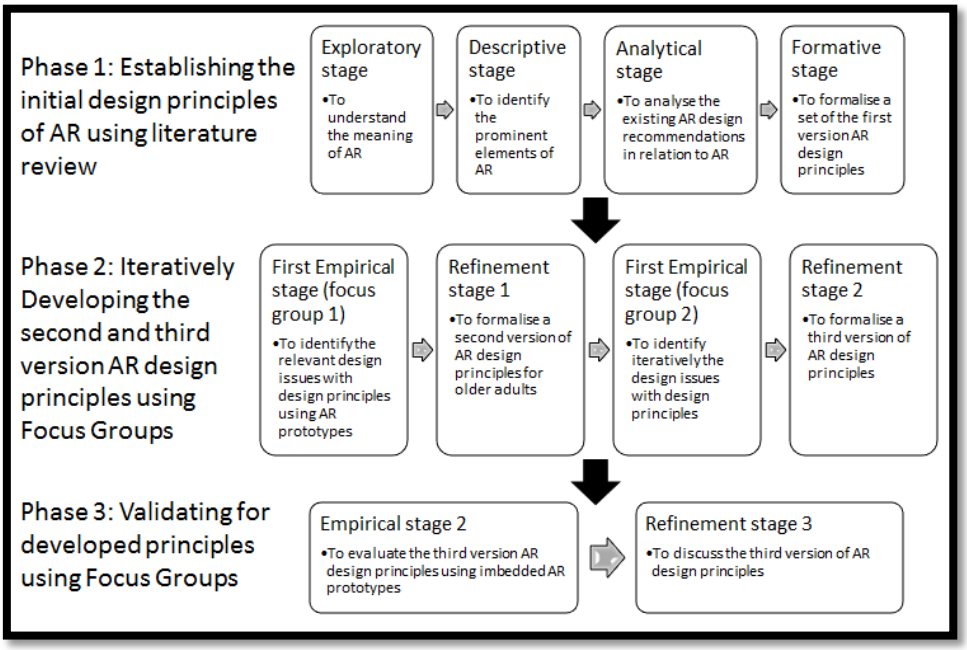


Figure 0.4: This research's strategy

3.3.2 Stages of the Research Strategy for this research

The **Exploratory** stage (see **Section 2.2**) is the first stage in conducting this research, which involves collecting existing literature related to the specific topics of the research and exploring the general characteristics of AR. In this stage, it is useful to find out *'what is happening; to seek new insights; to ask questions and to assess phenomena in a new light'* (Saunders, 2011). This stage is also an *'iterative and flexible one that seeks new information and ideas'* (Dawson, 2005). The Exploratory stage is best suited when there is little knowledge about a particular research area (Clark, Huddleston-Casas, Churchill, Green, & Garrett, 2008). Specifically, this stage reviews the different AR-related literature and examples, and explores AR architecture in order to understand the meaning of AR and explain the relationship between each of its elements. Therefore, the Exploratory stage provides a more flexible and adaptable way to articulate AR elements and their interrelationships, and to clarify the AR-related terminology used in this research (see **Section 2.2**).

In the **Descriptive** stage, the most relevant features of AR are identified and described by identifying the prominent elements of the pre-established architecture that differentiate AR from more traditional technology (**Section 0**). This stage aims to differentiate the most important components of AR from other technologies.

Next, the **Analytical** stage of this research analyses the existing AR design recommendations in relation to different AR features (**Section 0**). Because of the fundamental differences between traditional Graphical User Interfaces (GUIs) and AR-based interfaces (Dünser et al., 2007), it is important to identify existing AR design recommendations as the basic for formalising the first version of the design principles.

The **Formative** stage plans to develop a set of the first version AR design principles based on the existing AR literature, AR features and design recommendations for AR (see **Section 4.3**). This stage aims to

formalise the first version principles as the fundamental work for this research. However, these principles are unconnected to older adults and their design issues.

First Empirical stage (focus group 1)

The principles developed in the previous steps represent the outcome of an analytical assessment of the existing AR-related literature, architecture, features, design recommendations and examples. As such, they require empirical study (Rogers et al., 2011), which means, in this research, involving the stakeholders in establishing the requirements of older adults (**Section 5.1**), designing AR alternatives (**Section 5.2**), prototyping AR (**Section 5.3**), and assessing the first version of the AR principles (on the first focus group, see **Chapter 5**). The aim of this research stage is formatively to assess these principles by identifying the AR-related design issues using prototypes. The reactions and performance of the stakeholders using AR prototypes and principles are observed and measured.

For the purposes of the empirical stage, it is also important to distinguish between two major research designs: the between-subject design and within-subject design. The between-subject design could be interpreted as an 'unrelated' design that involves examining the differences between various participants. Within-subject design is a sort of 'related' design which happens in the same group of participants with regard to the variability of a particular value (Howitt & Cramer, 2007; Lazar, Feng, & Hochheiser, 2010).

In this research, there were two reasons for choosing a within-subject design:

Firstly, in order to assess the design principles, the participants must be experienced designers who are familiar with technology and/or user-centred design. If a between-subject design were to be used by dividing the participants into groups, it would be difficult to guarantee

the same level of familiarity with technology-design between both groups.

Secondly, from a practical point of view, a within-subjects research design effectively provides the required feedback from a smaller sample size (Wickens, 2004). Researchers need to recruit more participants when implementing a between-subject strategy. Additionally, as argued above, design principles are to be discussed with the AR community and so the participants need have some related experience. Realistically, it would be difficult to recruit a high number of AR designers to participate in this stage.

The particular data collection techniques and data analysis procedures employed in the first part of the empirical stage were discussed in terms of the **qualitative focus group** (see **Section 3.6.2** and **Section 3.7.1**).

Refinement stage 1

Based on the feedback obtained from the previous stage, this stage discusses the reasons for refining the first version of the design principles and identifies the second version of the AR design principles. The aim of this stage is to develop a new version of AR principles, which take into account design for older adults (for more details, see **Section 6.5**).

First Empirical stage (focus group 2)

In order to establish iteratively the third version of AR design principles for older adults, this stage assesses the second version of the AR design principles in comparison with certain traditional design principles, taking into account the aim of designing for older adults (see **Chapter 5**). After comparing the relevance of design-related issues for older adults with regard to two sets of principles, this research was able to identify the benefits of the second version of AR design principles. A **mixed-methods focus group** (on the rationale for choosing this, see **Section 3.6.4** and **Section 3.7.2**) was selected in order to collect

feedback in order to produce, share and shape the participants' own ideas with different purposes. A statistical test was employed to analysis the quantitative data.

Refinement stage 2

After two cycles of formalisation (empirical assessment first part - refinement - empirical assessment second part), the set of second version AR design principles is refined in this stage. After collecting feedback on the previous stage (**second part of the Empirical stage**), the third version of the AR design principles is discussed in **Chapter 6**.

Second Empirical Stage

In order to apply the third version of AR design principles for older adults in practice in order to evaluate them, the strategy for this research in the second empirical stage, based on the iterative HCI design process in order to evaluate the AR prototypes for older adults, applied the third version of principles. Because this stage focuses on assessing the satisfaction and preferences regarding AR prototypes among older adults, the participants recruited in this stage need to be recruited as target users – older adults (for more details, see **Chapter 7**). A **qualitative focus group** (on the rationale for choosing this, see **Section 3.6.2** below) was selected to collect older adults' feedback.

Refinement stage 3

Based on the reflection on the participants' feedback in the second empirical stage, the third version of the AR design principles was evaluated and refined in this stage (for further details, see **Chapter 7**).

3.4 RESEARCH CHOICE

Saunders (2011) refers to the way in which researchers choose to combine quantitative and qualitative data collection techniques and data analysis procedures as their *'research choice'*. This section

discusses the fourth layer of the *'Research Onion'* model (**Figure 0.1**) and discusses three different ways of combining quantitative and qualitative techniques and procedures, including the **Mono-method choice**, **Multi-method choice** and **Mixed-methods choice** (see **Table 0.2**).

The existing literature on HCI suggests that mixed methods is a suitable approach for developing design principles. Challis' research (2000) created a set of design principles for the integration of non-visual interaction into an HCI interface. He did not follow any particular fundamental theory when developing these design principles, but reviewed the various existing guidelines and principles related to non-visual interaction, then assessed how the non-visual information could be embedded into the human-computer interface. He conducted four different experiments (quantitative), observed the subjects' behaviour (qualitative), and then evaluated design principles using mixed methods. Chattratichart (2003) also applied mixed methods to investigate usability issues relating to visual programming languages (VPLs) in order to suggest a set of design principles that emphasised usability. Empirical studies were undertaken employing both qualitative and quantitative methods.

No.	Research Choice	Data Collection Technique (s)	Data Analysis Procedure (s)
1.	Mono-method choice	A single qualitative technique	Qualitative procedure
2.		A single quantitative technique	Quantitative procedure
3.	Multi-method choice	More than one qualitative technique	Qualitative procedure
4.		More than one quantitative technique	Quantitative procedure
5.	Mixed-methods choice	Combining qualitative technique/s with quantitative technique/s	Qualitatively analysing qualitative data and quantitatively analysing quantitative data
6.		Combining qualitative technique/s with quantitative technique/s	Quantitatively analysing qualitative data and qualitatively analysing quantitative data

Table 0.2: A Summary of the Different Types of Research Choice

A Mixed-methods approach was utilised in this research, involving two stages: the first and second empirical validation, with the use of both qualitative and quantitative data collection (**Section 3.6**) and analysis (**Section 3.7**), in order to be consistent with the pragmatist research philosophy. The predominant research choice is to use qualitative techniques and procedures (see **Section 3.6.2**). The mixed-methods choice provides a fruitful combination and robust findings when one of these (e.g. the qualitative method) generates surprising results that can be understood by employing the other method. To achieve the current research purposes, combining qualitative and quantitative methods can create a wider scope for selecting different data collection techniques and data analysis procedures.

3.5 TIME HORIZON

The time horizon of research could be divided into two different types: cross-sectional and longitudinal. A c**cross-sectional time horizon** means the study of a particular phenomenon at a particular time (Saunders, 2011). Conversely, a **longitudinal time horizon** concentrates on events and behaviour using concentrated samples over an extended period of time. This research does not focus on identifying the relationships between observations and changes over different time periods, and hence adopts a **Cross-sectional time horizon**.

3.6 DATA COLLECTION TECHNIQUES

The final layer of the '*Research Onion*' (see **Figure 0.1**) relates to the data collection techniques and data analysis procedures employed. This section mainly discusses what type of data collection techniques (qualitative and quantitative) was employed and which specific techniques work best. All of the decisions must fit the research philosophy, research approach, research strategy, research choice and time horizon.

3.6.1 Qualitative Techniques

Qualitative techniques attempt to make sense of or interpret phenomena in terms of the meaning people ascribe to them (Lincoln & Denzin, 2003). According to Domegan and Fleming (2007), qualitative techniques aim to explore and discover issues when very little is known about a problem. Maxwell (1998) listed different research purposes for which employing qualitative techniques could be more useful:

1) To understand the meaning that the participants involved in a particular event or situation ascribe to their actions, and the accounts they give of their experiences.
2) To understand the particular context within which the participants act and the influence of this context.

3) To identify unforeseen influences or phenomena, and generate new grounded theories about these.
4) To understand the process whereby events and actions occur.

Naturally, qualitative techniques have a strong association with social research. Extensively, they are used related to the use of technology in human contexts, such as human-computer interaction (HCI). Many of the phenomena that interest HCI researchers can be assessed qualitatively.

3.6.2 The Use of Qualitative Techniques for this Research

The employment of qualitative data collection techniques is appropriate for two empirical stages of this research, which aim to assess the AR prototypes and design principles for older adults. The ideal participant should have the experience of both AR technology design and older adults, so it is challenging to recruit a large number of these. Qualitative techniques are predominantly employed in this research, which make it easier to understand a small number of participants involved in a particular event or situation. It also benefits this research to identify the unforeseen influences or limitations associated with the pre-established design principles. Several qualitative techniques can be selected to collect the data. In this research, **focus group** (Rogers et al., 2011) was applied to assess the design principles and prototypes in the two empirical stages, gain a consensus view and highlight areas of conflict and disagreement. Focus group is an effective technique that makes it possible to collect different participants' feedback to produce, share and shape their ideas. All of the information about the specific aims in conducting the focus group and its design in both of the empirical stages is discussed respectively in **Chapter 5** and **Chapter 7**.

3.6.3 Quantitative Techniques

Quantitative research techniques are mainly concerned with gathering data in a form that allows it to be treated as measurable and suitable for statistical analysis; for example, quantitative techniques can confirm

the number of respondents needed to establish a statistically significant relationship between different variables (Goddard & Melville, 2004). Quantitative techniques are strongly associated with the positivist philosophy but can still be integrated within the pragmatist philosophy.

3.6.4 The use of Quantitative Techniques in this Research

For the strategy of this research, the main purpose of the first part of the empirical assessment was to identify the advantages and disadvantages of applying the first version design principles. As the focus is on AR design for older adults, gathering qualitative data was more appropriate for identifying the relevant benefits or limitations based upon the participants' feedback than using quantitative techniques. However, after formalising the second version of the design principles, the second part of the first empirical assessment aimed to compare the refined AR principles of this research with the existing AR principles. Combing both quantitative and qualitative techniques helped to produce data that can be numerically analysed.

3.7 DATA ANALYSIS PROCEDURES

According to Corbin and Strauss (1998), qualitative data analysis in HCI generally consists of three stages:

- Clarifying the major component of the substance (a group of users, a specific technology, interaction behaviour in a specific context, etc.).
- Drilling down into each component and studying the properties and dimensions of each one.
- Gaining from studying each individual component a better understanding of the original substance and drawing inferences from this.

Returning to this research, the predominant procedure is a qualitative data analysis which is executed in two empirical stages based upon Theme Based Content Analysis (TBCA).

3.7.1 Theme Based Content Analysis

Theme Based Content Analysis (TBCA) (Neale & Nichols, 2001) is employed in this research after the data had been collected in the two empirical stages. This is a qualitative procedure that provides useful, detailed information about users' opinions or behaviour and, most importantly, can also produce meaningful categories based on the results through grouping the data. TBCA has five major fundamental elements, which are as follows:

1) Data collection. The data can be collected using any method that yields qualitative data.
2) Data collation. The raw data need to be grouped and systematically displayed based upon the question or hypothesis addressed.
3) Theme definition and classification. The data should then be categorised further, according to the raw data themes.
4) Higher order theme selection. Higher order or more general themes should be generated.
5) Presentation of the classification matrix. The raw data, data themes and higher order themes should be presented at the end.

Some of the advantages of TBCA include (Neale & Nichols, 2001):

- Less time-consuming qualitative data analysis.
- Allows both the summary of the results and retention of raw data.
- A flexible method that can be applied in a number of different circumstances with a variety of different virtual environments and multimedia technology.

3.7.2 Descriptive statistical analysis

Descriptive statistics (Bryman, 2015) are used to describe the basic features of the data. They provide simple summaries of the sample and

the measures. Together with simple graphics analysis, they form the basis of virtually every quantitative data analysis method. Common descriptive statistics include the mean, minimum and maximum values (Wickens, 2004). **Section 6.9** discusses how to use descriptive statistical analysis in the first empirical stage (second focus group).

3.7.3 Non-parametric statistical test

Descriptive statistical analysis alone is insufficient to compare the difference between two pairs. Parametric statistics is a common type of statistics, which assumes that sample data are drawn from a population that follows a probability distribution. However, a non-parametric statistical test is one that makes no such assumptions (Lazar et al., 2010). Returning to this research, the aim of using statistical test is to compare the relevance of design-related issues between this research's five design principles and other existing design principles. There were two reasons for choosing a non-parametric statistical test:

1) Because of the limited sample size, the data were collected from a population that is not normally distributed.

Recruiting a large number of participants who are familiar with either AR technology design or older adults is challenging. It is difficult to guarantee that the population is normally distributed, from an AR design-related perspective.

2) The variables are measured through categorical or ranking scales that are not distributed at intervals, as the distance between any two adjacent data units is unequal.

This research will use the ranking scales to rate the relevance of the issues and principles from one and five. The distance between 4 and 5, as rated by participant 1 could be very different from that rated by participant 2. Because all of the participants need to comment on both this research's five design principles and the other existing design principles, the two samples are dependent. A sign test (Lazar et al.,

2010) was applied to test whether the pair samples are drawn from distributions with equal medians (for further details, see **Section 6.9**).

3.8 CHAPTER SUMMARY

Based upon the original *'Research Onion'* (see **Figure 0.1**) developed by Saunders (2011), this research chose appropriate methods in terms of the research philosophical paradigm, research approach, research strategy, research choice, time horizon, data collection techniques and data analysis procedures (see **Figure 0.5**).

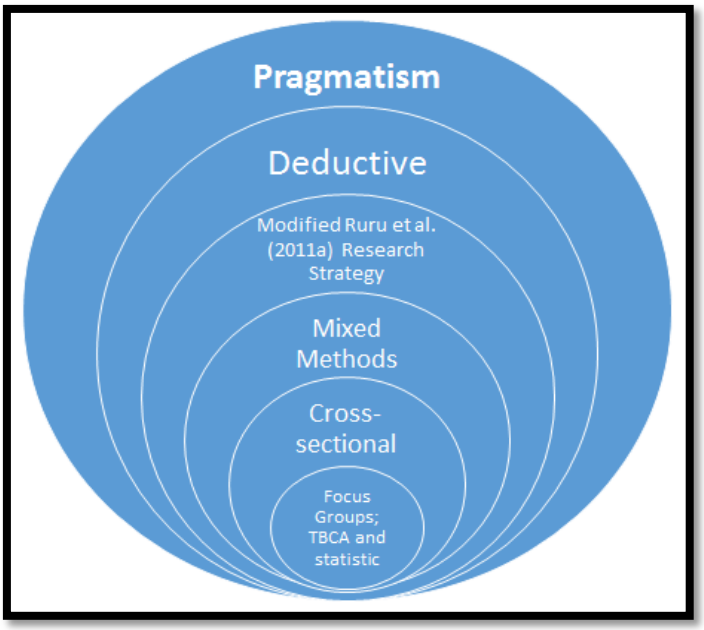


Figure 0.5: Research Onion for this Thesis

By comparing the different research philosophical paradigms, including positivism, interpretivism, realism and pragmatism, the pragmatist paradigm was found to be the most appropriate for this research, as it provides a more flexible and adaptable way to gain knowledge about AR design principles. Because the starting point for this research was the general existing theory of AR design principles, the deductive approach was selected. According to the research strategy, little research has focused on the strategy of establishing AR design principles. This research employs the research strategy by modifying

Ruru et al. (2011) with the aim of developing usability principles. **Section 3.3** discusses the reason and potential for applying this strategy. This research's strategy includes eight steps: **Exploratory stage**, **Descriptive stage**, **Analytical stage**, **Formative Stage**, **First Empirical stage (Focus group 1)**, **First Refinement stage**, **First Empirical stage (Focus group 2), Second Refinement stage, Second Empirical stage** and **Third Refinement stage**. In terms of research choice and time horizon, this research utilises **Mixed-methods** and a **Cross-sectional time horizon**, which are consistent with the research philosophy, research approach and research strategy. Specifically speaking, this research selects a qualitative focus group for the first Empirical stage (Focus group 1) and second Empirical stage, then applies a mixed-methods focus group (combining the qualitative and quantitative methods) in the First Empirical stage (Focus group 2), which aims to make a comparison between this research's design principles and the existing principles. The qualitative data analysis, based on theme-based content analysis (TBCA), is the predominant data analysis procedure applied in both empirical stages. In the First Empirical stage (Focus group 2), this research also implements the descriptive and non-parametric statistical data analysis procedure.

CHAPTER 4 THE INITIAL AUGMENTED REALITY DESIGN PRINCIPLES

Because several fundamental differences exist between traditional graphical user interfaces (GUIs) and AR-based interfaces, it is necessary to establish the AR design principles that are closely related to the characteristics of AR. This chapter aims to formalise the first version design principles of AR for this research following the research strategy exactly, including the **Descriptive stage** (see **Section 0**), **Analytical stage** (see **Section 0**) and **Formative stage** (see **Section 4.3**).

4.1 DESCRIBING THE FEATURES OF AR

As described in **Section 3.3**, which focused on the **Exploratory Stage** of this research strategy, a literature review was conducted to explore the conceptual architecture of AR, aiming to ascertain the relationship between different elements that must be considered in the design of an AR system and gain a clearer understanding of the concept of AR. This AR architecture (see **Figure 2.3**) is a reflection and abstraction of the existing AR experiences and characteristics, consisting of seven key elements: **User**, **Interaction**, **Device**, **Server, Virtual Content, Real Content** and **Physical World**. From the AR design perspective, in this research, the critical aspect is the process of understanding the relationship among virtual content, real content and the physical world (see **Section 2.2**).

In order to fulfil the second stage of the research strategy, the **Descriptive Stage** (see **Section 3.3**), this research focuses on the most relevant features, which are described using the elements of the proposed AR architecture. After reviewing several representative AR-related papers (Azuma, 1997; Craig, 2013; Madden, 2011; Word Lens, 2012) and critically reflecting on them, five prominent features of AR were identified in terms of *Changeability, Synchronicity and Instant,*

Partial one to one, Hidden Reality and *Registration* (Liang & Roast, 2014). **Table 4.1** summarises these features:

Feature	Description
Changeability	Virtual content born of the real content can be changed during an AR event.
Synchronicity	Changing the real content could result in the synchronous and instantaneous transformation of the virtual counterpart.
Partial one to one	There is only one real content that corresponds with the virtual content. However, there might be one or more than one piece of virtual content that corresponds with the real content.
Hidden Reality	In an AR system, generating the virtual content will often result in the obstruction of the real content.
Registration	The objects in the virtual content and physical world must be properly aligned with each other or the illusion that these two worlds coexist will be compromised.

Table 4.1: The Characteristic Features of AR; source from (Liang & Roast, 2014) *and* (Azuma, 1997)

These features are not design principles, but fundamental work for formalising a set of appropriate AR design principles.

Changeability is the key relationship between virtual and real content; for example, Wikipedia World (Madden, 2011) is an AR application that provides users with the location of stations, hotels, etc. When users use this app and move around, the virtual content, in the form of 'a bubble', pops up automatically. After clicking on this 'bubble', more Wikipedia information (e.g. a website or text related to a particular station) appears. This additional information replaces the previous virtual bubble. The modality of the virtual content is changed easily and completely.

Synchronicity describes instantaneous virtual content that reflects changes in the real content. Word lens (Word Lens, 2012) is an AR translation application that scans target texts and displays a translation of them in real time. Once the user changes his/her point of view to another word, the displayed translation (virtual content) on the device also quickly changes.

Partial one to one describes another relationship between real and virtual content. Word lens (Word Lens, 2012) translator can, for example, display a translated word such as '¡Hola!' (virtual content) in Spanish, when scanning the physical word 'Hello!' in English. The meaning of a one-to-one relationship is that the virtual content '¡Hola!' should only be present based on the corresponding physical word 'Hello!', without any relationship to other physical words. However, AR translator could also render the English word 'Hello!' (physical world information) into different foreign language, such as '你好!' in Chinese, 'Bonjour!' in French, etc., as the virtual content.

Hidden Reality suggests that the real content is more or less hidden in an AR system. When the application generates the virtual content (e.g. translated words), the real content (e.g. the original words) might be obstructed at the same time.

Registration emphasises that the virtual content has a physical space or location in the physical world; for example, if the virtual content being displayed as part of an AR experience is a vase, the vase should stand on a physical table in the physical world. If the user moves or turns away from the physical table, the vase remains standing on the table, which is registration with the physical world.

4.2 ANALYSIS OF AR DESIGN RECOMMENDATIONS

In the **Analytical stage** (see **Section 3.3.2**), this research aimed to identify which existing design recommendations are related to AR's prominent features (see **Section 0**) in order to formalise the first version of the AR design principles. **Design recommendations** involve understanding design-related information under the unified title of different design formats, including: design principles, pattern, design guidelines, usability principles, etc. Hence, these existing design recommendations differ from design principles but are fundamental in formalising them. This research reviewed 18 AR-related papers

(Azuma, 1997; Azuma, 1993; Feiner, 1999; Feiner, MacIntyre, Haupt, & Solomon, 1993; Gabbard, 2001; Hix & Hartson, 1993; Hollerbach & Wampler, 1996; Jacobs & Livingston, 1997; Ko et al., 2013; MacWilliams, Reicher, Klinker, & Bruegge, 2004; Mynatt, Back, Want, & Frederick, 1997; Richard et al., 1996; Santos et al., 2015; Summers, Booth, Calvert, Graham, & MacKenzie, 1999; Ware & Balakrishnan, 1994; Wickens & Baker, 1995; Wloka & Anderson, 1995; Xu et al., 2011) in terms of usability principles, design patterns, AR design guidelines and reviews of AR papers. After that, 28 design recommendations were selected which are related to the five most prominent AR features.

Feature	Design recommendation
Changeability	Use progressive disclosure for information-rich interfaces. Pay close attention to the visual, aural and haptic organisation of the presentation (e.g., eliminate unnecessary information, minimise overall and local density, group-related information, and emphasise information related to user tasks) (Hix and Hartson, 1993) (Gabbard, 2001).
	Provide an abstraction layer for different types of viewers (AR, speech, text, etc.) that can handle certain document types, then provide viewers with the appropriate documents (MacWilliams et al. 2004).
	Reduce the complexity of the user interface by suppressing the output requests of individual applications (MacWilliams et al. 2004).
	A modality such as sound as well as a visual screen should be used when information is provided (Ko et al. 2013).

Table 4.2: Correlating AR Design Recommendations with a Changeability Feature

Based upon the feature of **changeability**, there are four design recommendations (**Table 2.1**) that focus on the changeability of the virtual content between different modalities. Hix and Hartson (1993) and Gabbard (2001) discussed the possibility of changing the modality among different forms in terms of the visual, aural and haptic elements. Ko et al. (2013) recommended a combination between the visual and sound modalities to enrich the virtual content, while Macwilliams et al. (2004) mentioned the alternation between the speech and text modality of virtual content. Conversely, Macwilliams et al. (2004) suggested reducing the complexity between different types of virtual content.

Overall, designers considered that the diversity of the virtual content modality is enriched by using this feature.

Eight AR design recommendations mentioned the AR feature – **synchronicity** (**Table 4.3**). Two recommendations (Azuma, 1993; Feiner et al., 1993; Gabbard, 2001; Jacobs & Livingston, 1997; Richard et al., 1996; Ware & Balakrishnan, 1994) discussed the importance of reducing the latency or decreasing the lag in AR systems to help users to achieve their goals. Azuma and Gabbard recommended three different ways to reduce the delay and how to address statistical errors (Azuma, 1993; Gabbard, 2001). A further two recommendations (Ko et al., 2013; Mynatt et al., 1997) discussed the importance of timing and quick reactions. The consensus was that designers should guarantee the generation of virtual content instantaneously, without delay.

Feature	Design Recommendation
Synchronicity	Strive for high frame rates and low latency to assist users in three-dimensional target acquisition (Ware and Balakrishnan, 1994)(Richard et al., 1996)(Gabbard, 2001).
	Relative latency is a source of mis-registration and should be reduced (Jacobs, Livingston and State, 1997)(Gabbard, 2001).
	Consider using a Kalman Filter in head tracking data to smooth the motion and decrease lag (Feiner, et al., 1993)(Gabbard, 2001).
	Minimise the combined latency of the tracker and the graphics engine (Azuma, 1993)(Gabbard, 2001).
	Minimise dynamic errors (maximise dynamic registration) by 1) reducing system lag, 2) reducing apparent lag, 3) matching temporal streams (with video-based systems), and 4) predicting future locations (Azuma, 1993)(Gabbard, 2001).
	Timing and responsiveness of an AR system are crucial elements (e.g., they effect user performance) (Mynatt, et al., 1997).
	It should react quickly to the action of the users (Ko et al. 2013).
	Minimise dynamic errors by isolating and evaluating 1) optical distortion, 2) errors in the tracking system/s, 3) mechanical misalignment, and 4) incorrect viewing parameters (e.g., field of view, tracker-to-eye position and orientation, interpapillary distance) (Azuma, 1997)(Gabbard, 2001).

Table 4.3: Correlating AR Design Recommendations with a Synchronicity Feature

Partial one to one emphasises that several types of virtual content can correspond to a single type of real content. Relatively, designers aim to add the meaningful virtual content to enhance the AR experience (Santos et al., 2015) and provide the necessary virtual

content to reduce the users' short-term memory (Ko et al., 2013). In terms of the Hidden Reality feature, there are five relevant design recommendations. Three of these focus on the occlusion relationship between real and virtual content in terms of operating the AR device to reveal the hidden virtual content (Santos et al., 2015), maintaining proper occlusion (Gabbard, 2001; Wloka & Anderson, 1995) and determining the occlusion in real-time (Gabbard, 2001; Wloka & Anderson, 1995). A further two design recommendations were partially to reveal the virtual content (Xu et al., 2011) and display it as optically transparent to the user (Feiner, 1999; Gabbard, 2001). In summary, there is a trade-off between the design recommendations related to the features of **Partial one to one** and **Hidden Reality**. The former suggests enriching the differentially meaningful and necessary virtual content while the latter suggests diminishing the virtual content in order to reveal the sufficient and significant real content in an AR system (see **Table 4.4**).

Feature	Design Recommendation
Partial one to one	Add meaningful virtual content that contributes to the overall game experience (Santos et al. 2015).
	The necessary information should be provided efficiently so that the users are not required to use their short-term memory (Ko et al. 2013).
Hidden Reality	Allows users to navigate hidden virtual information by operating the camera (Santos et al. 2015).
	Supports significant occlusion-based visual cues for the user by maintaining proper occlusion between real and virtual objects (Wloka and Anderson, 1995)(Gabbard, 2001).
	The information that can be hidden and partially revealed can foster emergent social play (Xu et al. 2011).
	Ensure that the wearable display is sufficiently comfortable and optically transparent for the user (Feiner, 1999)(Gabbard, 2001).
	Whenever possible, determine the occlusion, dynamically, in real-time (i.e., in every graphics frame) (Wloka and Anderson, 1995) (Gabbard, 2001).

Table 4.4: Correlating AR Design Recommendations with Partial One To One and Hidden Reality Features

Based upon the feature of **registration**, nine design recommendations were selected to discuss the importance of properly aligning virtual content with the physical world. Wickens et al. (1995), Azuma (1993) and Gabbard (2001) recommended providing an accurate depiction of

the location and orientation in an AR system. Xu et al. (2011) suggested the virtual content following the laws and rules of the physical world and mapping them intuitively. Jacobs et al. (1997), Azuma (1993) and Gabbard (2001) discussed reducing the lag or latency to minimise the mis-registration between virtual and real content. A further three recommendations (Gabbard, 2001; Hollerbach & Wampler, 1996; Santos et al., 2015; Summers et al., 1999) focussed on the calibration and tracking methods used to display the virtual content in an appropriate registration with the physical world (see **Table 4.5**).

Feature	Design Recommendation
Registration	Provide an accurate depiction of the location and orientation of the graphics and text (Wickens and Baker, 1995) (Gabbard, 2001).
	Relative latency is a source of mis-registration and should be reduced (Jacobs, Livingston and State, 1997)(Gabbard, 2001).
	The calibration requirements for AR tracking systems should include: calibration methods which are statistically robust; a variety of calibration approaches for different circumstances; metrological equipment that is sufficiently accurate and convenient to use (Hollerbach and Wampler, 1996)(Summers, et al., 1999)(Gabbard, 2001).
	For testbed AR environments (i.e., those used for research purposes), the calibration methods should be independent. That is, the separate parts of the entire calibration should not rely on each (Summers, et al., 1999)(Gabbard, 2001).
	Trackers should be accurate to a small fraction of a degree in terms of orientation and a few millimeters in terms of position (Azuma, 1993)(Gabbard, 2001).
	Minimise dynamic errors (maximise dynamic registration) by 1) reducing system lag, 2) reducing apparent lag, 3) matching temporal streams (with video-based systems), and 4) predicting future location (Azuma, 1993)(Gabbard, 2001).
	Select the most appropriate tracking method for your target game (Santos et al. 2015).
	Intuitive mapping between physical and digital objects (Xu et al. 2011).
	Whether the laws and rules in physical world is applicable in the digital world (Xu et al. 2011).

Table 4.5: Correlating AR Design Recommendations with the Registration Feature

4.3 FORMALISING THE FIRST VERSION OF THE AR DESIGN PRINCIPLES

This section formalises the first version of the design principles based on the critical process: exploring the AR architecture and relative elements, identifying five prominent features based on the key elements, and reviewing the existing AR design recommendations related to these five features. These are **Diminished Augmentation, Modality-rich Augmentation, Instantaneous Augmentation, Augmented Augmentation, Accurate Augmentation** and **Transparent Augmentation**. All of these first version design principles were summarised following a general and high-level reflection on the design suggestions (satisfying the design principles' definition in **Section 2.3.1**), closely related to AR features (see **Section 0**) in respect of the designing of virtual content and describing the relationship among virtual content, real content and the physical world. Nevertheless, the main difference between AR design principles and AR features in this research is the former are used to orient designers while the latter emphasises the basic characteristic of AR. The first set of six design principles are strongly related to five AR features but aim to provide useful design knowledge for designers, without considering older adults.

The term 'Augmentation' in these principles is the main element of an AR system (see **Section 0**). The format used to present these AR design principles is based upon the modified approach (Saenz-Otero, 2005), which consists of six items including *Name, Definition, Motivation, Explanation* and *Diagrammatic Example* (see **Section 2.3.4**). At the beginning of each principle, we also discuss why it is important and the value of its use. The important terms within the principles' definitions and explanations are defined in **Section 1.3**.

4.3.1 Diminished Augmentation

Designing the virtual content of AR needs to take into account what will be hidden as much as what will be shown. Applying this principle

allows designers to develop a better understanding of the appropriate amount of occlusion between real and virtual content.

Definition: Virtual content obscures the real content. AR designers might weaken the impact of virtual content in order to reveal the meaningful real content.

Explanation: When users look at an AR device, the virtual content hides some of the real content. If designers could weaken the impact of the augmentation, which includes diminishing and minimising the diversity of the virtual content, more of the real content would be revealed.

Diagrammatic Example:

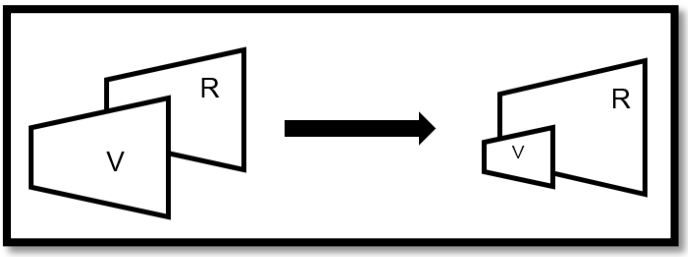


Figure 4.1: Diminished Augmentation Principle

On the left-hand side of all design principles' example diagram, the virtual content (V) is overlaid onto and partially obscuring the real content (R). The arrow in the middle of this figure aims to represent the transition between an original AR system and an AR system that applies a particular design principle. All of the diagrammatic examples used in this thesis apply the same annotations to express the meaning of AR design principles.

On the right-hand side of **Figure 4.1**, it is clear that the 'size' of the virtual content is decreased compared with the image on the left-hand side. This aims to represent the diminishing of the impact of augmentation and the revealing of more meaningful real content.

Basis: This idea was drawn from the existing design recommendations regarding the feature of *Hidden Reality* (Liang & Roast, 2014), which

emphasises the obstruction relationship between virtual and real content. The literature related to this principle include: (Santos et al., 2015), (Wloka & Anderson, 1995), (Gabbard, 2001) and (Xu et al., 2011).

4.3.2 Modality-rich Augmentation

Applying this principle aims potentially to enhance users' various senses, including hearing, touch and even smell; for example, generating visual-based augmentation can benefit users with impaired hearing. Conversely, implementing audio-based information can assist visually impaired people.

Definition: Virtual content can comprise a wide range of modalities, such as haptic and auditory content rather than, or in addition to, visual content.

Explanation: Different modalities (like audio or vibration) could be applied to enhance or replace the traditional visual-based augmentation; for example, combining the visual and audio modalities can ensure that information is available to users who may prefer either mode of communication.

Diagrammatic Example:

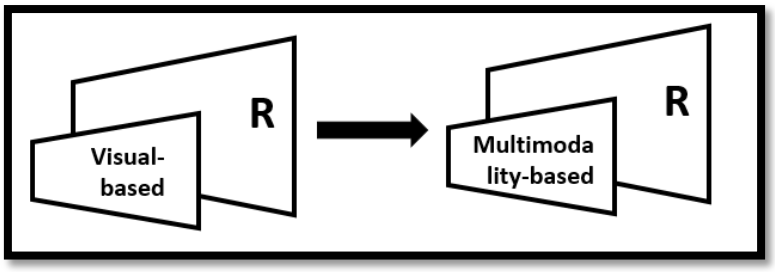


Figure 4.2: Modality-rich Augmentation Principle

According to **Figure 4.2**, the visual-based AR system depicted on the left-hand side could be designed by other modality augmentation, including audio-based, haptic-based or mixed-modality augmentation (e.g. combining visual and audio augmentation).

Basis: The *Modality-rich Augmentation* principle extends the meaning of the *changeability* (Liang & Roast, 2014) feature. *Changeability* states that there exist a wide variety of modalities, which the virtual content can adopt, including visual, audio, vibration, etc. The literature related to this principle includes: (Hix & Hartson, 1993), (Gabbard, 2001), (MacWilliams et al., 2004) and (Ko et al., 2013).

4.3.3 Instantaneous Augmentation

This principle aims to reassure users that the AR system is working properly. Improving the speed at which the virtual content is presented might enhance the AR users' experience.

Definition: The virtual content could be displayed instantaneously when activating the AR system.

Explanation: When the process of generating virtual content is delayed, users might become frustrated when seeking to obtain useful information. It is necessary to react quickly to the actions of the users by reducing the length of time required to generate the augmentation.

Diagrammatic Example:

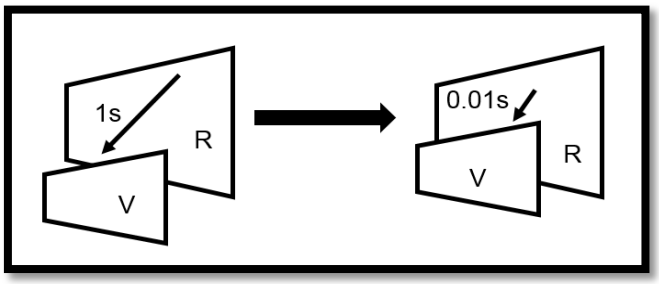


Figure 4.3: Instantaneous Augmentation Principle

The V-R Augmented Reality system shown on the left-hand side of **Figure 4.3** shows that it takes a short time (e.g. there is a one second delay) after scanning the real object(s) in the physical world. The image on the right-hand side of the diagram demonstrates the updated AR system that minimises the delay before the virtual content is presented (e.g. to about 0.01 seconds).

Basis: *Instantaneous Augmentation* mainly originated from the *Synchronicity* feature of AR (Liang & Roast, 2014). The literature related to this principle includes: (Ware & Balakrishnan, 1994), (Richard et al., 1996), (Gabbard, 2001), (Jacobs & Livingston, 1997), (Feiner et al., 1993), (Azuma, 1993), (Mynatt et al., 1997), (Ko et al., 2013) and (Azuma, 1997).

4.3.4 Augmented Augmentation

The aim in applying this principle is to provide more virtual content triggered by the original augmentation to correspond with the real content.

Definition: AR designers could create more than one piece of virtual content that corresponds with the real content.

Explanation: If one piece of virtual content is unable to provide sufficient virtual information, this might help AR users by improving the amount of virtual content, but it is the trade-off between Augmented Augmentation and Diminished Augmentation, i.e., by augmenting more virtual content, more real content could be hidden.

Diagrammatic Example:

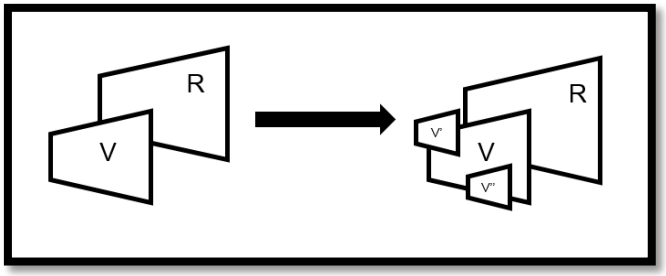


Figure 4.4: Augmented Augmentation Principle

The Augmented Reality system (see the left-hand side of **Figure 4.4**) could be transmitted to the new AR system (see the right-hand side of this figure). The signs V' and V'' represent the additional virtual content after triggering the original virtual content (V).

Basis: The principle of *Augmented Augmentation* is drawn from the existing design recommendations literature related to the feature of *partial one to one* (Liang & Roast, 2014). The related literature includes: (Ko et al., 2013) and (Santos et al., 2015).

4.3.5 Accurate Augmentation

This principle aims to decrease users' difficulty with understanding spatial awareness.

Definition: The virtual content is displayed in the proper registration with the real content.

Explanation: When the position of the virtual content seriously deviates from that of the real content in an AR system, it is difficult to establish a correlation between the two types of content.

Diagrammatic Example:

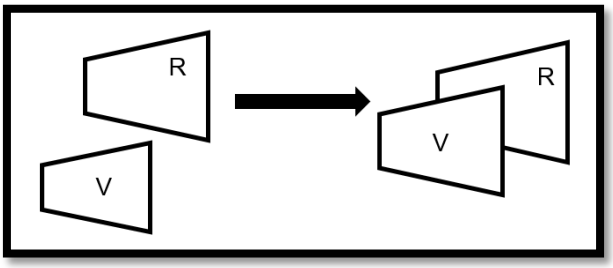


Figure 4.5：Accurate Augmentation Principle

The left-hand side of **Figure 4.5** shows the augmentation breaking away from the real content, which makes it difficult for users to establish a correlation between them. The right-hand side of the diagram clearly illustrates the appropriate AR system, with the overlaid virtual content originating from the real content.

Basis: This idea is drawn from the existing design recommendations related to the *registration* feature of AR (Azuma, 1997). It is the basic requirement for a successful AR system in terms of generating the virtual content, which should be displayed in an appropriate registration with the real content. The related literature includes: (Wickens & Baker, 1995), (Gabbard, 2001), (Jacobs & Livingston, 1997), (Hollerbach &

Wampler, 1996), (Summers et al., 1999), (Azuma, 1993), (Santos et al., 2015), (Xu et al., 2011) and (Huang et al., 2012).

4.3.6 Transparent Augmentation

The aim in applying this principle is to provide more meaningful surrounding information (real content) for users who find it difficult to understand the relationship between virtual and real content.

Definition: Users can see the real content clearly through the virtual content.

Explanation: Similar to the Diminished Augmentation principle, several researchers have suggested the alternative way to weaken the impact of virtual content in order to reveal the real content. Changing the level of transparency of the virtual content might make it easier for the user to understand the relationship between real and virtual content.

Diagrammatic Example:

The virtual content with the black shadow shown on the left-hand side of **Figure 4.6** is completely blocking the real content. However, the level of the virtual content's transparency could be increased (designed like transparent glass) to allow the user to see the real content as well (see the right-hand side of the following figure):

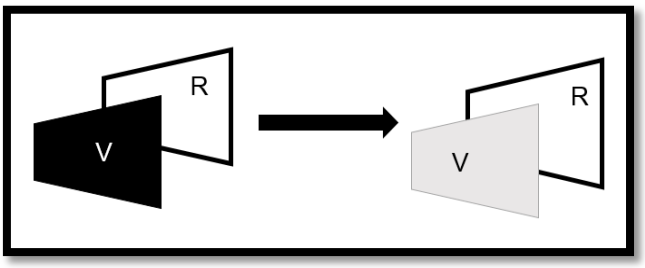


Figure 4.6: Transparent Augmentation Principle

Basis: The *Transparent Augmentation* principle is another way of interpreting the feature of *Hidden Reality* and this principle is drawn from the existing relevant AR design recommendations: (Feiner, 1999), (Gabbard, 2001) and (Wloka & Anderson, 1995).

4.4 CHAPTER SUMMARY

This chapter discusses how to formalise the first version of the AR design principles for this research by reviewing the existing literature based upon the research strategy (see **Section 3.3.2**) in terms of the first four steps: the **Exploratory**, **Descriptive**, **Analytical** and **Formative** stages. In the **Exploratory** stage, a conceptual AR architecture is explored by reviewing the AR-related literature and examples (see **Section 2.2**). From an AR design perspective, the critical aspect of this research is the process of understanding the relationship among virtual content, real content and the physical world. In the **Descriptive stage**, five prominent features of AR were described by undertaking an in-depth analysis of AR's characteristics according to its most relevant elements, including virtual content, real content and the physical world. These five features comprise **Changeability, Synchronicity, Partial one to one, Hidden Reality** and **Registration** (Azuma, 1997; Liang & Roast, 2014). In the **Analytical stage**, 28 design recommendations were reviewed and their relationship with the predominant AR features were identified and used as the basis for formalising the first version of the AR design principles; namely, **Diminished Augmentation, Modality-rich Augmentation, Instantaneous Augmentation, Augmented Augmentation, Accurate Augmentation** and **Transparent Augmentation**.

CHAPTER 5 DEVELOPMENT OF AUGMENTED REALITY APPLICATIONS FOR OLDER ADULTS

The first version AR design principles can be criticised for not being strongly related to older adults. In order to address the weakness of the research, it is necessary to examine whether these principles are applicable for designing AR for older adults and how these principles could address the AR-related issues for older adults. This chapter discusses the two initial AR applications developed in this research based on the design lifecycle, including establishing requirements, designing alternatives and prototyping. These applications aim to help the stakeholders to understand the meaning of AR in a concreate way and identify the AR-related issues for older adults.

5.1 ESTABLISHING REQUIREMENTS FOR OLDER ADULTS

Based on the design lifecycle of developing applications (see **Section 2.5**), the four main steps are establishing requirements, designing alternatives, prototyping and evaluating. Starting with establishing requirements, older adults fear a loss of independence and being required to move into an assisted living or nursing home environment. It is important for older adults to remain in an independent living environment for personal and societal reasons (Rogers & Fisk, 2006). Therefore, this research decided to develop AR applications for the home activities' domain, as the example (see **Section 2.6**), motivated by the concept of improving the older adults' everyday autonomy and life quality (Saracchini, 2015). Rogers et al. (2011) divided home activities into three categories:

- Basic activities of daily living (ADLs), such as bathing, using the toilet and eating, required physical capabilities.

- Instrumental activities of daily living (IADLs), such as meal preparation, home maintenance, financial management and medication management, requiring both physical and cognitive capabilities.
- Enhanced activities of daily living (EADLs), such as learning to use a new technology, communicating with family and friends, tended to be the most cognitively intensive of the three categories.

Augmented Reality may provide support for the physical needs associated with ADLs (Schega et al., 2011) and for the more cognitive needs associated with EADLs (Simão & Bernardino, 2017). However, this research selects two activities - medication management and meal preparation based on IADLs. Older adults with cognitive decline are at risk of developing medication-related problems and becoming incapable of following their prescribed regimens (Aston, Hilton, Moutela, Shaw, & Maidment, 2017). Two existing AR applications (Lera et al., 2014; Quintana & Favela, 2013) have been developed based on these two activities to support older adults' physical and cognitive needs.

5.2 DESIGNING THE AR ALTERNATVIES

Due to the diversity of AR modalities (text, audio, video, etc.), a single AR application makes it difficult for stakeholders to understand thoroughly the meaning of AR and identify a sufficient number of AR-related issues.

It was decided to design an AR Pillbox and AR Reminder, providing information according to medication management and meal preparation.

5.2.1 AR Pillbox

Older adults, especially those with memory deficits, often find it difficult to manage their medication. This can be caused by a number of reasons, such as inadequate knowledge regarding the medication, its

correct dose and the appropriate time to take it (Aston et al., 2017). In addition, according to the different conditions of patients, doctors could provide different instructions which are not written down on the tablet packaging. Rogers and Fisk (2006) also summarised two key requirements of medication management for older adults: keeping

No.	Requirements:	Design Alternatives (conceptual design):	Design Alternatives (physical design):

medication up to date and taking medicine on time at the correct dosage.

This research used the use case diagram to describe the user goals and emphasise the user-system interaction when designing an AR Pillbox, which is a dramatic way to describe the Use Case (Rogers et al., 2011) (see **Figure 5.1**).

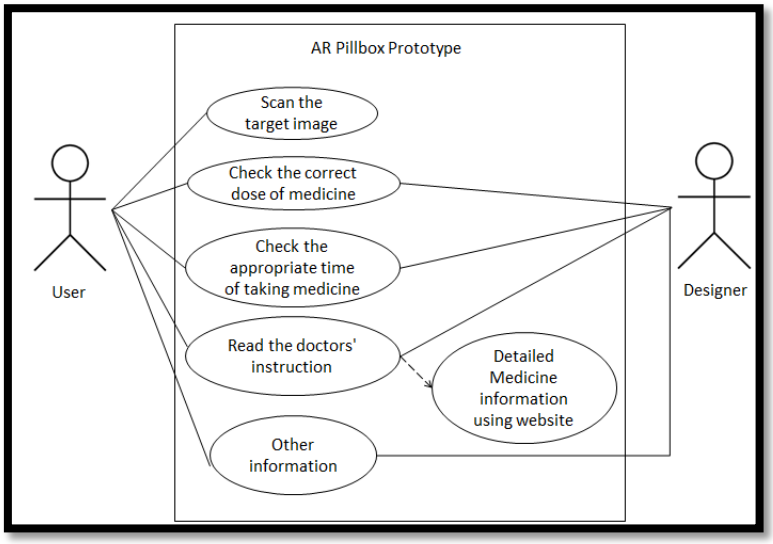


Figure 5.1: Use Case Diagram for an AR Pillbox

There are two actors identified in this Use Case: the main actor – the user - who is the immediate intended beneficiary of the AR system and the other actor - the doctor - who provides the medicine for the user. There are five cases identified in using AR Pillbox. Scanning the target image aims to trigger the AR system. Another four cases and one additional case (detailed medicine-related information) are discussed in the following (

1	The correct dose of medicine	Use the virtual content to display how many tablets need to be taken every day.	Write '2 tablets per day' as the text-based virtual content.
2	The appropriate time for taking the medicine	Use the virtual content to display what time the tablets need to be taken.	The virtual content could be added in the form of text, like 'take at 18:00 --- 2 hours 24 mins next'.
3	The doctor's instructions	Use the virtual content to display how many tablets need to be taken every day.	Add relevant information about the doctor's instructions; for example: 'do not miss taking the medicine'.
No.	**Requirements:**	**Design Alternatives (conceptual design):**	**Design Alternatives (physical design):**
1	The correct dose of medicine	Use the virtual content to display how many tablets need to be taken every day.	Write '2 tablets per day' as the text-based virtual content.
2	The appropriate time for taking the medicine	Use the virtual content to display what time the tablets need to be taken.	The virtual content could be added in the form of text, like 'take at 18:00 --- 2 hours 24 mins next'.
3	The doctor's instructions	Use the virtual content to display how many tablets need to be taken every day.	Add relevant information about the doctor's instructions; for example: 'do not miss taking the medicine'.
4	Detailed medicine-related information	Apply a website to describe the tablet after clicking the tablet information text.	Use the tablet's website (e.g. Aspirin) to provide information.
5	Other information.	Apply the virtual content to show the number of tablets remaining and when to request more.	Use the text-based button which could be written like '12 pills left so contact the doctor'.

Table 5.1). The dosage and time information (No.1 and No.2) of medicine are very important information for older adults, which should be placed in a prominent position (in a large bold font). The doctor's instruction (No.3) and other information (No.5) might not need to be seen repeatedly, and so can be placed in a less obvious position, at the bottom of the virtual content. The medicine-related information (No.4)includes a lot of detailed contents, which are hard to display within the same virtual content. Therefore, a pop-up website could be developed after clicking on the initial virtual content.

3	The doctor's instructions	Use the virtual content to display how many tablets need to be taken every day.	Add relevant information about the doctor's instructions; for example: 'do not give to children under 6 years old'.
4	Detailed medicine-related information	Apply a website to describe the tablet after clicking the tablet information text.	Use the tablet's website (e.g. Aspirin) to provide information.
5	Other information.	Apply the virtual content to show the number of tablets remaining and when to request more.	Use the text-based button which could be written like '12 pills left so contact the doctor'.

Table 5.1: A Set of Design Alternatives for an AR Pillbox

Users could hold the device (e.g. IPhone or IPad) and scan the physical pillbox image (e.g. Aspirin) so that the Pillbox virtual content can be displayed. Users can easily see detailed information, including how many pills need to be taken every day, what time they need to be taken and the doctor's instructions. Then, users could tap on the virtual image and a website of medical description could pop up (see **Figure 5.2** and **Figure 5.3**).

Figure 5.2: AR Pillbox Prototype

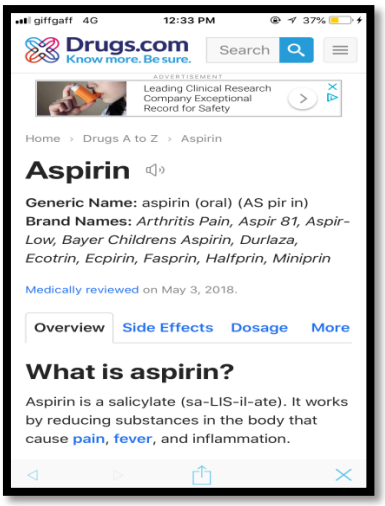


Figure 5.3: Website providing a Medical Description

5.2.2 AR Reminder

The memory deficits experienced by older adults can disrupt their daily life. In particular, older adults with dementia have difficulty recalling recent information and need to be constantly reminded of tasks that need doing. The use of written instructions and reminders are commonly recommended to deal with this problem (Quintana & Favela, 2013). Applying Augmented Reality could provide an alternative way to notify users through digital reminders, which can be overlaid onto the physical objects in the users' field of view. AR Reminder, developed in this research, aims to assist older adults with memory deficits to carry out everyday tasks, such as making a cup of hot chocolate or hamburger.

A Use Case diagram (**Figure 5.4**) shows how the user and designer will interact with this system and what user cases will be involved.

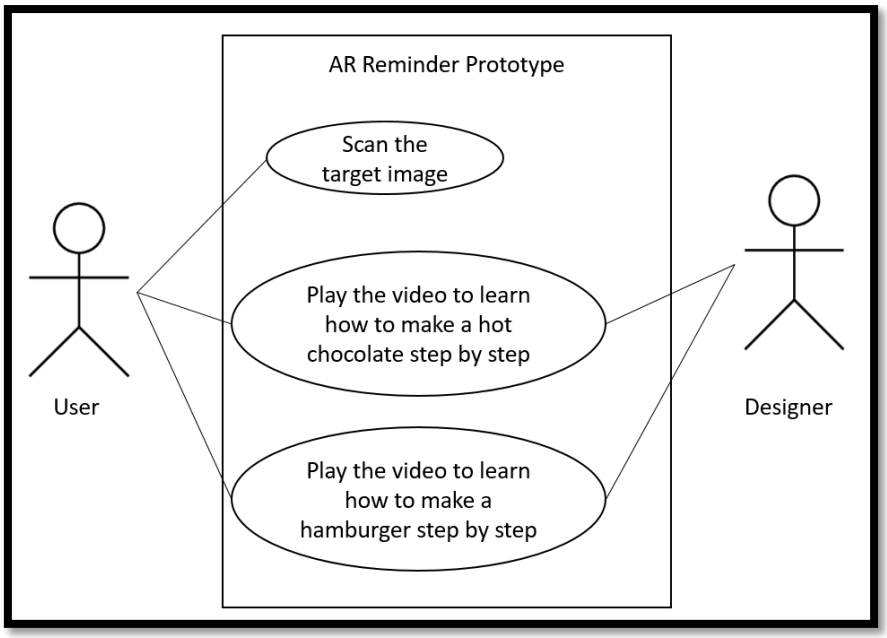


Figure 5.4: Use Case Diagram for AR Reminder

Therefore, the virtual content in AR reminder could overlay two video clips to explain the procedure of making a cup of hot chocolate and a hamburger. However, users may confuse the correspondence between the video and the task. Two big physical target pictures need to be printed out and stuck onto the fridge (see **Figure 5.5**).

Figure 5.5: The Target Object of AR Reminder

Users could hold an AR device (e.g. an IPad) and scan the target object (e.g. the fridge). Two video clip hints will be displayed and users could click on one of them. This AR reminder prototype consists of two video clips, including how to make a cup of hot chocolate and a hamburger step-by-step (see **Figure 5.6**).

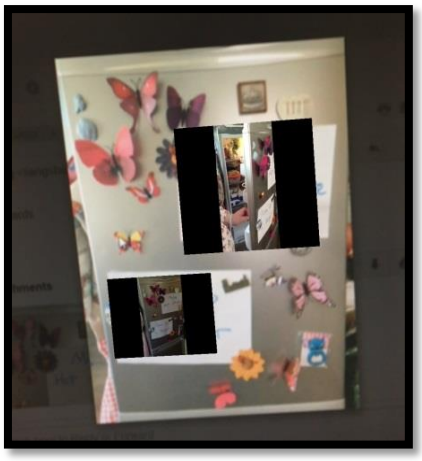


Figure 5.6: AR Reminder Prototype

5.3 PROTOTYPING

A group of software tools could be considered to prototype the AR application. These tools can be used to develop AR apps for smartphones, tablets and a range of wearable devices. The Augmented Reality tools on the market to date (2018) include: Kudan, ARToolkit, Maxst, Apple ARkit, Vuforia, Wikitude, XZIMG and EasyAR. Vasylchenko and Baskhanov (2018) compared these tools based on different criteria (see **Figure 5.7**):

	Vuforia	Wikitude	EasyAR	Kudan	ARToolKit	Maxst	Apple ARKit	XZIMG
Licence	Free, Commercial	Commercial	Free, Commercial	Free, Commercial	Free Open Source	Free, Commercial	Free	Free, Commercial
Supported platforms	Android, iOS, UWP	Android, iOS	Android, iOS, UWP, macOS	Android, iOS	Android, iOS, Linux, Windows, macOS	Android, iOS, Windows, macOS	iOS	Android, iOS, Windows
Smart glasses support	+	+	-	-	+	+	+	-
Unity support	+	+	+	+	+	+	+	+
Cloud recognition	+	+	+	-	-	-	+	-
3D recognition	+	+	+	+	-	+	+	-
Geolocation	+	+	-	-	+	-	+	-
SLAM	-	+	+	+	-	+	+	-

Figure 5.7: A Comparison between different AR development tools (source from (Vasylchenko & Baskhanov, 2018)*)*

Choosing the most appropriate tool depends on the functionality, price and supported platforms that the AR tools can provide. Most of the above Augmented Reality platforms offer support for multiple platforms, including iOS, Android, Google Glass, Windows and Unity. However, using a simple AR toolkit (e.g. drag-and-drop tool) could achieve the purpose of this state of the research, which is to develop AR mixed-fidelity prototypes without using any fully-featured tools. Therefore, this research applies the HP Reveal AR tool (called Aurasma editor up until December 2017) to develop the two initial AR prototypes. HP Reveal (https://www.hpreveal.com/) is an easy-to-learn online drag-and-drop AR toolkit for recognising physical world images and overlaying different types of augmentation (e.g. 2D images, 3D animation, Audio, Videos, Websites, etc.) on top of them.

Figure 5.8 shows the HP Reveal studio - the online editing interface. The trigger image is uploaded, which the users scan and onto which they overlay any type of virtual content. Then, the HP Reveal studio editor can save this content and place it into a 'channel' (Connolly & Hoskins, 2014). The link to the channel, which can be set as either private or public, can be shared with as many people as required and scanned by any device (e.g. IPhone, IPad, etc.) using the HP Reveal editor available on iOS and Android. This HP Reveal meets the basic functional requirements of developing mixed-fidelity prototypes (de Sá & Churchill, 2012) to help stakeholders to explore the design issues older adults through an effective interactive platform. However, if further functions (a button, GPS or face tracking) are required to develop high-fidelity AR prototypes, HP Reveal studio is unable to provide these.

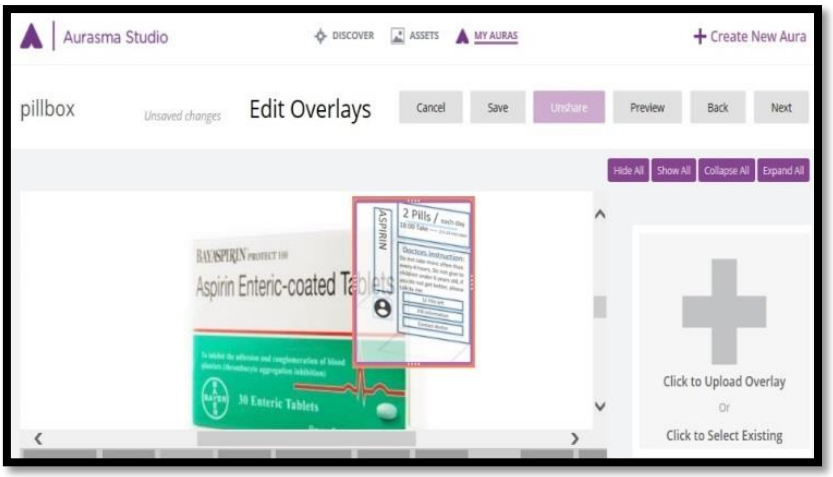


Figure 5.8: Creating Overlay Media via HP Reveal Studio

5.4 CHAPTER SUMMARY

This chapter discusses two initial AR applications that are developed in this research. Both the AR Pillbox and AR Reminder prototypes aim to assist older adults with memory deficits to recall information related to their daily life (e.g. taking medicine and preparing meals). Both applications require imaged-based objects to be scanned, but the modality of the virtual content is different. The AR Pillbox displays a clickable virtual image and the AR reminder plays video clips. Developing AR applications with different modalities could help designers to identify the design issues that arise when applying AR for older adults. From the older users' perspective, they have more opportunities to experience AR technology, but these two prototypes cannot represent all AR applications for older adults. The number of applications remains limited. Developing more prototypes and updating their level of fidelity could be undertaken in future research (for further details, see **Chapter 7**). The next chapter discusses how these two applications have been evaluated with the AR design principles.

CHAPTER 6 FIRST EMPIRICAL FOCUS GROUP CONSULTATION

This chapter describes the first empirical stage of developing the initial Augmented Reality (AR) design principles established in **0** and identifying the second and third version design principles. The data collection technique employed was to gather empirical feedback from two focus groups in order to highlight the participants' conflict and reach a consensus at the end. **Section 6.1** outlines the main purpose

of these two focus groups and **Section 6.2** and **Section 6.6** discuss how they were planned in order to achieve these aims. These focus groups employ two representative AR prototypes with scenarios for addressing issues that older adults are likely to encounter. After generating the agreed design issues by the participants, the AR design principles were evaluated by the participants by comparing the relationship between the principles and the issues. **Section 6.3** and **Section 6.7** describe the focus groups attendees. **Section 6.4** and **Section 6.8** analyse the collected data and discuss the results. A new set of AR design principles (second version) is then identified in **Section 6.5**. **Section 6.9** and **Section 6.10** to explain the changes to AR design principles resulting from the analysed feedback.

6.1 THE PURPOSE

The purpose of these two focus groups is to develop the first version AR design principles based upon the designers and stakeholders' feedback. It is important to note here that the 'designer' in this context means those who are most likely to be the direct beneficiaries. Stakeholders refer to those who share common benefits. Ensuring that the attendees fully understood the research context was considering challenging, since AR design is not an established discipline and AR expertise combined with knowledge of older adults' requirements is rare.

Hence, these focus group aimed to ensure that the attendees would understand:

- Older adults' requirements.
- The potential design knowledge of AR for older adults.

The specific objectives of these focus groups were (**Table 6.1**):

First Focus Group	Second Focus Group
1. To assess the relevance between the first version of the AR design principles and	1. To assess the relevance between the second version of the AR design principles and AR usability-related issues for older

AR design-related issues for older adults.	adults, which are judged and used alongside the existing AR design principles.
2. To identify the second version of AR design principles.	2. To identify the third version of the AR design principles.

Table 6.1: The Specific Objectives of these Focus Groups in the First Empirical Stage

The participants in the first focus group were encouraged to focus on how design principles could relate to, address or prevent design issues. However, it appears that the AR design principles were unrelated to the issues of broadening the design space or communication of different design ideas, based on the feedback from the first focus group. The participants pointed out the relationship between the principles and usability issues. For the second planned focus group, it was decided to ensure that there was a stronger emphasis upon usability issues. In addition, to support an assessment of the revised principles (second version) in the second focus group, it was decided to introduce existing principles to facilitate a comparative assessment.

6.2 FIRST FOCUS GROUP DESIGN

The first focus group was divided into four different activities (see **Table 6.2** below). The table shows the reason for designing this activity (**Purpose**), what was planned to happen in this activity (**Detailed Design**), the **Resources** used to facilitate the activity, and the **Instruments** used to obtain feedback.

No.	Activity	Purpose	Detailed Design	Resources and Instruments
1	Familiarisation (Collect qualitative data about general older adults' requirements).	Inspire the participants to think about older adults.	Organiser introduces the purpose of this focus group and the characteristics of older adults.	Portrait-drawing task slide.
				Story-telling task slide.
				Blank paper.
2	Collecting Design Issues (Collect qualitative data	Provide the fundamental resources for assessing the	Organiser introduces AR and existing AR applications for	Two AR scenarios.
				Two concrete prototypes.

	about AR design issues).	design principles.	older adults, together with a prototype demonstration.	Collecting design issues forms.
3	Matching Design Principles with Issues (Collect qualitative data about the connection between design principles and design issues).	Identify the how the first version AR design principles could be used in designing AR for older adults.	Organiser demonstrates the principles and the participants fill in the matching forms.	AR principles video clips. Matching forms. Blank paper for collecting the new principles.
4	Summarising the focus group (Collect qualitative data about demographics and the focus group comments).	Identify the participants' background and overall comments.	Organiser summarises the focus group.	Semi-structured Questionnaire.

Table 6.2: The Overall Plan for the First Focus Group

6.2.1 First Activity – Familiarisation

This activity aims to ensure a common level of awareness of older adults, their issues, needs and requirements. The participants are also encouraged to take ownership of the older adults' domain through describing their senior relatives using fictional names.

All of the participants are required to draw a portrait of an older adult with whom they are familiar. They are also asked to write a short story to characterise the older adult for example, interests, family support, age-related decline, etc. (see the relevant presentation slides in **Figure 6.1** and **Figure 6.2**).

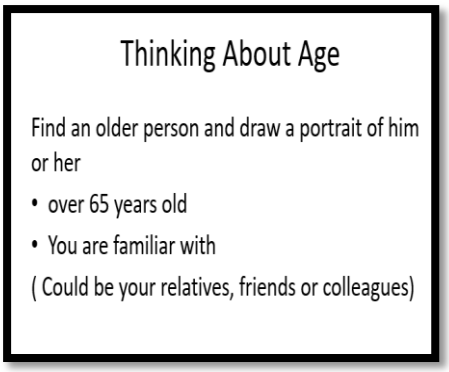


Figure 6.2: Story-telling Task Slide

Figure 6.1: Portrait-drawing Task Slide

6.2.2 Second Activity – Collecting Design Issues using Scenarios and Prototypes

This activity aimed to identify the AR design issues for older adults, which was achieved by exposing the participants to potentially relevant AR scenarios and AR prototypes.

The scenarios provide specific examples of users and their experience to help designers to understand what might happen in a real situation, in order to produce insights and understanding (Stanton, Salmon, & Rafferty, 2013). The two scenarios were based on pre-developed AR applications (AR Pillbox and AR Reminder):

1) The AR Pillbox scenario describes Sue's story of using the AR Pillbox application to remind her how many pills to take and the doctor's instructions (see **APPENDIX A.2**).
2) The AR Reminder scenario tells Alicia's story about how to help older adults with memory loss to make lunch by using pre-prepared video clips (see **APPENDIX A.3**).

Using the AR Pillbox and AR Reminder scenarios could help the participants to understand how AR technology can support older adults living independently. Understanding why and what the older adults are trying to achieve in a real situation allows designers to concentrate on the raised design and ageing-related issues.

Before collecting the design issues, a short introduction to Augmented Reality technology and the existing AR applications for older adults was required. Then, all of the participants played with the two AR prototypes and read their scenarios. There were two different tasks in this section: individually producing a list of specific design issues, and agreeing on a list of relevant design issues after a discussion within each participant's group.

Norman (1986) argues that the first step towards establishing design principles is to make the designers understand the level of the seriousness of the design issues that the principles could address. Tackling serious design issues is an important indicator of the relevance of design principles. Therefore, this research should ask the participants to rate the seriousness of them after writing down their design issues.

The AR prototypes, AR scenarios and task explanation slides (see **APPENDIX A.4**) are the key resources for this part of the focus group. The participants need to use blank paper to list the specific design issues during the first task. The second task requires them to complete the prepared form to list the agreed design issues after the participants' group discussion (see **Figure 6.3**). At the beginning of the second task, two or three participants form a group and are then asked for a group name, which can help the organiser to clarify who generated the design issues. The importance of each design issue is estimated by commenting on its seriousness: serious, normal or trivial (Ko et al., 2013).

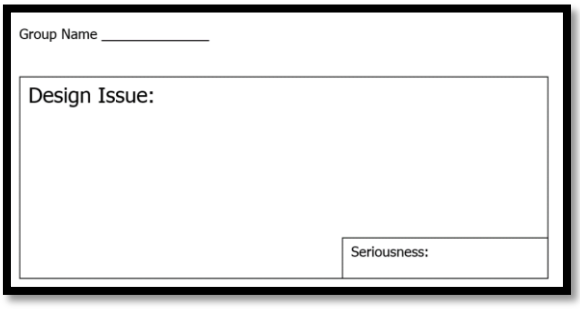
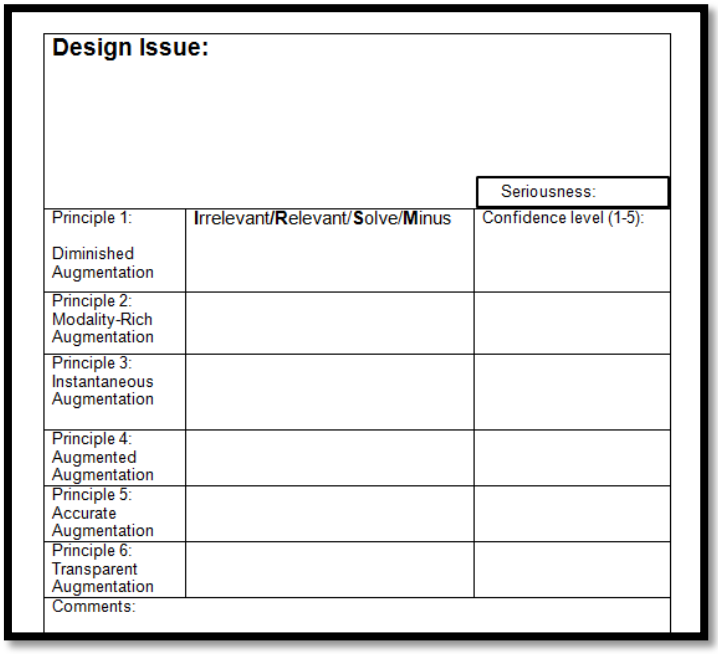


Figure 6.3: The Prepared Form for Listing the Agreed Design Issues

6.2.3 Third Activity – Matching Design Principles with Issues

The relevance of AR design principles to design issues for older adults has been identified in this activity. The focus group organiser introduces the six design principles, providing a definition, explanation and examples of each one. Then, the participants are asked to match the six design principles with the design issues agreed in the previous task. Four different type of relevance between design principles and issues are proposed:

- **Irrelevant**: there is no relationship between the principle and the design issue.
- **Relevant**: a particular principle could probably deal with the current issue but it is hard to tell whether the problem could definitely be solved.
- **Solve**: the issue could be exactly and completely eliminated or improved by following the design principle.
- **Minus**: the principle provides a bad idea which raises further design issues.



Design Issue:		
		Seriousness:
Principle 1: Diminished Augmentation	**I**rrelevant/**R**elevant/**S**olve/**M**inus	Confidence level (1-5):
Principle 2: Modality-Rich Augmentation		
Principle 3: Instantaneous Augmentation		
Principle 4: Augmented Augmentation		
Principle 5: Accurate Augmentation		
Principle 6: Transparent Augmentation		
Comments:		

Figure 6.4: The Prepared Form for Matching Design Principles with the Agreed Design Issues

The participants need to compare different principles with the pre-developed design issues and indicate their relevance on the prepared forms (see **Figure 6.4**). This form includes a confidence rating for each case and helps the participants to examine which pair of relevance are important to them. A video clip (Liang, 2017) is developed to introduce the design principles based on the principles' diagrammatic examples.

6.2.4 Fourth Activity – Summarising the focus group

Following the activity of matching the principles with issues, the organiser summarises the focus group and expresses appreciation for the participants' contribution. A focus group questionnaire is prepared to collect the participants' background information and gather feedback on the focus group. They include structured questions focusing on the participants' occupation, design experience and familiarity with AR in the field of HCI, as well as open questions about the general comments of this focus group, what were the best things and how to improve it (see the questionnaire in **APPENDIX A.5**).

6.3 PARTICIAPNTS IN THE FIRST FOCUS GROUP

Lowgren and Stolterman (2004) defined three main abilities needed by designers, including critical judgment, creative and analytical ability, and rationality and the ability to communicate with clients. This research applies this definition and so the participants should be familiar with either AR technology design or older adults' requirements.

To recruit the participants, the focus group organiser first searched 80 UK universities and found approximately 40 researchers interested in AR research or working with AR, as well as seven labs, which focus on AR-related research. After that, invitation letters (**APPENDIX A.1**) were sent by email to these researchers, as well as relevant companies in Sheffield working with older adults (e.g. South Yorkshire Housing Association Ltd, Sheffield Royal Society for the Blind, etc.). Thirdly, the organiser advertised this focus group via various social media, including Facebook, LinkedIn, Twitter, Eventbrite, etc. In addition, a

website was created using WordPress to convey more information to the potential participants (Liang, 2016).

Participant No.	Current Work	Experience in Technology Design	Frequency of using AR
1.	Older adult's research fellow	None	Once a week
2.	Learning Technologist	1 to 3 years	Once a month
3.	Lecturer in HCI	More than 3 years	Never
4.	Psychology PhD student	None	Once a month
5.	HCI PhD student	1 to 3 years	Never
6.	HCI PhD student	1 to 3 years	Never
7.	Older adults' research fellow	(n/a)	Never
8.	Lecturer in HCI	*'Formal = 0, as a user = 50 + years'*	Depends on the meaning of AR
9.	Lecturer	None	Never
10.	Participant only attended the familiarisation activity and then withdrew from the focus group.		

Table 6.3: Demographic Background of the First Focus Group Participants

This focus group was organised at the end of a serious workshop - Designing Alternatives Reality - and held in a classroom at Sheffield Hallam University during the afternoon. Tea and coffee were provided. Twelve participants registered for this focus group and, on the day, ten attended. One participant withdrew due to personal issues, but managed to complete the Familiarisation Activity - drawing a portrait and writing a story about an older adult. The other nine participants completed all of the activities (6 males, 3 females). Six of them were from Sheffield Hallam University, one from the University of Sheffield and two from Sheffield Royal Society for the Blind (SRSB). The participants' current work, experience of technology design and frequency of using AR are shown in **Table 6.3**. Although not all of the participants used AR very often, they had experience of either technology design or working with older adults. Hence, the first focus group participants generally met the requirements for recruitment.

6.4 FIRST FOCUS GROUP OUTCOMES AND RESULTS

The first focus group was organised on a June afternoon in 2016 and lasted 90 minutes (see the information sheet in **APPENDIX A.6** and the consent form in **APPENDIX A.7**). The organiser also emphasised the ethic consideration in terms of protecting the confidentiality of the collected data and the observers of this focus group helped the participants who might have found it difficult to complete the tasks (e.g. they cannot hear, see or write down any words).

Generally, all of the activities of this focus group went as planned. They commented: *'learning to understand Augmented Reality was very useful', 'specific terms were explained in a good way, helping the participants to understand'*. On the other hand, the participants also suggested that some of the prepared forms needed to be simplified and certain tasks removed: *'the first drawing task was irrelevant'* and *'simplifies the tasks section'*.

In the **Familiarisation activity**, ten portraits and stories of older adults (see **APPENDIX A.8** and **APPENDIX A.9**) were collected to discuss older adults' key issues, needs and requirements. Twenty-eight different AR-related issues for the older adults are also collected in the **Collecting Design Issues activity** (see the **APPENDIX A.11**). All of the participants were then divided into different groups and they generated seven agreed issues (see **Table 6.4**).

Group Number	Participants Number	Agreed Issues
Group A.	Participant 4, Participant 5 and Participant 6.	*'Personalised content'.*
		'How many tasks should be shown on the fridge'.
		'User can control the speed of the information being displayed'.
Group B.	Participant 2 and Participant 8.	*'User doesn't realise that the augmentation connotes to the QR code being given. (Put in other words) Do people realise that pressing the button to read the QR code will lead to extra information?'*
		'Making people reduce it can be augmented [sic]'.
Group C.	Participant 3 and Participant 9.	*'The software generates an AR layer that covers the scanned object. Now, when there is something next to it, it is covered by the layer and it is invisible; for example, if there are two packages next to each other and one of them is scanned, the AR layer will cover them both'.*

Group D.	Participant 1 and Participant 7.	*'Accessibility for visually impaired screen readers will not read the 2D image; false colours may also be a problem'.*

Table 6.4: The Agreed Design Issues Generated by the Different Groups

Some of the issues that the participants agreed on are difficult to understand; for example, the comment written by Group B as *'Making people reduce it can be augmented'* in difficult to interpret, but this research proposes a possible meaning for these issues and analyses them in the following section.

In the **Matching Design Principles with Issues activity**, the participants evaluated all of the principles by describing the relationship between them and the agreed issues (relevant, irrelevant, solve or minus). Some of the participants also wrote comments about the reason for describing a relationship; for example, one participant commented on the difficulty associated with applying the Modality-rich Augmentation principle when designing for screens to be read by people with visual impairment: *'to scan the object someone may not see when recognised perhaps a beep or vibration when successful'*. However, some of participants felt confused about the meanings of these four different relationships; for example, if the participants thought that one principle made one particular issue worse, this meant that the principle and issue were still relevant to each other. Additionally, some of the prepared forms were not fully completed by the participants, such as the lack of comment on the seriousness level and confidence rate of each relationship between the design principles and issues. The high burden of these tasks might result in the partial completion of the confidence rate and the organiser needed to simplify the form for the next focus group. The relationship of matching principles with issues (see the raw data in **APPENDIX A.12**) are transcribed into Excel form (**APPENDIX A.10**).

In the **Summarising the focus group activity**, the participants' demographics and overall focus group comments are collected from all nine participants using a questionnaire (for the comments of this focus group, see **APPENDIX A.18**).

Participant 8 also pointed out that it is important to clarify the meaning of AR. He wrote that his frequency of using AR '*depends what you mean. I use my phone as a magnifies [sic] glass at least once a week. Discussed with group, we think 'yes', and I use my phone as a torch to get up my drive if dark. Is a torch Augmented Reality? OK: I have discussed this with the group. Answer = no'.*

Additionally, some of the participants thought that it was a very interesting topic but that it takes time to understand these principles and ask questions. They suggested that some of the forms needed to be simplified and some of the irrelevant tasks could be removed. They also wanted time to play with the AR prototypes and identify different AR applications for older adults.

In summary, several key points needed to be considered in preparation for the next design focus group:

1) To simplify the tasks and remove the irrelevant ones (e.g. portrait drawing).
2) To allow more time for the participants to play with the prototypes and understand the design principles.
3) To clarify the meaning of AR using concrete examples.
4) To evaluate the relationship between issues and principles in an appropriate way instead of using relevant, irrelevant, minus and solve.

6.4.1 Theme-Based Content Analysis in practice

There are three main contents that needed to be analysed in this focus group, including general older adults' requirements, AR design issues for older adults, and the relationship between the agreed issues and the design principles. Theme-Based Content Analysis (TBCA) (Neale & Nichols, 2001) was adapted to analyse older adults' requirements (**Section 6.4.2**) and AR design issues in this focus group (**Section 6.4.3**). It provides useful, detailed information about the participants' opinions and can also provide general indications of the results through

the participants' feedback by the grouping of data into meaningful categories. Classifying the agreed design issues into different categories provides evidence for identifying what themes within the design issues are related to the first version of the design principles. Based upon the themes' classification and participants' feedback on the relationship between issues and principles, this analysis discusses how the first version of the design principles is related to the design issues (**Section 6.4.4**), before assessing the first version of the AR design principles and presenting the upgraded versions of these.

In practice, TBCA was implemented as follows:

1) Data collation. The qualitative data collected during the focus group in terms of the general older adults' requirements and specific AR design issues were transcribed.

2) Theme definition and classification. The raw data including the older adults' requirements and AR design issues were then categorised into different raw data themes.

3) Higher order theme selection. According to the categorised items, this analysis generated higher themes for both the older adults' requirements and the AR design issues.

4) Presentation of the classification matrix. The raw data themes and higher themes were presented.

6.4.2 General older adults' requirements

No.	Story
1	*'Recently **widowed**, trouble with **vision (cataracts**), **mobility** problems, Has one daughter living close to her, **two children** **dispersed throughout the world**, **cognitive problems**, possible **dementia** related.'*
2	*'This is Mavy, she **likes to do crafts** and she is **social**. She has a **painful knees** but she **does not let that stop her getting a boot**. She **likes food and is an emotional eater**. She was a scientist and her career has been.'*
3	***'Needs a support car for his trip** (cycle from Stafford to St Davids) charity cycle; **needed support to book hotel** stays on way there; needed feedback on his + advice (**GP, family, career**); **anxiety**; link to previous.'*
4	*'Very old, had a **stroke**; **needs a career.'***

5	*'He is still working on his private clinic; still strong.'*
6	*'Ex: professional. Sharp intellect/**Recent serious illness**/**cannot do nearly as much as wants to** - not frustrated, but **gets tired quickly**/ (with picture) **trowel for doing gardening**.'*
7	*'Kibekym he was **widowed** last year. So **misses having someone in the house to talk to**. But goes to a weekly lunch club. Has **had 4 TIAs so has balance problems**.'*
8	***'Husband is in the hospital after medical problems that he cannot address**. Has to **go to the hospital every day**. He bit **isolated**.'*
9	*'To draw an elderly person would be to draw personality traits as well as physical and it just is not possible.'*
10	*'She is my mother **lives alone**, but with **family support**. **Diminishing sight**, **mobility** / **balance** and **confidence**; does not go out alone anymore; **cannot read a recognise faces** [sic]**.'***

Table 6.5: Highlighted Key Words based upon Ten Stories

All of these data were collected during the **Familiarisation** activity of this focus group. The participants made up different fictional names, described their older adults and wrote a short story about their ageing-related issues, needs or requirements (see **APPENDIX A.9**). Nine participants named the older adults, who may or may not have been related to them, Rita, Mavy, Richard, Jimmy, Az, Brett, Martin, Linda and Sarah. Participant No. 10 wrote a short story about a nameless older adult. After transcribing the participants' paper-based feedback, some of the terms related to the older adults' current situation, issues and requirements were highlighted (see **Table 6.5**). Some of these terms referred to the issues of the older adults (e.g. '*serious illness*'), others referred to their basic needs (e.g. '*a support car*'), others referred to general terms (e.g. '*family support*'), while others were detailed examples (e.g. '*had 4 TIAs so has balance problems*').

This analysis classified these stories into eight raw data themes under three higher themes, including society, family and individuals (see **Figure 6.5**) to present the older adults' requirements. The eight raw data themes were described for the purpose of this focus group, including Sensation, Perception Cognition, Mobility, Interest, Treatment,

Support of relatives and Support of social people and groups (**Table 6.6**).

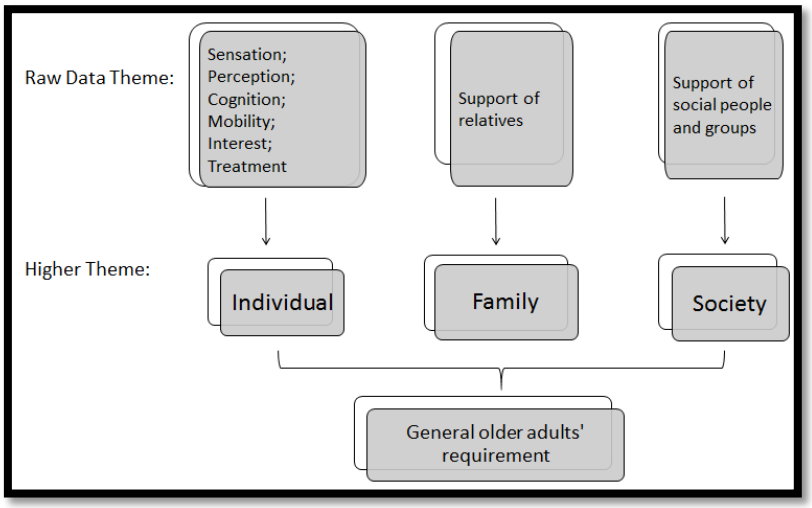


Figure 6.5: The Higher and Raw Data Themes related to the General Older Adults' Requirements

Three of them (sensation, perception and cognition) were described based on the existing literature's classification of the characteristics of older adults (Fisk et al., 2009). The rest of the raw data themes were described by the focus group organiser based on the participants' feedback. All of the themes related to the older adults' requirements are discussed respectively (see **Section 6.4.2.1**-**Section 6.4.2.8**).

Raw Data Theme	Description
Sensation (Fisk et al., 2009).	Any comments relating to the deficiency of different sensory modalities.
Perception (Fisk et al., 2009).	Any comments relating to the awareness of complex characteristics of things and the interpretation of information.
Cognition (Fisk et al., 2009).	Any comments relating to age-related changes in cognitive processing in terms of dementia, anxiety, confidence, etc.
Mobility	Any comments relating to the limitation of carrying out an action based on sensory perception or cognition.
Interest	Any comments relating to age-related interests or hobbies.

Treatment	Any comments relating to the effects of disease and drug problems.
Support of relatives	Any comments relating to the effects of bereavement or children who live far away.
Support of social people and groups	Any comments on the need for people and groups in society.

Table 6.6: A Description of the Raw Data Themes related to the Individual Older adults' Requirements

6.4.2.1 Individual - Sensation

The *sensation* raw data theme consisted of the deficiency in sensory modalities that affects older adults (e.g. visual deterioration). This theme focused on the prevalence of chronic conditions, which increased with age, rather than illness or medical-related issues (see the treatment theme). For example, participant 10 told a story about his/her mother (who was given the fictional name 'Sarah' by the participant):

'She is my mother lives alone…with diminishing sight….'

6.4.2.2 Individual - Perception

The raw data theme of *perception* focused on the difficulties associated with older adults' awareness with regard to interpreting information; for example, participant 10 mentioned that Sarah (a fictional name) '*cannot read a recognise face [sic]'*, which was related to the recognition difficulties associated with perceptive awareness.

6.4.2.3 Individual - Cognition

Age-related changes in *cognition* may be an important feature to consider when designing for older adults. Terms like '*Anxiety'* (fictional name - Richard) and '*Confidence'* (Sarah) were classified under the *Cognition* raw data theme. Memory loss is an important cognitive factor when designing for older adults. No participant wrote about this point, but participant 1 mentioned '*dementia*', which was classified under the *treatment* theme.

6.4.2.4 Individual - Mobility

Both participants 1 and 10 mentioned the *Mobility* raw data theme. The feedback from participant 3 was as follows:

'Needs a support car for his trip (to cycle from Stafford to St Davids - charity cycle)…'

Participant 2 stated that Mavy (fictional name) '*has painful knees*', which might limit her mobility. Balance problems were classified under this theme, and were mentioned by participants 7 and 10.

6.4.2.5 Individual - Interest

According to the feedback, two participants mentioned interest-related requirements in their ageing stories. Participant 2 wrote about Mavy as follows:

'She likes to do craft…she does not let that stop her getting a boot...She likes food and is an emotional eater'.

Participant 6 described Brett, who wished to use a '*trowel for doing gardening*'.

6.4.2.6 Individual – Treatment

Under the raw data theme of *treatment*, participant 6 stated that Brett had a *'recent serious illness…cannot do nearly as much as wants to…'*. Participant 8 introduced a short story about Kibekym: *'Has had 4 TIAs...'* (Transient Ischemic Attacks). Participant 1 thought that visual impairment affected older adults considerably (for example, '*Cataracts*').

6.4.2.7 Family

Under the theme of *Family*, the participants discussed the older adults' issues such as bereavement and living far away from their children. Participants 1 and 7 mentioned that both of their older adult relatives were recently widowed. Participant 1 also wrote that Rita *'has one daughter living close to her, two children dispersed throughout the world…'*

6.4.2.8 Society

The theme of *Society* included older adults who needed social help, based upon the participants' feedback. Participant 2 described the distinctive requirement of 'Mavy' as *'social support'*. Participant 3 mentioned that 'Richard' needed advice from his *'GP, family and carer'*. Participant 10 stated that 'Sarah' '*cannot go out any more*', which might belong to the raw data theme – *mobility* under individual theme. The reason for classifying this text under Society was that some social support could help the older adults to go out (e.g. door-to-door public transport, etc.).

Higher theme	Raw Data Theme	Raw Data Examples
Individual.	Sensation	*'Diminishing sight'*
	Perception	*'Cannot read the recognise faces'*
	Cognition	*'Lack of confidence'*; *'Anxiety'*
	Mobility	*'Balance problems'*; '*Painful knees*'; '*Gets tired quickly*'
	Interest	'*Nothing can stop her getting about*'; '*Likes to do Craft*'; '*Likes food and is an emotional eater*'; '*Trowel for doing gardening*'
	Treatment	'*Stroke*'; '*Got transient ischemic attack (TIA)*'; '*Cataracts*'; '*Dementia*'
Family.	Support of relatives	'*Widowed*'; '*Children dispersed throughout the world*'; '*Lives alone'*; '*So misses having someone in the house to talk to*'
Society.	Social Support	'*Needs support to book hotels*'; '*Cannot go out alone any more*'; '*GP support*'; '*Carer support*'

Table 6.7: A Summary of the General Older Adults' Requirements collected from Focus Group

In summary, **Table 6.7** provides the evidence for generating the raw data and the higher themes related to then. It might be difficult to create better design principles for older adults after analysing only certain of their basic needs or issues and identifying some raw data themes and higher themes related to older adults' requirements, but it is crucial to understand what capabilities and limitations of older adults are and undertake the fundamental work of improving the designs, capitalising on the strengths and capabilities while guarding against the limitations.

6.4.3 Design Issues regarding AR for Older Adults

Raw Data Theme	Description
Text	All comments related to the difficulties associated with designing the style, size, colour and font of virtual text.

Video	All comments related to the overlaid video issues (speed, subtitle, audio, etc.).
Alarm	All comments related to the trade-off between adding an alarm reminder and reducing confusion.
Iconography	All comments related to the use of virtual images and symbols to represent ideas.
Accuracy	All comments related to the virtual content properly registering on the physical world.
Confidentiality	All comments related to whether some of the virtual content needed to be treated as confidential.
Trustworthiness	All comments related to the trustworthiness of the virtual content.
Personalisation	All comments related to updating or modifying the virtual content by the users or stakeholders.
Complexity	All comments related to the effects of task complexity.
Wearability	All comments related to the difficulties associated with using an AR device (e.g. size and weight).
Internet	All comments related to the difficulties associated with data transaction due to a poor internet connection.
QR Code	All comments related to the difficulties associated with recognising the QR code.
Goal	All comments related to AR design depending on the user's goals.
Acceptance	All comments related to AR design's acceptance by users.

Table 6.8: A Description of the Raw Data Theme regarding AR Design Issues for Older Adults

The **Collecting design issues** activity of this focus group aimed to collect the participants' feedback on AR design issues after they had interacted with two AR prototypes for older adults as well as general AR issues based on the participants' discussion. Thirty-five different design issues (28 specific issues are listed in **APPENDIX A.11** and seven general issues in **Table 6.4**) were classified into 14 raw data themes, including Text, Video, Alarm, Iconography, Accurate, Confidentiality, Trustworthiness, Personalisation, Complexity, Wearable, Internet, QR code, User goal and User acceptance (see **Table 6.8**).

All of these raw data themes regarding design issues related to the AR context and the elements of the AR conceptual architecture (see **Section 2.2**) were pre-defined fully and independently of each other. Hence, this analysis observed the possibility of applying AR conceptual architecture to generate the higher themes of the issues related to AR design for older adults, based on the raw data themes. Hence, 14 raw data themes were classified into five higher themes, based upon the various elements of AR architecture, including device, virtual content, server, physical world and user (see **Figure 6.6**).

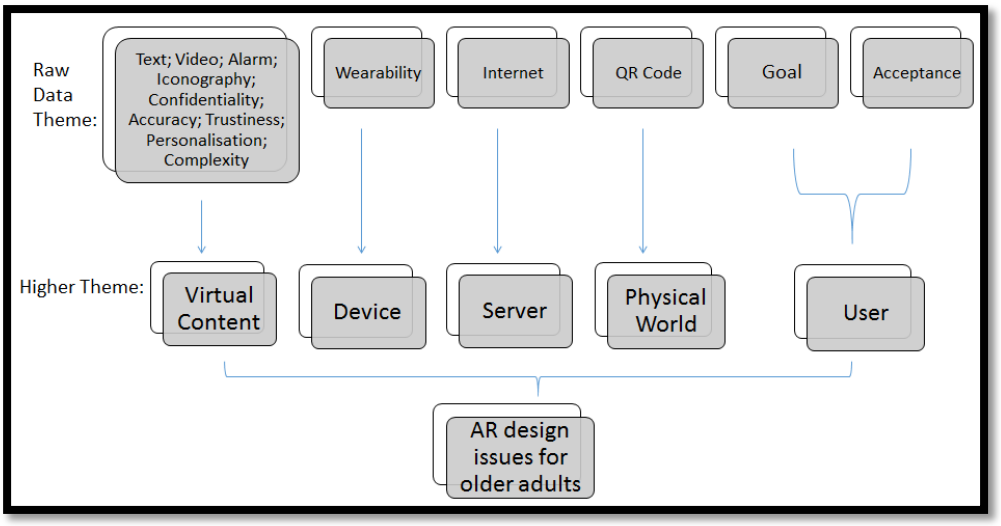


Figure 6.6: The Raw Data Themes and Higher Themes related to the Issues Regarding AR Design for Older Adults collected from Focus Group I

This analysis discussed different higher themes for each section, from **6.4.3.1**-**6.4.3.5**.

6.4.3.1 Device

All of the comments on this higher theme were related to the difficulties regarding the use of current AR devices (e.g. IPad, IPhone); for example, size and weight issues. Participant 1 was worried that older adults might find it *'difficult to hold an IPad…an IPhone is too small'*. The participant also mentioned that older adults with *'Parkinsons'* have more difficulties in using a smartphone. Participant 2 pointed out that the '*IPad is not suitable for older adults*' and also stated that 'devices' should be considered first. Participant 3 commented that it is important for older adults to focus on *'what kind of device for you to use'*. He/she stated that *'wearable'* devices could compensate for the limitations of the traditional AR devices (e.g. IPad, IPhone).

6.4.3.2 Virtual Content

All of the comments related to designing the augmentation of AR were classified under this higher theme - virtual content. This is the main aspect of identifying issues related to AR design for older adults, and may be divided into nine raw data themes:

1) Text: participant 1 mentioned that it creates more difficulty to apply the '*small type fonts on the website*' or other pop-up content. It is important to design an appropriate size of virtual text content (e.g. fonts, icons, pictures, etc.) for older adults.
2) Video: a video overlaid onto one of the AR prototypes (AR Reminder), demonstrated how to make a cup of tea or hot chocolate. Participant 1 was concerned about the sound, as older adults might be unable to hear it clearly. Participant 2 suggested that the video, *'should be divided into several steps so that they can control their pace...speed of tasks'.* He/she also suggested adding subtitles to the video in case some older adults cannot hear the audio properly. Following the participants' discussion, group A agreed that the option to '*control the speed of the information been played'* is an important general issue when designing AR for older adults.
3) Alarm: some of the participants considered adding an alarm function to the AR system for older adults. Participant 4 wrote about the possibility of using an *'audible alarm and vibration alarm'* to indicate to older adults what time to have a meal and where the food was located. Conversely, he/she was also worried that the older adults who might *'confuse this with an alert button'*.
4) Iconography refers to the interpretation of the content of visual image and symbols. Participant 4 commented that the importance of applying *'iconography of information…indicator of being helped…prompt'*. Participant 1 wrote about the familiarity required to *'navigate to launch an app'.*
5) Confidentiality: participant 4 identified the confidentiality issue associated with AR design. Interestingly, some of the existing AR papers also focus on privacy issues when designing AR systems; for example, Kourouthanassis (2013) stated the importance of designing AR functionality to protect the private sphere. Google Augmented Reality glasses (Wikipedia, 2016) also raised the privacy concern. A built-in camera, Internet

connection and GPS system in AR glasses enable the wearer to see plenty of published information, correlating a person's real life activities with their online presence.

6) Accuracy: the comments related to the importance of registering the virtual onto the physical world were collected under the raw data theme of *accuracy*. Some of the participants pointed out that *'information should be heavily situated'*. Group C mentioned the same issue relating accuracy and wrote that '*if there are 2 packages next to each other and one of them is scanned. The AR layer will cover them both with into for one*'. Possibly, the older adults could suffer due to the connection between the physical objects and the pop-up information (virtual content).
7) Trustworthiness: participant 4 was concerned about the trustworthiness of the virtual content: *'is the information true?'* Therefore, adding some auxiliary information might verify the trustworthiness of the original virtual content. Additionally, it might be necessary to provide some relevant content about who supplies the information.
8) Complexity: this raw data theme was identified from the group A participants' discussion. They wrote: '*How many tasks should be shown on the fridge*'. They might be concerned about displaying complex virtual content, which affects the users' completion of tasks.
9) Personalisation: participants 3 and 4 mentioned the possibility of creating customised virtual content; for example, *'how to personalisation (made by family members/who is going to make contents)'* and providing *'tailored information'.* On the AR Reminder prototype, participant 2 wrote: *'Caregivers should create a video*'. According to Participant 4, it is necessary to modify or *update* the virtual content according to the different requirements of older adults. Group A also mentioned that *'Personalised content'* was a general AR design issue for older adults.

6.4.3.3 Server

The term ‘server’ was defined in **Section 2.2.4**, which is another relevant higher theme of AR design issues. The data transaction could be achieved via a wired or wireless connection. However, a poor internet connection could block the data transaction. Participant 1 asked how to *‘get access to the internet?’*

6.4.3.4 Physical world

In an AR system, users need to scan the physical-world QR code as the trigger image to generate the virtual content. However, participant 4 stated that, in some QR code, it is *‘not obvious that you follow some instructions*’. Group B added a further agreed design issue, that *'User doesn't realise that the augmentation connotes to the QR code being given. (Put into other words) Do people realise that pressing the button to read the QR code will lead to extra information?'*

In the future, improving the process of implementing AR apps could help older adults to understand and use AR more effectively.

6.4.3.5 User

There are two raw data themes under the **User** higher theme, including user goal and user acceptance. Group B identified the general design issue: *'Making people reduce it can be augmented'.* There could be different ways of understanding this comment. Possibly, this group may aims to consider the less important information that could be designed as the AR contents, depending on the users’ goal.

Following the participants’ discussion, Group D thought that the most important general issue for older adults is related to user acceptance. They wrote: ‘*Accessibility for visually impaired screen readers will not read the 2D image; false colours may also be a problem’.*

In summary, a lot of the comments focused on the 'virtual content' higher theme. The raw data examples corresponding to each raw data theme and higher theme are summarised in **Table 6.9**:

Higher theme	Raw Data Theme	Raw Data Examples
Device	Wearability	*'Device is hard to use (e.g. Parkinson's); Elderly are difficult to hold IPad; IPhone is too small something wearable; what kinds of device for you to use; Paid is not suitable for elderly; Should think about the devices'*
Virtual Content	Text	*'Small type fonts on the website?'*
	Video	*'Elderly might not listen the sound clearly; control pace or using subtitles? Speed of the video'*
	Alarm	*'What the audible and vibrating alarm system will be; whether the alert button will confuse the users; related to meal times'*
	Iconography	*'Indicator of being helped; prompt; navigate to launch app'*
	Accuracy	*'Information should be heavily situated' 'The software generates an AR layer that covers the scanned object. Now when there is something next to it, it is covered by the layer and it's not visible; for example, if there are 2 packages next to each other and one of them is scanned. The AR layer will cover them both within two for one'*
	Complexity	*'How many tasks should be shown on the fridge?'*
	Confidentiality	*'Confidentiality'*
	Trustworthiness	*'Is the information true; who supplies the information?'*
	Personalisation	*'Update; Caregivers should create a video; how to personalisation (made by family members/who is going to make contents.'*
Server	Internet	*'Internet'*
Physical world	QR Code	*'QR code: not obvious that you follow some instructions'*
User	Goal	*'Making people reduce it can be augmented'*
	Acceptance	*'Accessibility for visually impaired screen readers will not read the 2D image; false colours may also be a problem'*

Table 6.9: Summary of the Issues related to AR Design for Older Adults

6.4.4 Evidence for the First Version of the Design Principles Development

This section summarises the feedback based on the **Matching with Design Principles** activity of the first focus group, which aims to find the correlation between the agreed design issues and the first version of the design principles. After classifying the seven general design issues resulting from this focus group into different themes, **Table 6.10** summarises the raw data themes and higher themes.

It is clear that virtual content is the prominent higher theme relating to four general AR issues for older adults (No.1, No.2, No.3 and No.5). Hence, designing an appropriate virtual content system may be an important factor when designing an AR system for older adults. In

addition, two of the general AR issues are classified into a user-related higher theme, which does not appear in the previous classification of specific AR issues.

No.	Group Number	The General Design Issues	Raw Data Themes	Higher Themes
1.	Group A	*'Personalised content'*	Personalisation	Virtual Content
2.		*'How many tasks should be shown on the fridge?'*	Complexity	Virtual Content
3.		*'User can control the speed of the information been played'*	Video	Virtual Content
4.	Group B	*'User doesn't realise that the augmentation connotes to the QR code being given. Do people realise that pressing the button to read the QR code will lead to extra information?'*	QR code	Physical World
5.	Group C	*'The software generates an AR layer that covers the scanned object. Now when there is something next to it, it is covered by the layer and it's not visible; for example, if there are 2 packages next to each other and one of them is scanned, the AR layer will cover them both within two for one'*	Accuracy	Virtual Content
6.	Group D	*'Accessibility for visually impaired screen readers will not read the 2D image; false colours may also be a problem'*	Acceptance	User
7.	Group B	*'Making people reduce it can be augmented'*	Goal	User

Table 6.10: Themes of the General Issues related to AR Design for Older Adults from the First Focus Group

The relationships between these issues and the design principles as provided by the focus group participants are shown in

Design issues No.	Seriousness	Diminished Augmentation	Modality-rich Augmentation	Instantaneous Augmentation	Augmented Augmentation	Accurate Augmentation	Transparent Augmentation
1	-	I	S	R (3)	S	R (4)	R (4)
2	-	I	I	R	M	S	R (4)
3	-	I	S (4)	R (3)	R (3)	R (4)	I (4)
4	-	-	-	-	-	-	-
5	High	R (1)	I (1)	I (1)	-	-	S
6	Medium	I	R (5)	-	I	M (4)	I
7	-	M	S	R	-	R	R

Table 6.11. As discussed, the categories for the relevant issues and design principles were: the number after the category (e.g. S (4)) indicates the confidence level of the participants and their assessment of the relationship: Irrelevant (I), Relevant (R), Solve (S) and Minus (M).

Design issues No.	Seriousness	Diminished Augmentation	Modality-rich Augmentation	Instantaneous Augmentation	Augmented Augmentation	Accurate Augmentation	Transparent Augmentation
1	-	I	S	R (3)	S	R (4)	R (4)
2	-	I	I	R	M	S	R (4)
3	-	I	S (4)	R (3)	R (3)	R (4)	I (4)
4	-	-	-	-	-	-	-
5	High	R (1)	I (1)	I (1)	-	-	S
6	Medium	I	R (5)	-	I	M (4)	I
7	-	M	S	R	-	R	R

Table 6.11: Raw Data for the Matching Design Principles with their Associated Issues for the First Focus Group

As shown in

Design issues No.	Seriousness	Diminished Augmentation	Modality-rich Augmentation	Instantaneous Augmentation	Augmented Augmentation	Accurate Augmentation	Transparent Augmentation
1	-	I	S	R (3)	S	R (4)	R (4)
2	-	I	I	R	M	S	R (4)
3	-	I	S (4)	R (3)	R (3)	R (4)	I (4)
4	-	-	-	-	-	-	-
5	High	R (1)	I (1)	I (1)	-	-	S
6	Medium	I	R (5)	-	I	M (4)	I
7	-	M	S	R	-	R	R

Table 6.11, issue No.4 was not used to assess the principles. The participants in group B who generated this issue wrote the following comments: *'we have struggled with scenario A because we do not think looking at something else (a mobile) instead of the pillbox is augmented reality. It is an alternative source of information*'. This comment highlights the importance of defining AR and updating the AR

prototype. This AR Pillbox fulfils the AR definition employed in this research and so is AR, but the reason why some of the participants thought that AR Pillbox is not AR could be that the overlaid virtual content is a 2D image without a button and 3D animation. This version of AR Pillbox needs to be updated in order to elicit more ideas from the participants rather than a simple piece of alternative information.

They also generated some new principles, written in the blank area, including: '*Appropriate/relevant augmentation; alternative augmentation; interacting*'.

In order to assess the principles and identify the new versions of them, it is important to reflect on the participants' comments about the three relationships - **Solve**, **Relevant** and **Minus**. **Irrelevant** relationships between the issues and principles might fail to provide evidence for assessing these principles.

Design issues No.	**Seriousness**	**Diminished Augmentation**	**Modality-rich Augmentation**	**Instantaneous Augmentation**	**Augmented Augmentation**	**Accurate Augmentation**	**Transparent Augmentation**
1	-	I	S	R (3)	S	R (4)	R (4)
2	-	I	I	R	M	S	R (4)
3	-	I	S (4)	R (3)	R (3)	R (4)	I (4)
4	-	-	-	-	-	-	-
5	High	R (1)	I (1)	I (1)	-	-	S
6	Medium	I	R (5)	-	I	M (4)	I
7	-	M	S	R	-	R	R

Table 6.11 also shows that four design principles (**Modality-rich Augmentation, Instantaneous Augmentation, Accurate Augmentation and Transparent Augmentation**) can solve or address four different design issues. **Augmented Augmentation** can only solve or address two design issues. The relevance of Diminished

Augmentation (DA) is the lowest (only one design issue is related to DA and another issue could be exacerbated by it).

The following section explains why the participants wrote **Solve**, **Relevant** and **Minus** to describe the relationships between the principles and issues. Some of the potential relationships were not found by the participants because of the short time which they had in which to make decisions and the tasks' burden. This research discusses all of these general issues and themes which are related to the first version of the AR design principles, the limitations of these design principles, and how the analysis of the focus group can be used to create the second version of the principles.

6.5 IDENTIFYING THE SECOND VERSION OF THE AR DESIGN PRINCIPLES

Because the first version of the AR design principles was disconnected from older adults, this first focus group aimed to assess design principles for older adults. **Table 6.12** outlines the changes between the first and second versions of the AR design principles in this research. All of these changes were based on a reflection on the participants' feedback about the relationship between design principles and design issues.

First Version Principles	Second Version Principles	Status
Diminished Augmentation: Virtual content obscures the real content. AR designers could weaken the impact of the virtual content in order to reveal the meaningful real content.	**Hidden Reality**: Virtual content overlays or hides the real content, where the real content is not required to achieve the users' goals.	Changed
Transparent Augmentation: Users can see the real content clearly through the virtual content.		

Modality-rich Augmentation: Virtual content can comprise a wide range of modalities, such as haptic and auditory content, instead of, or in addition to, visual content.	**Modality-focus Augmentation**: Virtual content can be provided in different modalities (such as visual, audio vibration, etc.). depending on the users' goals.	Changed
Instantaneous Augmentation: The virtual content could be displayed instantaneously when activating the AR system.	**Instantaneous Augmentation**: If the virtual content cannot be displayed promptly, then provide prompt and informative feedback to the users.	Changed
Augmented Augmentation: AR designers could create more than one piece of virtual content to correspond with the real content.	**Layer-focus Augmentation**: Where more than one piece of virtual content is required, these can be displayed in separate layers if that supports the users' goals.	Changed
Accurate Augmentation: The virtual content is displayed in the proper registration with the real content.	**Accurate Augmentation**: The virtual content is displayed in the way that users would expect, given their goals.	Changed

Table 6.12: Outline of the Definition Changes between First and Second Version of the AR Design Principles

The most prominent change between the first and second versions of the AR principles is that two previous principles (**Diminished Augmentation** and **Transparent Augmentation**) were combined into a single principle: **Hidden Reality**. As described in **Section 4.3**, the Diminished Augmentation design principle aims to minimise the impact of virtual content in order to reveal the real content, and one way to achieve this is by adjusting the transparency of the virtual content. The benefit of merging Diminished Augmentation with Transparent Augmentation is that this makes it possible to clarify the consistent concept of hiding real content, which always happens when designing AR systems.

During the review process, the need to emphasise the importance of the users' and their goals became evident. The definition of each design principle was therefore reviewed and updated to focus on the user and their goals. The following sections (**Section 6.5.1**-**Section 6.5.7**) discuss the relationship between design issues and principles, the limitation of the first version of the AR design principles, and why

there was a change between the first and second versions of the AR design principles. All five second versions of the AR design principles are shown in **APPENDIX A.13**-**APPENDIX A.17**.

6.5.1 Diminished Augmentation to Hidden Reality

After analysing the feedback on matching Diminished Augmentation (DA) with the themes of the general issues, it was found that the DA principle could provide different design alternatives for addressing or solving two issues and also raised one issue in the following themes (**Table 6.13**).

Relevant Higher Theme	Relevant Raw Data Theme	Relationship between different Issues and the Principle
Virtual Content	Complexity	Address or solve: Decrease the complexity of the virtual content by decreasing the amount of virtual content.
	Accuracy	Address or solve: Provide the accuracy by revealing more meaningful real content.
User	Goal	Raise: It is not meaningful to weaken the impact of virtual content augmentation without considering the significance of the users' goals.

Table 6.13: The Relationship between the Themes of the Design Issues and Diminished Augmentation Principle in the First Focus Group

The group B participants (for the groupings, see **Table 6.4**), for example, wrote that the No.5 design issue (see **Section 6.4.4**), classified under the **Accuracy** theme, was relevant to Diminished Augmentation, which could indicate that the correspondence is obscure between one piece of virtual content and one piece of real content. This implies that, if there are two identical physical packages next to each other, only one of them needs to be scanned. Diminished Augmentation could be an important principle in leading designers to weaken the impact of the virtual content of identical packages (that do not need to be scanned as well) in order to have space to reveal some more meaningful real content. To visualise the meaningful real content, designers should understand the users' goals, which the real content is not required in order to achieve.

However, while the first version principle (Diminished Augmentation) only explains how to decrease the number or size of the augmentation

(e.g. a virtual button or text), it does highlight the significance of the users' goals. The second version of this principle (Hidden Reality) must be defined with reference to the users' perspective. Additionally, there is a trade-off between increasing and decreasing the amount of augmentation; for example, if users need to watch more additional information, overlaid over the real content, the limited space for the virtual content might not insufficient to contain this information, according to the participants' comments. Hence, the **Explanation** of Hidden Reality should take into account the balance between the hidden and revealed real content (see the second version of the Hidden Reality principle in **APPENDIX A.13**).

6.5.2 Modality-rich Augmentation to Modality-focus Augmentation

Relevant Higher Theme	Relevant Raw Data Theme	Relationship between different issues and the Principle
Virtual Content	Personalisation	Address or solve: Different modalities of virtual content address a variety of older adults' issues (e.g. audio-visual problems) and creates audio or vibration content to fulfil older adults' requirements.
	Video	Address or solve: Gives designers ideas about choosing different modalities of virtual content rather than video format only.
User	Acceptance	Address or solve: provides older adults with an opportunity to perceive the additional information.
	Goal	Raise: it is important to choose the appropriate modality of virtual content depending on the users' goals.

Table 6.14: The Relationship between the Themes and Modality-rich Augmentation Principle in the First Focus Group

According to the participants' feedback on matching Modality-rich Augmentation (MA) with the themes of general issues, the MA principle could provide different design alternatives to address or solve three issues and raise one issue (see **Table 6.14**).

The group A participants stated that Modality-rich Augmentation (MA) could bring benefits in terms of personalising content, possibly because different modalities address different issues associated with older adults (e.g. audio-visual problems) and create audio- or vibration-based content to fulfil older adults' requirements. The group D

participants thought that MA principle solved the design issue, which was related to accessibility for visually impaired screen readers, who cannot read 2D images or text and find it difficult to distinguish between different colours. Modality-rich augmentation provides older users with an opportunity to perceive the additional information.

After the participants had read the definitions of the design principles, Participant 8 (a HCI lecturer) in group B crossed out the word '-rich' and wrote down another word - 'specific' - under the Modality-rich augmentation principle. Possibly, the meaning of the Modality-specific Augmentation mentioned by the participant focuses on generating the virtual content following by a particular modality (e.g. either visual or audio) rather than mixed modality augmentation (e.g. both visual and audio), depending on the users' goals.

Participant 8 also explained the meaning of Modality-specific Augmentation as 'Alternative Augmentation', which *'is appropriate to the perception and meets the users' needs User can choose different format, depth or length of AR'.* The participant might worry about showing text to blind people. Putting the information into a different form could be useful for these users. Hence, the definition of the second version emphasises that the choice of different modalities depends on the users' goals.

The second version principle is named Modality-focus Augmentation, which aims to cover the meanings between '-rich' and '-specific' modality (see the second version of the **Modality-focus Augmentation** principle in **APPENDIX A.14**).

6.5.3 Instantaneous Augmentation

The reflection on matching the Instantaneous Augmentation (IA) with the themes of general issues shown in **Table 6.15** raises one issue and provides various design alternatives for addressing or solving two issues.

Relevant	Relevant Raw	Relationship between different issues and

Higher Theme	Data Theme	the principle
Virtual Content	Video	Address or solve: Support designers to find different design alternatives in order to assist users easily to realise what the actions with which they can interact.
	Complexity	Address or solve: When activating the AR system, the complex virtual content could be difficult to display instantaneously.
User	Goal	Raise: The virtual content should be displayed promptly depending on different users' goals.

Table 6.15: The Relationship between the Themes and Instantaneous Augmentation Principle in the First Focus Group

No.3 design issue, for example, focused on controlling the speed of the video classified under the video raw data theme, which might be highly relevant to this principle and could help designers to identify different design alternatives in order to assist users easily to realise that there are other actions with which they could interact. However, the definition of the first version - Instantaneous Augmentation - failed to explain what content should be provided if the virtual content cannot be displayed promptly. Hence, the second version needs to clarify the starting point for scanning the particular physical tag when the AR system cannot provide the reaction quickly. Perhaps a beep or vibration would help users to understand the trigger point (see the second version of the **Modality-focus Augmentation** principle in **APPENDIX A.15**).

6.5.4 Augmented Augmentation to Layer-focus Augmentation

Augmented Augmentation (AA) offers various design alternatives to address or solve two design issues related to personalisation and video themes, based on the participants' feedback. One issue relating to complexity might be exacerbated due to the AA principle (see **Table 6.16**).

Relevant Higher Theme	Relevant Raw Data Theme	Relationship between Different Issues and the Principle
Virtual Content	Personalisation	Address or solve: Provide more opportunities for designers to choose different tailored information to meet the users' needs.
	Video	Address or solve: Overlaying the additional button or reminder could assist users to select different video functions.
	Complexity	Raise: Adding additional information increases

		the complexity of the virtual content which makes users feel confused and leads them to make mistakes.

Table 6.16: The Relationship between the Themes and Augmented Augmentation Principle in the First Focus Group

One of the most important ways of employing this principle is to help designers to design some of the personalised content (based on the comments of the group A participants). Compared with single augmented virtual content, multiple augmented virtual content can provide more opportunities for designers to choose different tailored information to meet the users' needs. Additionally, some of the overlaid buttons or additional reminder icons could also assist users to select the different functions (e.g. control the speed at which video is played). Participant 8 (an HCI lecturer) in group B also stated that a directional focal point could be another way of augmenting the information, which *'shows where the scanned object is'* and helps users to understand the counterpart of the virtual content. Hence, the definition of the second version of this design principle emphasises the importance of the users' goals.

Contrary to the view of the group A participants, if one or more task has already been shown, this might '*cause confusion and mistakes'*, classified under a complexity theme, once further information has been added. Therefore, it is illogical to articulate the design principle in terms of generating more augmented virtual content, and preferable to explain how to display the virtual content (e.g. separate layers) where more than one piece of virtual content is required (see the second version of the **Layer-focus Augmentation** principle in **APPENDIX A.16**).

6.5.5 Accurate Augmentation

After analysing the feedback on matching the Accurate Augmentation (AA) with the themes of the general issues, it was found that the AA principle may provide different design alternatives for addressing or solving three issues and raise two issues in terms of the **User** theme (**Table 6.17**).

Relevant Higher Theme	Relevant Raw Data Theme	Relationship between the Issues and the Design Principle
Virtual Content	Accuracy	Address or solve: Provide more precise task instructions.
	Video	Address or solve: Clarify the layout for playing the video.
	Complexity	Address or solve: Accurate content presents a concise vision.
User	Goal	Raise: The AA Principle fails to consider the users' goal.
	Acceptance	Address or solve: Inaccurate virtual content could be difficult for older adults hard to read.

Table 6.17: The Relationship between the Themes and Accurate Augmentation principle in the First Focus Group

Specifically speaking, the accurate augmentation principle could provide more precise task instructions (summarised from the '*relevant*' relationship referred to by participant 8). Otherwise, the focus group A participants wrote '*solve*' and '*important*' regarding the second design issue related to the complexity of the virtual content theme. In addition, one of the possible benefits of employing this principle could be to support designers to create design alternatives by focusing on the users, who may feel confused about the correspondence between virtual and real content; for example, the video clip overlaid on the hot chocolate image gives instructions on how to make a cup of hot chocolate rather than a hamburger or chips. The Group D participants commented that the relationship between the accurate augmentation principle and accessibly design issue was '*minus*' and also wrote '*the angle of text can make it harder to read*' followed by '*minus*'. This suggests that they thought that the Augmented Reality might not be very strongly aligned with reality. Therefore, the second version design principle added the meaning of the virtual content, which is based on the users and their goals (see the second version of the **Accurate Augmentation** principle in **APPENDIX A.17**).

6.5.6 Transparent Augmentation to Hidden Reality

The participants thought that the transparent augmentation principle could solve or address two design issues related to the virtual content theme and raise one design issue related to the users (see **Table 6.18**).

Relevant	Relevant Raw	Relationship between the Issues and the

Higher Theme	Data Theme	Principle
Virtual Content	Personalisation	Address or solve: Different levels of shading of the virtual content could provide designers with different alternatives for addressing the users' requirements.
	Accuracy	Address or solve: Provide accuracy by revealing more meaningful real content.
User	Goal	Raise: lack of consideration of for the users' goal.

Table 6.18: The Relationship between the Themes and the Transparent Augmentation Principle in the First Focus Group

According to their feedback, the participants thought that the transparent augmentation principle could be useful when designers are designing personalised content for older adults. The reason why one designer wrote '*solve*' could be that this principle provides the solution of partially obscuring the virtual content. Different levels of shading of the virtual content could help the user to understand the different correspondences between one piece of virtual content and one piece of real content. In other words, adjusting the transparency of the virtual content could be another way of hiding the real content. Therefore, the second version of the Hidden Reality principle combines both the Diminished Augmentation principle and the Transparent Augmentation principle.

6.5.7 Format changes of the design principles

The first version of the AR design principles used **Diagrammatic Examples** in order to help designers to understand the principles in a graphical way. However, some of the participants commented that the diagrams were too abstract to understand. Hence, the second version of the AR design principles added practical examples to facilitate the designers' understanding of these principles.

According to the **Motivation** item of the first version of the AR design principles, it is useful to discuss the main reasons and advantages associated with employing these principles. However, the ideas in the first version are currently immature and have not been validated by any AR designers or developers. After conducting the first focus group, the participants clearly pointed out the benefits of using these principles.

Hence, the second version of the AR design principles removed the **Motivation** item and added the **Benefit or Problem Solving** item, which aimed to discuss the possibility and benefits associated with applying these principles and what sort of design issues might be addressed or solved, based upon the first focus group participants' feedback.

The **Basis** item in the first version related the design principles to the previous literature in order to explain the basis upon which they were derived. Basis in the first version also discussed which principles came from which AR features. This part had to be removed because all of these papers relate to the first rather than second version of the principles.

The following section discusses the second focus group, which aimed to assess the second version of the Augmented Reality design principles.

6.6 SECOND FOCUS GROUP DESIGN

Each activity in the second focus group is described using the same pattern as for the first one, including **Activity, Purpose, Detailed Design**, **Resources** and **Instruments** (see **Table 6.19**).

The design of the second focus group comprised two main activities (Collecting usability Issues and matching the Design Principles with these issues) and removed two irrelevant activities compared with the first focus group (portrait drawing and the collection of the older adults' requirements). This design gave the participants more time to road-test the prototypes and understand the design principles, using concrete examples.

No.	Activity	Purpose	Detailed Design	Resources and Instruments
1.	Familiarisation	Briefly introduce	Organiser introduces	Related presentation slides

		the relevant background.	augmented reality (AR), the characteristics of older adults and two AR prototypes with scenarios.	AR prototypes
2.	Collecting usability Issues	Provide the fundamental resources for matching the design principles.	Organiser demonstrates two AR prototypes: AR Pillbox and AR Reminder, and invites the participants to write down any usability issues.	Specific usability issues forms
				General usability issues forms
3.	Matching the Design Principles with the issues	Assess the connection between the principles and the issues.	Organiser demonstrates the principles. Participants complete the forms.	AR design principles explanation
				The form of matching principles with a issues.
4.	Summarising the focus group	Identify the participants' background and the overall comments.	Organiser summarises the focus group.	a semi-structured questionnaire.

Table 6.19: An Overview of the Plan for the Second Focus Group

6.6.1 First Activity - Familiarisation

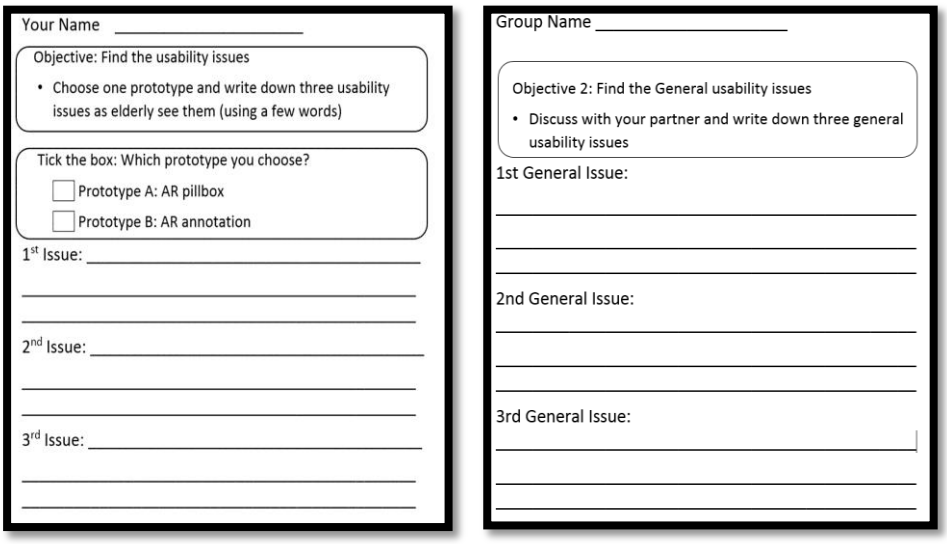
The introduction for the participants included the aim of this focus group, the concept of augmented reality (AR) and the characteristics of older adults. Participants can also learn from two pre-defined AR scenarios, and road-test the same AR prototypes (AR Pillbox and AR Reminder) used in the first focus group. Based upon the feedback of the first focus group, the familiarisation activity in the second omitted the portrait sketch task and collection of older adults' requirements, which are irrelevant to the main purpose of this focus group.

6.6.2 Second Activity – Collecting Usability Issues

This activity, similar to the second activity of the first focus group, is designed to identify the usability issues (e.g. those related to learnability, effectiveness, ease-of-use, etc.) related to two AR prototypes' (AR Pillbox and AR Reminder) and the general usability

issues associated with AR. Usability issues can be interpreted in different ways and the focus group organiser needed to clarify their meaning in advance. Taking some examples from the first focus group, the usability issues were identified as follows:

- The virtual content is inaccurately registered onto the real content.
- The device does not offer ease-of-use for older adults.
- The size of the front is not easy to read.



(a) *(b)*

Figure 6.7: (a) Form for collecting specific usability issues;

(b) Form for collecting general usability issues.

Then, each participant was asked to write down three specific usability issues from older adults' perspective (using a few words). At the end, the participants could discuss these with their partners and identify general usability issues related to AR use by older adults, which were not necessarily linked to one particular prototype (see **Figure 6.7**).

6.6.3 Third Activity - Matching the Design Principles with the Issues

This activity involved comparing the research principles with other existing principles and assessing the relevance between these principles and general issues.

a) All ten principles are clearly and consistently presented with simple memorable acronyms in an arbitrary order. These include five AR design principles (second version), formalised from the first focus group, and five existing principles from (Dünser et al., 2007; Kourouthanassis et al., 2013), in an arbitrary order. The process of selecting the existing principles follows three different aspects:

1) They are all design principles focusing on AR for older adults.
2) Some of these principles are relevant to the AR issues identified by the first focus group; for example, the privacy principle could be relevant to the confidentiality raw data theme of virtual content.
3) Some of these principles are relevant to the general older adults' requirements identified by the first focus group; for example, Reducing Cognitive Overhead is related to the cognition raw data theme of older adults' requirements.

b) The participants filled in the forms of matching principles with issues and work individually to rate the relevance of the design principles to their agreed issues between 1 and 5. The organiser needs to accept that the participants differ in terms of their individual, subjective responses to such relevance scales. Compared with the first focus group, rating the relevance between the issues and principles offers a more appropriate way compared with using relevant, irrelevant, minus and solve; for example, participants who choose a ‘minus’ relationship should be involved in the selection of a ‘relevant’ relationship.

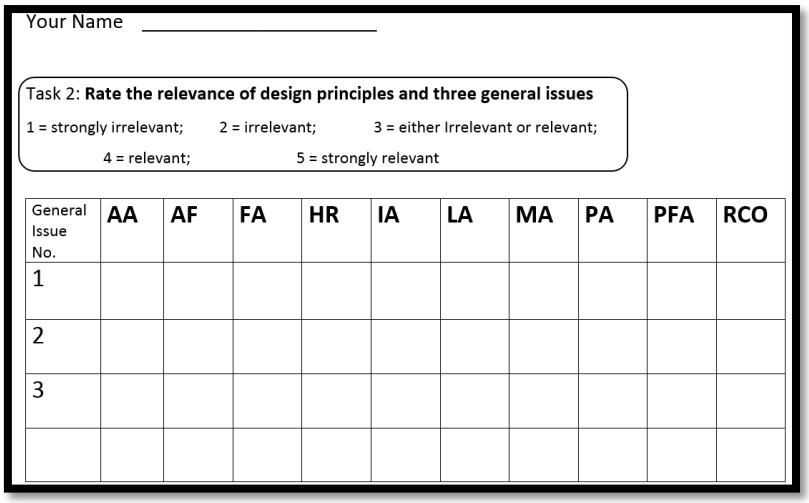
All of the design principles are written in the same format, including the name, definition, explanation and diagram (see the list of ten design principles in **Table 6.20** and these principles in **APPENDIX A.19** and **APPENDIX A.28**).

No.	Abbreviation of letters	AR design principles	Reference

1.	RCO	Reducing Cognitive Overhead	(Dünser et al., 2007).
2.	MA	Modality-focus Augmentation	This research's design principles (second version).
3.	PFA	Physical-focus Augmentation	(Dünser et al., 2007).
4.	IA	Instantaneous Augmentation	This research's design principles (second version).
5.	FA	Familiarity-focus Augmentation	(Kourouthanassis, Boletsis et al. 2013)
6.	AF	Affordability	(Dünser et al., 2007)
7.	LA	Layer-focus Augmentation	This research's design principles (second version).
8.	AA	Accurate Augmentation	This research's design principles (second version).
9.	HR	Hidden Reality	This research's design principles (second version).
10.	PA	Privacy Augmentation	(Kourouthanassis, Boletsis et al. 2013).

Table 6.20: A list of the Ten AR Design Principles

The participants need to mark a value from one to five to indicate the relevance of each design principle to the identified issues using this form (**Figure 6.8**). The corresponding principles are printed for the participants using abbreviations.



Your Name _____

Task 2: **Rate the relevance of design principles and three general issues**

1 = strongly irrelevant; 2 = irrelevant; 3 = either Irrelevant or relevant;
4 = relevant; 5 = strongly relevant

General Issue No.	AA	AF	FA	HR	IA	LA	MA	PA	PFA	RCO
1										
2										
3										

Figure 6.8: The Form for Matching the Ten Principles with the Issues

6.6.4 Fourth Activity – Summarising the focus group

The final activity identifies the participants' background and the overall comments of this focus group. The organiser summarised the focus group and thanked the participants for their contribution. Additionally, a semi-structured questionnaire (**APPENDIX A.29**) was used to collect the participants' background information and gather the feedback from this focus group.

The structured questions focus on the participants' background in terms of experience of Augmented Reality design and working with older adults. Three open questions are designed to evaluate the advantages, disadvantages and improvements suggested by this focus group.

6.7 PARTICIPANTS IN THE SECOND FOCUS GROUP

Fourteen participants registered to attend the second focus group (see the information sheet in **APPENDIX A.30**, invitation letter in **APPENDIX A.32** and consent form in **APPENDIX A.31**) and nine participants finally attended (4 females and 5 males). Three of them took part in the first focus group (see the participants marked in bold in **Table 6.21** below). Participants who attended the first focus group were appropriate since they were more familiar with the AR prototypes

for older adults and had a good understanding of the relevant issues and different AR principles.

Although not all of the participants used AR very often, they had experience of either technology design or working with older adults. The participants in the second focus group had more experience than those who attended the first one (more HCI researchers), so the outcome of the second one might be more reliable and valuable than that of the first one.

Participant Number	Demographic Background
1.	HCI Reader, with over three years of experience in technology design, uses AR technology once a month and also attended the first focus group of this research.
2.	HCI researcher, who has 1-3 years' experience in technology design.
3.	**Older adults' research fellow, who has worked with the older adults for more than three years, uses AR technology once a week and also attended the first focus group.**
4.	**Older adults' information officer, who has worked with older adults for more than three years and attended the first focus group.**
5.	**Technology developer, who has 1-3 years' experience in technology design, uses AR technology once a month and attended the first focus group.**
6.	Technology developer, who has experience 1-3 years' experience of technology design and uses an AR application (Nintendo 3ds) once a week.
7.	HCI student, who has 1-3 years' experience in technology design and normally uses an AR application once a month.
8.	HCI Lecturer, who has 1-3 years' experience in technology design and uses AR technology once a month.
9.	HCI researcher, who has more than three years' experience in technology design.

Table 6.21: Demographic Background of the Participants in the Second Focus Group

6.8 SECOND FOCUS GROUP OUTCOMES AND RESULTS

This focus group was organised in the afternoon and lasted an hour. One of the participants (No.9) arrived 10 minutes late but completed all

of the tasks. The participants were assigned to different groups (see **Table 6.22**) in order to help them to discuss the issues with their partners in greater depth.

Group Number	**Participants**	
Group A	Participant 1: HCI Reader	Participant 2: HCI researcher
Group B	Participant 3: Older adults' research fellow	Participant 4: Older adults' information officer
Group C	Participant 5: Technology developer	Participant 6: Technology developer
Group D	Participant 7: HCI student	Participant 8: HCI lecturer
Group E	Participant 9: HCI researcher	

Table 6.22: Groupings of the Participants

During the Familiarisation activity, the organiser explained the aim and relevant terms of the research. The participants were particularly interested in road-testing the two AR prototypes after the organiser demonstrated them.

In terms of the second activity – collecting the Usability Issues, all of the participants wrote down their own issues initially, then listed the general issues after discussing these with their partner. Group A worked productively and produced two specific usability issues respectively for the AR Pillbox prototype and three general issues following their discussion. All of these issues were written down using complete sentences. Both of the participants in Group B provided three specific usability issues for the AR Pillbox and AR Reminder prototypes. After discussing the prototypes with each other, three general issues were also generated and clearly written down. Group C identified specific issues related to AR Pillbox and AR Reminder and Group D wrote down specific usability issues related to the AR Pillbox prototype. The HCI lecturer (Participant 8) led group D and the general issues were mainly his/her idea. Participant 9 in group E arrived slightly late and wrote down the generate AR issues for older adults directly after the organiser explained the relevant concepts of this focus group and demonstrated both of the prototypes. In the process of generating

general AR issues for older adults, all of participants engaged in an intense discussion. In all, 37 AR usability issues for older adults were collected through this activity (see **Table 6.23**).

Group Number	Specific Issues	General Issues	Total
Group A	4	3	7
Group B	6	3	9
Group C	6	3	9
Group D	6	3	9
Group E	0	3	3
All	22	15	37

Table 6.23: Specific and General AR Issues for Older Adults collected from the Second Focus Group

In the third activity – Matching principles with issues, all of the participants individually rated the relevance of the design principles and their three general issues from 1 to 5, except for group C.

Issue Number	Group Number	General issue content
General Issue 1.	Group A	'*How can the user recognise that they can use AR (If there is nothing like a QR code)?*'
General Issue 2.		'*Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.*'
General Issue 3.		*'Issues in targeting the correct AR (what if the wrong pillbox was shown?)'*
General Issue 4.	Group B	*'Engagement with object reliant on at lease some memory.'*
General Issue 5.		*'Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.'*
General Issue 6.		*'Acceptance: they have to accept / understand to some level that sort of technology.'*
General Issue 7.	Group C	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*
General Issue 8.		*'Technology issues with software/hardware. Apps crash + also need updating'*
General Issue 9.		*'How the information is presented. Is video the best format? It could depend on what is being treated. (Who will receipt this (GP/CARER/ Patient)'*
General Issue 10.	Group D	*'Screen size of device (readability); appropriate view - icon?'*
General Issue 11.		*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon'*
General Issue 12.		*'Reliance on a single device (battery could be that - may not be familiar with it's use'*
General Issue 13.	Group E	*'too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound'*
General Issue 14.		*'IPad - 'weight' - maybe a little bit heavy'*
General Issue 15.		*'it might open up the video by proxy of the IPad - not by touch's the video on the screen?'*

Table 6.24: General AR Issues for Older Adults identified in the Second Focus Group

The two developers evaluated the design principles as a group and agreed on their ratings before writing them down. All ten principles were placed on a central table, clearly and consistently presented with simple memorable acronyms in alphabetical order, which match the order in the first row of the matching forms. The participants produced 15 general issues and assessed the relevance between these 10 written principles and 15 AR usability issues for older adults (see **Table 6.24**).

Both the qualitative (the issues that were written down) and quantitative data (see the raw data on the relevant ratings in **APPENDIX A.36**) collected from the second focus group are more complete than that those obtained from the similar matching task carried out in the first focus group. This might be due to the time allocation and the amount and content of the tasks conducted in the second focus group.

In the fourth Summary activity, eight participants completed the questionnaire to evaluate this focus group. Some of the participants stated the advantages of this focus group, such as, in general, that it was *'well organised and well run'* (Participant 1). Firstly, the participants felt engaged and interested in this focus group. Participant 2 described it as *'Interesting grounds for research good level interaction and participation'.* Participants 5 and 6 also mentioned the word '*Interesting'* in their comments. Secondly, this focus group was learnable and useful for them. Participant 5 wrote that it was *'Good to see refurbishment of previous finding'* while Participant 2 mentioned *'learning about the augmented reality design principles and trying to apply them to issues'*. Some of the participants mentioned *'design principles'* (Participant 3) and '*Learning meaning about AR'* (Participant 6). Thirdly, the participants thought that it was helpful for '*identifying different issues*' (Participant 8) and views and also that it raised *'questions on principles and problems'* (Participant 7). In addition, Participant 4 stated that the best thing about this focus group was *'exchanging ideas'*, and that it was '*Good to discuss the subject with others and to enquire and evaluate the possibilities with AR…gaining*

new understanding of a subject' which he/she did not *'completely understand'*.

Conversely, the participants also pointed out the limitation of this focus group in terms of AR prototypes, raised issues, design principles and data collection methods. The participants suggested allowing *'a bit more time with the prototypes and their behaviours'* (Participant 1) *and 'an active AR DEMO on IPad maybe better'* (Participant 6). Participant 2 thought *'discussing the raised issues more would have been interesting'.* In terms of the design principles, a longer verbal explanation would have been useful (Participant 5) and also if the focus group had considered *'more aspects of augmentation other than visual*' (Participant 3). Participant 8 suggested that *'Experiential or video of use could help to explain/understand'* these design principles.

6.8.1 Theme-Based Content Analysis in Practice

Similarly to the first focus group**,** Theme-based content analysis (TBCA) (Neale & Nichols, 2001) was adopted in this focus group to analyse the qualitative usability issues. This section explains how TBCA was implemented in practice. The procedure was as follows:

1) Data collation. Based on the paper-based feedback from the collecting usability issues activity, all of the qualitative data (37 usability issues) were transcribed (see **APPENDIX A.33**).
2) Theme definition and classification. The raw data including the specific usability issues and agreed usability issues were then categorised under different raw data themes with their descriptions (see **APPENDIX A.34**).
3) Higher order theme selection. According to the categorised items, this analysis generated the higher or more general themes (see **APPENDIX A.35**).
4) Presentation of the classification matrix. The raw data themes and higher themes were presented in Figures (see **Section 6.8.2**).

6.8.2 Overall Themes of the AR Usability Issues

After analysing the raw data on the usability issues, all of these issues were classified into raw data themes with higher themes (see **Figure 6.9**). Most of these usability issues could be classified into different high themes similar to the classification of the design issues collected from the first focus group, which were based on the pre-established AR architecture. In the following sections (**Section 6.8.3-6.8.7**), these higher items will be discussed, respectively.

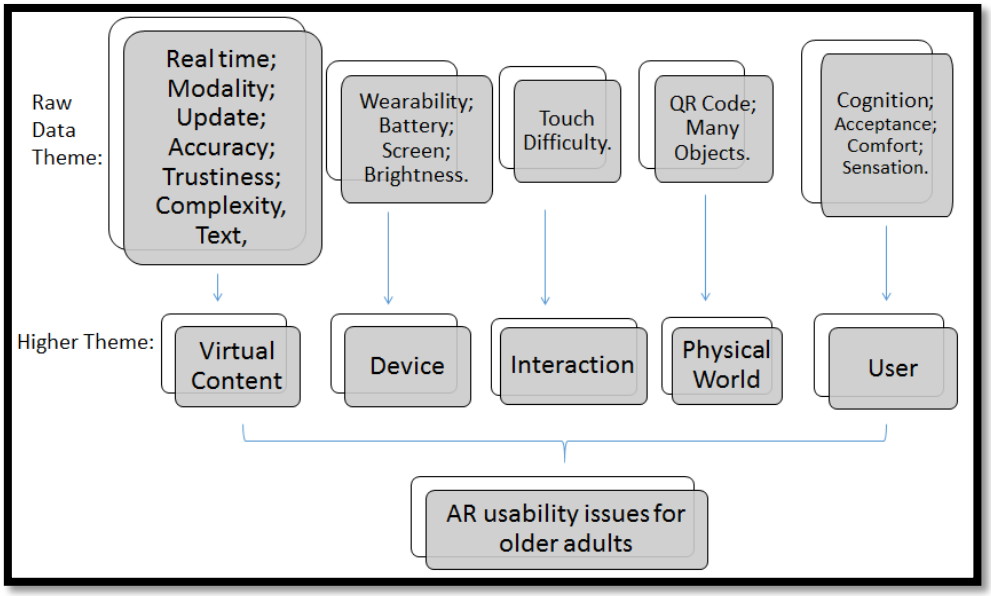


Figure 6.9: The Raw Data Themes and Higher Themes of AR Usability Issues for Older Adults gathered from the Second Focus Group

6.8.3 User Higher Theme

Under the *user* higher theme, all of the participants' comments were classified according to the raw data themes in terms of Cognition, Acceptance, Comfort and Sensation. The term *user* was defined in **Section 2.2**. The Comfort and acceptance themes were highly recommended, being mentioned five times respectively. All of these raw data themes were defined by this analysis based on the participants' feedback and the pre-defined themes' classification from the first focus group (see **Table 6.25**).

Raw Data Theme	Description
Comfort	All comments related to the comfort issues associated with wearing an AR device or using an AR system.
Cognition (Described in the first focus group)	All comments related to age-related changes in cognitive processing in terms of dementia, anxiety, low confidence, etc.
Sensation (Described in the first focus group)	All comments related to deficiency in different sensory modalities (e.g. visual, auditory).
Acceptance (Described in the first focus group)	All comments related to the user's technology acceptance in terms of understanding why users accept or reject AR technology.

Table 6.25: Description of the Raw Data Themes under the User Higher Theme

The **User comfort** raw data theme contained issues which could affect user comfort, including the difficulties of looking at a screen, wearing the device, etc.; for example, participant 2 wrote:

'When a user has a headache they may not want to be looking at a screen maybe have audio?'

Participant 8 also mentioned the issue of *'Drifting from subject due to weight and or unsteady hands'*.

Similar to the **raw data theme - cognition** (see **Section 6.4.2**) generated by the first focus group, **user cognition** consisted of memory- and attention-related issues. Participant 3 wrote down an issue related to AR Pillbox:

'If they cannot remember what the doctor has said. There is a good chance they won't remember login details'.

Since two of the participants had extensive experience of working for older adults with visual deterioration, **user with visual impairment** issues were highlighted under the Sensation raw data theme. Participant 4 emphasised several important issues related to the AR Reminder prototype from the perspective of older adults with visual impairment as follows:

‘Will there be a voice over/voice activated input/audio described element for someone who has poor vision? I think it could be a simpler device than a smart phone’.

The **User acceptance** raw data theme was the agreed usability issue and identified in the first focus group. It included issues related to reliance, ease of understanding, familiarity and accessibility. There are three general issues related to this raw data theme:

'Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.' - Group A

‘Physical accessibility; seeing the device/where the device issued being able to use a touch screen device.’ and ‘*Acceptance: they have to accept/understand to some level that sort of technology*’. - Group B

6.8.4 Virtual Content Higher Theme

Another higher theme - virtual content - was defined in **Section 2.2.3** and used as the higher theme for classifying the AR design issues in the first focus group. There were 13 usability issues related to virtual content, which was the highest number among all of the higher themes. Modality-related issues were mentioned four times, which was the highest number. Under the virtual content higher theme, seven raw data themes were generated and described (see **Table 6.26**)**.**

Raw Data Theme	Description
Real time	All comments related to how the virtual content could provide the real-time information.
Trustworthiness (Described in the first focus group)	All comments related to the wrong virtual content which did not match the physical objects.
Accuracy (Described in the first focus group)	All comments related to the virtual content properly registering onto the real content.
Modality	All comments related to the difficulties of using a single modality.
Update	All comments related to the difficulties associated with updating the virtual content and keeping it up to date.
Complexity (Described in the first focus group)	All comments related to the complexity of virtual content due to information overload.
Text (Described in the first focus group)	All comments related to the difficulties associated with recognising the text's size, type, etc.

Table 6.26: A Description of the Raw Data Themes of Virtual Content from the Second Focus Group

Interestingly, the issues relating to the **modality** raw data theme that were most frequently mentioned were not identified by the previous focus group; for example:

'Difficulty with hearing/sound not playing. Maybe needs subtitles.' (Participant 5)

'Too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound'. (Participant 9)

However, both the first and second focus groups mentioned the general issues relating to the Accuracy raw data theme after the participants' discussion:

'…if there are 2 packages next to each other and one of them is scanned. The AR layer will cover them both within two for one'. - written by Group C in the first focus group.

'Issues in targeting the correct AR (what if the wrong pillbox was shown?)' - written by group A in the second focus group.

6.8.5 Physical World Higher Theme

The **Physical world higher theme** was defined in **Section 2.2** and also identified by the first focus group. All of the comments made during this focus group related to the physical world theme concentrated upon issues related to many objects and QR code. The **Many objects** raw data theme could be described as any comments related to the difficulties associated with recognising many physical world objects; for example:

'If there are several pill boxes, might I misassociate the information?' (Participant 1).

'How to pick one box, when there are many available?' (Participant 8).

For the QR Code raw theme, Group A produced one of the general issues related to this:

'How can the user recognise that they can use AR (If there is nothing like a QR code)?'

Participant 2 also emphasised that:

'There is no distinguishable mark on the box to remind the user that they can use the app to find out more information'.

The QR code raw data theme was also identified by the first focus group based upon the participants' general issues. From the designer's perspective, it is important to consider whether it is necessary to design the QR code as the indictor and how to design it appropriately when designing an AR system.

6.8.6 Interaction Higher Theme

The **Interaction** higher themes were new themes, which were not mentioned by the first focus group. The term 'Interaction' was also pre-defined as the action between the user and AR device or virtual

content (see **Section 2.2.2**). The participants' comments related to the Touch Difficulty raw data theme were classified into Interaction higher themes. Participant 9 (Group E) wrote down one general issue for older adults:

'It might open up the video by proxy of the IPad - not by touches the video on the screen?'

6.8.7 Device Higher Theme

All of the comments related to the four raw data themes, including: **Battery, Brightness, Wearability** and **Screen** (see **Table 6.27**), were classified under the Device higher theme, which was pre-defined as an element of AR architecture and identified by the first focus group:

Raw Data Theme	Description
Battery	All comments related to issues related to power shortages and a low battery.
Brightness	All comments related to the impact of the device's light on the users.
Wearability (described in the first focus group)	All comments related to difficulties in using an AR device. (e.g. size and weight issues).
Screen	All comments related to the impact of the device's screen.

Table 6.27: The Raw Data Themes of Devices from the Second Focus Group

The idea for the Battery raw data theme arose from Participant 7's comments - *'Phone battery reliant, stuck if it runs'.* Participant 8 wrote that the AR Pillbox issue *'Maybe too dark to identify'*, which was classified under the Brightness raw data theme. Group 4 thought that one of the most important general issues was *'Screen size of device (readability); appropriate view - icon?'* Participant 9 was concerned that the weight of an IPad *'maybe a little bit heavy'*, which was classified under the Wearability raw data theme, that was discussed by the first focus group as well.

6.9 EVIDENCE FOR THE SECOND VERSION OF THE DESIGN PRINCIPLES

In order to assess the second version of the principles, the rate of the relevance between the principles and usability issues was collected from the matching principles activity of the second focus group. This research applied a descriptive statistical and sign test analysis procedure to these data (see **Section 3.7.2** and **Section 3.7.3**).

Nine participants generated 15 general issues and rated their relevance to ten design principles (five of the research's design principles and five existing ones. All of the raw data were transcribed.

General Issues No.	Raw Data Theme	Higher Theme	Participants	AA	AF	FA	HR	IA		LA	MA	PA	PFA	RCO
1	QR Code	Phyiscal World	P1	4	4	2	3	3		1	5	1	3.5	4
2	Acceptance	User	P1	2	3	4	5	4		4	4	1	3	2
3	Accuracy	Virtual Content	P1	5	2	2	1	4		5	3	2	3.5	4
1	QR Code	Phyiscal World	P2	2	4	5	2	3		2	2	1	1	4
2	Acceptance	User	P2	4	3	3	3	3		3	4	1	4	4
3	Accuracy	Virtual Content	P2	4	4	3	4	5		4	2	1	4	4
4	Cognition	User	P3	5	5	5	2	5		3	5	4	3	5
5	Acceptance	User	P3	1	5	2	3	1		2	4	2	5	3
6	Acceptance	User	P3	5	5	5	4	5		5	3	5	4	5
4	Cognition	User	P4	5	5	5	2	5		3	5	4	3	5
5	Acceptance	User	P4	2	5	2	3	1		2	4	1	5	3
6	Acceptance	User	P4	5	5	5	4	4		5	4	5	5	5
7	Cognition	User	P5	5	2	5	3	5		4	5	2	5	5
8	Update	Virtual Content	P5	5	5	4	3	4		4	4	4	2	4
9	Modality	Virtual Content	P5	2	4	5	5	4		5	5	2	5	5
7	Cognition	User	P6	5	2	5	3	5		4	5	2	5	5
8	Update	Virtual Content	P6	5	5	4	3	4		4	4	4	2	4
9	Modality	Virtual Content	P6	2	4	5	5	4		5	5	2	5	5
10	Screen	Device	P7	4	4	4	5	2		5	5	2	3	5
11	Accuracy	Virtual Content	P7	5	4	4	3	5		4	5	2	3	5
12	Battery	Device	P7	2	2	1	1	1		2	1	3	5	3
10	Screen	Device	P8	1	2	5	3	4		5	5	2	4	4
11	Accuracy	Virtual Content	P8	5	2	5	5	5		5	5	5	5	5
12	Battery	Device	P8	1	1	4	1	4		3	4	4	4	4
13	Modality	Virtual Content	P9	5	5	4	5	5		5	5	1	2	5
14	Wearability	Device	P9	1	2	1	1	1		1	2	1	5	1
15	Touch Difficulty	Interaction	P9	4	3	3	5	5		3	3	1	2	5

Table 6.28: The Raw Data on the Relevance between the Design Principles and the Issues

The raw data on the relevance between the design principles and general issues are shown in **Table 6.28**, alongside the relevant themes of these general usability AR issues for older adults The left-hand side

of the raw data shows the relevance rate between this research's second version of the AR design principles and the general issues in terms of **Instantaneous Augmentation (IA)**, **Layer-focus Augmentation (LA)**, **Modality-focus Augmentation (MA), Hidden Reality (HR)** and **Accurate Augmentation (AA).** The right-hand side of both tables (after the **Blank** column) shows the relevance rate between the existing AR principles and general issues, including **Reducing Cognitive Overhead (RCO), Physical-focus Augmentation (PFA), Familiarity-focus Augmentation (FA), Affordability (AF)** and **Privacy Augmentation (PA)** (for the list of the design principles, see **Table 6.20**).

Figure 6.10 provides a chart showing the means of the ten design principles' relevance. The Reducing Cognitive Overhead design principle had the highest rate of relevance, scoring 4.13. The score of 2.27 represented the lowest relevance between the privacy augmentation design principle (established by Kourouthanassis et al. (2013)) and general issues, which was the only score lower than 3.

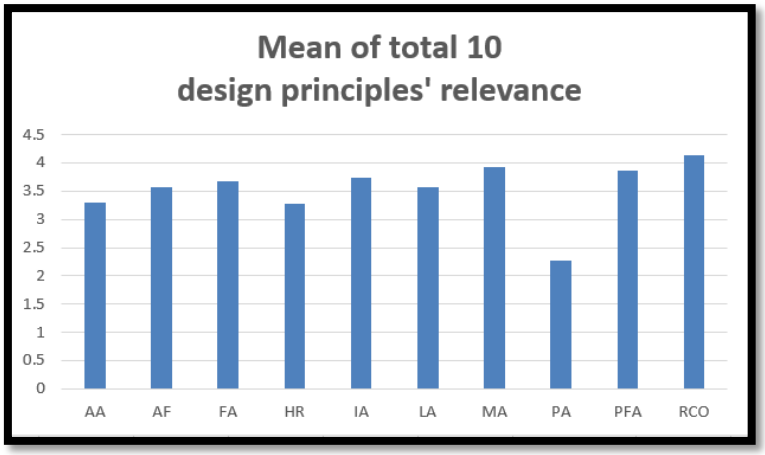


Figure 6.10: The Means of the Ten Design Principles' Relevance

Table 6.29 showed the means for all of the design principles' relevance in descending order. In the top five relevance rates, two of this research's design principles were involved: the Modality-focus Augmentation and Instantaneous Augmentation. In addition, the relevance rate for all this research's (second version) design principles

was over 3, which suggests that these principles are relevant to most of the general issues identified by the second focus group.

Ranking	Abbreviation of letters	AR design principles	Reference
1. (4.13)	RCO	Reducing Cognitive Overhead	(Dünser, Grasset et al. 2007).
2. (3.93)	MA	**Modality-focus Augmentation**	This research's design principles (second version).
3. (3.87)	PFA	Physical-focus Augmentation	(Dünser, Grasset et al. 2007).
4. (3.73)	IA	**Instantaneous Augmentation**	This research's design principles (second version).
4. (3.67)	FA	Familiarity-focus Augmentation	(Kourouthanassis, Boletsis et al. 2013).
6. (3.583)	AF	Affordability	(Dünser, Grasset et al. 2007).
6. (3.56)	LA	**Layer-focus Augmentation**	This research's design principles (second version).
8. (3.3)	AA	**Accurate Augmentation.**	This research's design principles (second version).
9. (3.27)	HR	**Hidden Reality**	This research's design principles (second version).
10. (2.27)	PA	Privacy Augmentation	(Kourouthanassis, Boletsis et al. 2013).

Table 6.29: The Order of Relevance of the Ten Design Principles (see this research's five principles in bold) and General Issues

However, this analysis cannot simply average these rates because some of the relevance was commented on by two people; for example, both Participants 1 and 2 evaluated the Accurate Augmentation (AA) design principle by using the second general issue and rated their relevance as 2 (irrelevant) and 4 (relevant), respectively. It is difficult to ascertain that the mean 3 (the average of 2 and 4) represents the relevance rate between the AA design principle and the second general issue because these are categorical in nature. Therefore, this

research applies the sign test to determine the significant difference of AR issues' relevance between this research's design principles and the existing ones. This research adds all of the relevant rates of the second version principles for every issue for each participant as the first set of sample data and uses the relevance rate for the existing principles as the second set of sample data. The null hypothesis is that there is no difference in the relevant rating between the research's design principles and the existing ones. The alternative hypothesis is that there exists a difference between the two.

Case	This researh's AR design principles	The existing AR design principles	Difference
1	16	14.5	+
2	19	13	+
3	18	13.5	+
4	11	15	-
5	17	15	+
6	19	16	+
7	20	22	-
8	11	17	-
9	22	24	-
10	20	22	-
11	12	16	-
12	22	25	-
13	22	19	+
14	20	19	+
15	21	21	0
16	21	18	+
17	22	18	+
18	7	14	-
19	18	17	+
20	25	22	+
21	13	17	-
22	25	17	+
23	6	10	-
24	20	14	+

Table 6.30: The Difference in Relevance Ratings between the Research's Design Principles and the Existing Ones

The differences between this research's design principles and the existing ones contained 13 positives (n+) and 10 negatives (n-). The sample size for this question was 24, with one zero, so $N=n_+ + n_-=23$ and $r=\min(n_+,n_-)=10$. Therefore, the two-sided p-value (see the binomial tables in **APPENDIX A.37**) is p = 5.74E-08<0.05. If there is no difference between the research's design principles and the existing

ones, the portability of a result p should be less than 0.05 (a two-side significant level). Therefore, it may be concluded that there exists no evidence of a difference between the two sets of design principles. One of the reasons for this might be that these general issues vary. Some of this research's design principles could address or solve some of the issues while some of the existing principles could deal with other issues.

Because this research's design principles focus on designing virtual content for an AR system, some of these general issues are also classified under the virtual content higher theme. Therefore, this research can assess the relevance of the augmentation-related issues in the two sets of design principles using a sign test. The null hypothesis is that there is no difference regarding the relevant rate between this research's principles and the existing ones in terms of augmentation-related issues. The alternative hypothesis is that a difference does exist between the two. A list of augmentation-related issues (general issues no.3, no.8, no9, no.11 and no13) were highlighted (**Table 6.31**). The differences between this research's principles and the existing ones had 6 positives (n+) and 0 negatives (n-). The sample size for this question was 7, with one zero, so $N=n_+ + n_-=6$ and $r=\min(n_+,n_-)=0$. Therefore, the two-sided p-value (from the binomial tables) is $p = 0.735>0.05$. Because the null hypothesis is not rejected at a significance level of $p = 0.05$, a difference does exist between the two sets of design principles in terms of virtual content related to issues for older adults.

However, while these results are potentially relevant, they cannot be statistically confirmed because this was not the hypothesis that drove the empirical focus group.

Case	This researh's AR design principles	The existing AR design principles	Difference
1	16	14.5	+
2	19	13	+
3	**18**	**13.5**	**+**
4	11	15	-
5	17	15	+
6	**19**	**16**	**+**
7	20	22	-
8	11	17	-
9	22	24	-
10	20	22	-
11	12	16	-
12	22	25	-
13	22	19	+
14	**20**	**19**	**+**
15	**21**	**21**	**0**
16	21	18	+
17	**22**	**18**	**+**
18	7	14	-
19	18	17	+
20	**25**	**22**	**+**
21	13	17	-
22	**25**	**17**	**+**
23	6	10	-
24	20	14	+

Table 6.31: The Differences regarding the Relevant Rate between the Research's Principles and the Existing Principles, highlighting Virtual Content-related Issues

6.10 DISCUSSION

In terms of the themes' classification regarding AR usability issues for older adults, further raw data themes were generated by this focus group. Fourteen raw data themes were identified by the first focus group and 18 by the second one. This result may be due to the fact that some of the participants attended both focus groups and so had pre-experience of road-testing the AR applications for older adults, which might have helped them to identify a variety of usability issues. In addition, as mentioned in **Section 6.7**, the second focus group participants had more design and academic experience related to using AR technology and designing for older adults than did the first focus group. Hence, they may have had a better understanding of AR issues for older adults.

The second focus group adopts five pre-defined elements from AR architecture (**Section 2.2**) as the higher themes for categorising the raw data themes in terms of virtual content, device, interaction, physical world and user. Compared with the first focus group, a new higher theme - interaction - was identified by the second focus group, which focused on touch issues. Issues related to the Server higher theme did not feature in this focus group. The elements of AR architecture could be applied as the higher theme classification of AR issues in both focus groups. This consistency may be due to the clear definition of each element and the completeness of this AR architecture.

In addition, there were more raw data themes relating to the **Device** and **User** higher theme in the second focus group than in the first one. Four raw data themes (**Wearability, Screen, Cognition, Acceptance**) under the Device and user higher theme related to the agreed usability issues after the discussion of the second focus group participants. Only one, the **Acceptance** raw data theme, was identified from the general design issues of the first focus group. Instead of focusing on the AR itself, designers could pay more attention to device- and user-related issues in light of the AR usability issues for older adults.

Fifteen general AR usability issues for older adults (see **Table 6.24**) were established by the participants' discussion, which needed to be assessed for the second version of the design principles. However, with a small sample size and incapacity to analyse the seriousness of these issues, these results need to be interpreted with caution. According to the result for the relevance between all ten design principles (including this research's five design principles and five existing ones) and general issues, the Reducing Cognitive Overhead (RCO) design principle (Dünser et al., 2007) was rated the highest (average rate = 4.13) of the principles. Hence, it could conceivably be hypothesised that the RCO design principle is more relevant regarding AR usability issues for older adults than the other design principles. Nevertheless, it is difficult to explain this result as indicating that RCO is more useful than the other principles because these 15 general

issues vary greatly. The relevance rate between the Privacy Augmentation (PA) design principle established by Kourouthanassis et al. (2013) and the agreed usability issues scored the lowest (average=2.27) of the ten principles, which was the only relevance rating for a principle lower than 3. Neither focus groups identified any agreed issues for older adults relating to privacy, although confidentiality-related issues were mentioned as a specific issue by Focus Group one. Possibly, when the designers noted the importance of privacy issues, but did not treat them as significant and universal usability issues.

6.11 CHAPTER SUMMARY

After conducting two focus groups to assess the design principles for older adults (involving participants with experience of either technology design or older adults), some of the key themes related to general older adults' requirements and AR-related issues have been identified. The general older adults' requirements collected from the familiarisation activity of the first focus group can be classified under the higher theme of **Individual**, **Family** and **Society**, together with eight raw data themes, including **Sensation**, **Perception**, **Mobility**, **Interest, Treatment, Support of relatives and Support of social people and groups.** It is crucial to understand the capabilities and limitations of older adults in order to undertake the fundamental work of facilitating appropriate designs that capitalise on older adults' strengths and capabilities while guarding against the limitations. The AR-related issues (seven agreed and 28 specific design issues from the first focus group, 15 agreed and 22 specific usability issues from the second one) for the older adults collected from participants are classified into 25 raw data themes, including: **Text**, **Real time, Modality**, **Update**, **Video**, **Alarm**, **Iconography**, **Accurate**, **Confidentiality**, **Trustworthiness**, **Personalisation**, **Complexity**, **Wearability**, **Battery**, **Screen**, **Brightness**, **Touch Difficulty**, **Many objects**, **Internet**, **QR code**,

Cognition, **Comfort**, **Sensation**, **User goal** and **User acceptance**. In order to categorise these raw data themes, this research finds the possibility of applying seven pre-defined terms: **Device**, **Virtual content**, **Device**, **Interaction**, **Server**, **Physical World and User** from the elements of AR architecture (see **Section 2.2**) for the higher themes. Then, the first focus group participants commented on the relationship between the first version design principles and the seven agreed design issues in terms of: irrelevant, relevant, solve and minus.

Following the first focus group, this research analysed how these principles are related to the themes of the AR issues, what could be the relationship between the principles and issues (see **Table 6.13**-**Table 6.18** and identified the second version of the AR design principles. By combining the characteristics of two similar design principles (**Diminished Augmentation** and **Transparent Augmentation**) in the first version, a new design principle - **Hidden Reality** - was generated in the second version. The **Modality-rich Augmentation** and **Augmented Augmentation design principles** in the first version were changed to **Modality-focus Augmentation** and **Layer-focus Augmentation**, which are broader terms. This chapter redefined the meaning of all five of the second version design principles and reworded their explanations. The **Diagrammatic examples** of the first version of the design principles are divided into **Diagrams** and **examples** in the second version, which use the abstract graphical annotation and practical AR application to illustrate the meaning of these principles more fully. The second version of the AR design principles omits the **Motivation** and **Basis** items and adds the **Benefit or Problem Solving** item in order to discuss the possibility and benefits of applying these principles and what sort of design issues might be addressed or solved as a result. However, the second version of the AR design principles are only identified based on seven agreed AR issues for older adults and the relevant themes of these issues. In order to establish a full set of AR design principles for older adults, the second focus group assessed the second version principles by

comparing them with other existing ones with the AR issues for older adults. The participants matched the general usability issues identified in the second focus group with the ten design principles (five established by this research and a further five drawn from the existing literature). The relevance ratings for the design principles with regard to general usability issues are summarised in **Table 6.28**. The Reducing Cognitive Overhead (RCO) design principle (Dünser et al., 2007) received the highest rating (average rate = 4.13). The relevance rating between the Privacy Augmentation (PA) design principle established by Kourouthanassis et al. (2013) and the agreed usability issues was the lowest (average=2.27) of the ten principles, and the only principle to receive a relevance rating lower than 3. However, due to the varied general issues, it is difficult to determine that the RCO design principle is more useful than the PA principle.

The participants in both focus groups also provided some paper-based suggestions regarding where these design principles could be implemented, what their limitations are, and some newly-developed design principles.

Based on the feedback and results of these two focus groups, the following chapter will discuss the assessment of the second version research design principles and how to identify the third version of the AR design principles.

CHAPTER 7 ESTABLISHMENT OF THE AUGMENTED REALITY DESIGN PRINCIPLES FOR OLDER ADULTS

Chapter 5 evaluated the relevance between the second version of the design principles and 15 general AR usability issues related to older adults. This chapter assesses the advantages and disadvantages of the five second version design principles for this research based upon their corresponding usability issues and relevance rating. This assessment provides a further iteration of the (third version) AR design principles for older adults. In addition, this chapter evaluates how these principles could match the existing AR applications in order to apply them in practice.

7.1 RELEVANT ISSUES OF THE SECOND VERSION OF THE AR DESIGN PRINCIPLES

Table 6.28 showed the relevance between the second version of the AR design principles and general issues (see **Table 6.24**). In general, all of the second version of design principles (**Instantaneous Augmentation**, **Layer-focus Augmentation**, **Modality-focus Augmentation**, **Hidden Reality** and **Accurate Augmentation**) are relevant to the No.13 general AR issue for older adults, according to the participants' relevance rating. No.13 issue is: '*too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound*' (all ratings = 5).

In contrast, all of these principles are irrelevant to the No.12 issue (mean<3), which focuses on the wearability of AR devices: '*IPad - 'weight' - maybe a little bit heavy*'. The participants also mentioned two

further important issues (no.14 and No. 10), but it is still difficult to identify a strong relationship with this research's principles. All of the principles mainly focus on how to improve or simplify the virtual content within an AR system rather than improving the AR device wearability or battery. Hence, all of the second version design principles are relevant to the AR usability issue (No. 13) in terms of simplifying the complex virtual content while also enriching its modality and interaction.

Nevertheless, the second version design principles are limited in terms of resolving AR issues relating to AR devices (e.g. the weight of an IPad). The five existing design principles (**Reducing Cognitive Overhead**, **Physical-focus Augmentation**, **Familiarity-focus Augmentation**, **Affordability** and **Privacy Augmentation**) are relevant to No.6 general issue (both of the participants who commented on this rated it >4). The No.6 issue is: '*Acceptance: they have to accept/understand to some level that sort of technology*'. Hence, compared with the second version of the design principles, the other five existing principles are more relevant to the AR usability issue (No. 6) in terms of user acceptance.

Based on the relevant themes of these general usability AR issues for older adults (**Table 7.1**) summarised from **Section 6.8.2** and the relevance rate collected from the participants' feedback (**Table 6.28**), the second version design principles are discussed respectively in **Section 7.1.1**-**Section 7.1.5**.

Issue Number	General issue content	Raw Data Theme	Higher Theme
General Issue 1	'*How can the user recognise that they can use AR (If there is nothing like a QR code)?*'	QR Code	Phyiscal World
General Issue 2	'*Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.*'	Acceptance	User
General Issue 3	*'Issues in targeting the correct AR (what if the wrong pillbox was shown?)'*	Accuracy	Virtual Content
General Issue 4	*'Engagement with object reliant on at lease some memory.'*	Cognition	User
General Issue 5	*'Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.'*	Acceptance	User
General Issue 6	*'Acceptance: they have to accept / understand to some level that sort of technology.'*	Acceptance	User
General Issue 7	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*	Cognition	User
General Issue 8	*'Technology issues with software/hardware. Apps crash + also need updating.'*	Update	Virtual Content
General Issue 9	*'How the information is presented. Is video the best format? It could depend on what is being treated. (Who will receive this (GP/CARER/ Patient)'*	Modality	Virtual Content
General Issue 10	*'Screen size of device (readability); appropriate view - icon?'*	Screen	Device
General Issue 11	*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon.'*	Accuracy	Virtual Content
General Issue 12	*'Reliance on a single device (battery could be that - may not be familiar with it's use.'*	Battery	Device
General Issue 13	*'too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound.'*	Modality	Virutal Content
General Issue 14	*'IPad - 'weight' - maybe a little bit heavy.'*	Wearability	Device
General Issue 15	*'it might open up the video by proxy of the IPad - not by touch's the video on the screen?'*	Touch Difficulty	Interaction

Table 7.1: The Raw Data Themes and Higher Themes regarding General AR Usability Issues for Older Adults, collected from the First Empirical Stage (Focus Group 1)

These sections firstly summarise the participants' feedback in terms of the ratings for the relationships between issues and principles, then analyses the reliability of these comments; for example, if the participants rated a principle as relevant to one issue, this research explains that this principle either improves or exacerbates this issue. If the participants state that a principle was irrelevant or hard to justify, this research could discuss their comment. However, some of the participants' comments are unreliable, possibly for the following reasons:

- The participants did not understand completely the meaning of the term “design principle”.
- It is difficult to guarantee all of the participants were focused on identifying the relationships between the ten different principles and general issues within a short time period.

7.1.1 The Relevant Issues of Hidden Reality

Based on the feedback of the second focus group, the relevance rate of Hidden Reality (HR) was ranked ninth out of the ten design principles, which is in fourth place in terms of this research's design principles (see **Table 6.29**).

After analysing the feedback on matching the Hidden Reality design principle with all general AR usability issues (see **APPENDIX B.1**), five issues were found to be obviously relevant to the HR principle: No.3, No.9, No. 11, No.13 and No.15. **Table 7.2** shows the relevant issues and how these might be related to the HR principle.

Issue No.	Raw Data Theme	Higher Theme	Relationship
No. 9 and No. 13	Modality	Virtual Content	Address or solve: Vibration or audio virtual content could be applied by decreasing the amount of virtual content and revealing more real content depending on different users' tasks.
No. 11 and No. 3	Accuracy	Virtual Content	Address or solve: Provide some ideas for designers to help users clearly to understand that the overlaid virtual content is relevant to the surrounding real content, indicating the physical world object in a particular position.
15.	Touch Difficulty	Interaction	Raise the issue: Weaken the impact of virtual content; smaller icons (virtual content) could make it difficult for users to touch the screen.

Table 7.2: AR Issues for Older Adults related to the Hidden Reality Design Principle

In summary, the HR design principle could provide the possibility of addressing or solving AR issues in terms of changing the modality of the virtual content and enhancing its accurate registration; for example, applying vibration or audio virtual content could decrease the amount of virtual content and reveal more real content depending on the different users' tasks. Taking another example, if too many objects are next to each other (e.g. two or more physical pillboxes) and one of them need to be recognised, applying the HR design principle could provide some ideas to enable designers to help users clearly to understand that the overlaid virtual content is relevant to the surrounding real content, indicating the physical world object in a particular position.

The HR principle could, however, also increase the difficulty of interacting with virtual content; for example, in order to weaken the impact of the virtual content, smaller icons (virtual content) could make it difficult for users to touch the screen. Therefore, applying the HR principle needs to satisfy the characteristics of older adults' physical and cognitive needs.

Interestingly, these relevant issues and possible design alternatives could also reveal a connection between different principles; for example, the possible design alternatives of the HR principle, focusing on the Modality-related theme, could address the issues caused by the Modality-focus Augmentation principle (see **APPENDIX A.14**).

7.1.2 The relevant issues of Modality-focus Augmentation

Based on the feedback of the second focus group, the relevance rate of Modality-focus Augmentation (MA) was ranked second out of the ten design principles, which is the highest of this research's design principles (**Table 6.29**).

After analysing the feedback on the matching Modality-focus Augmentation (MA) design principle and general issues (see **APPENDIX B.2**), seven relevant issues related to the MA design principle were identified. **Table 7.3** shows the themes of the general issues related to the MA principle.

Issue Number	Raw Data Theme	Higher Theme	Relationship
No.2, No. 5 and No. 6	Acceptance	User	Address or solve: Provide designers with different design alternatives to address older adults' issues.
No. 4 and No. 7	Cognition	User	Address or solve: Changing the modality of the virtual content (e.g. from visual to audio) may help designers to find design alternatives, which could meet the cognitive characteristics of the users.
No. 9. and No. 13	Modality	Virtual Content	Address and solve: Emphasising the variety of virtual content's modality (e.g. vibration or an audio reminder) might give designers different options regarding finding the appropriate modality.

Table 7.3: AR Issues for Older Adults related to the Modality-focus Augmentation Design Principle

The main reason for this principle having a high level of relevance to AR issues for older adults might be that it emphasises the diversity of how virtual content can be presented (e.g. visual, audio, vibration, etc.), depending on the users' goals. As older adults' ability deteriorates in terms of vision, hearing, etc., adjusting or focusing on the modality of

the virtual content could provide designers with different design alternatives for addressing the older adults' issues in terms of their acceptance and cognition. Further raw data theme described as Modality is clearly related to the MA principle; for example, focusing on the transformation of different modalities (e.g. from text only to sound and other interactive buttons, and *vice versa*) could help designers to simplify the virtual content and enrich it interactively and dynamically.

Similarly to the previous design principle - Hidden Reality - the third version of the AR design principles reworded the **Benefit or Problem solving** category by adding relevant themes to the issues, possible design alternatives and the limitations of this principle.

7.1.3 The Relevant Issues of Instantaneous Augmentation

Instantaneous Augmentation (IA) was ranked fourth out of the ten design principles in terms of its relevance, which is in the second place of this research's design principles (**Table 6.29**). After analysing the feedback on the matching Instantaneous Augmentation (IA) design principle and general issues (see **APPENDIX B.3**), eight relevant issues related to IA design principles were identified. **Table 7.4** shows the themes of these general issues related to the IA principle.

Issue Number	Raw Data Theme	Higher Theme	Relationship
No. 2, No. 5 and No. 6	Acceptance	User	Raise: The newly-generated virtual content might not be easy to understand by older adults who are unfamiliar with using AR. Designing informative feedback could place an additional cognitive burden on users, who might not understand the meaning of the informative feedback.
No.4 and No. 7	Cognition		
No. 3 and No. 11	Accuracy	Virtual Content	Address or solve: Designers could develop different informative reminders by employing the IA design principle to instruct the users where the virtual content is about to appear.
General Issue 8	Update	Virtual Content	Address or solve: Before generating the virtual content, designers could begin to consider error reminders or updating indicators in order to address App crashes and updating issues by applying the IA design principle.

Table 7.4: AR issues for Older Adults related to the Instantaneous Augmentation Design Principle

After summarising the relevance of the IA design principle and general issues, it was found that the former can provide designers with several design alternatives for resolving AR issues under the following two themes: the accuracy of the virtual content and the updating of the virtual content. In addition, in terms of the AR issues for older adults related to users' acceptance and user cognition, employing this design principle might instruct the users on what virtual content will appear or even suggest some tips or reminders related to the virtual content. However, the informative feedback might still be difficult for older adults to understand. Therefore, designing understandable and simple informative feedback is an important consideration when applying this principle in practice.

7.1.4 The Relevant Issues of Layer-focus Augmentation

Layer-focus Augmentation (LA) was ranked sixth out of the ten design principles with regard to relevance, which is in the third place of this research's design principles (**Table 6.29**).

Issue Number	Raw Data Theme	Higher Theme	Relationship
No. 2, No. 5, No. 6, No.4 and No.7	Acceptance Cognition	User	Address or solve: Adjusting the layers of the virtual content mainly aims to enhance the user's familiarity, make the virtual content easy to understand and reduce the cognitive overload of users.
No. 3 and No. 11	Accuracy	Virtual Content	Address or solve: Separating the virtual content into various small layers could help the user to understand which virtual content is overlaid with the corresponding physical object.
No 15	Touch Difficulty	Interaction	Raise: Although bringing the possibility of enriching the diversity of the virtual content (e.g. a virtual image can be divided into different layers, including buttons, signs, bubbles, etc.), more dynamic and playful virtual content might be difficult for users to touch.

Table 7.5: AR Issues for Older Adults related to the Layer-focus Augmentation Design Principle

After analysing the feedback on matching the Instantaneous Augmentation (IA) design principle and general issues (see **APPENDIX B.4**), eight relevant issues associated with the IA design principle were

identified. **Table 7.5** shows the themes of the general issues related to the IA principle. The summary of the positively relevant issues of the LA design principle shows that it can provide designers with different design alternatives for addressing the AR issues under the following relevant themes: user acceptance, user cognition and accuracy of virtual content, but might cause difficulty with regard to touching the screen, if a whole virtual image is divided into different layers, including buttons, signs, bubbles, etc., which may make users feel confused about the location of the touch point. Therefore, when applying this principle, it is important to consider how to distribute the virtual content in a structured manner. It is also important to work out what information needs to be kept and which information is less important and so can be hidden.

7.1.5 The Relevant Issues of Accurate Augmentation

The relevance rate of Accurate Augmentation (AA) was ranked eighth out of the ten design principles, which is in fourth place for this research's design principles (**Table 6.29**).

Issue Number	Raw Data Theme	Higher Theme	Comments by this research
No. 2.	Acceptance	User	Hard to say, depending on the level of their familarity.
No .6.			Address or solve: Make the virtual content easy-to-understand.
No. 4. and No. 7.	Cognition		Address or solve: If some of the virtual content is incorrectly placed, overlaying the physical world, the burden on the users' cognition might be increased and they might find it difficult to understand the relationship between the virtual content and physical world information.
No. 3.	Accuracy	Virtual Content	Address or solve: The clear advantage of employing the AA design principle is to provide design alternatives in order to generate accurate virtual content that is in the correct position after recognising the physical world objects.
No.11.			
No. 13.	Modality		Address or solve: When providing more interactive or dynamic virtual content, it is vital to ensure that the AR registration is accurate.

Table 7.6: AR Issues for Older Adults related to the Accurate Augmentation Design Principle

After analysing the feedback on the matching between the Accurate Augmentation (AA) design principle and general issues (see **APPENDIX B.5**), six relevant AA design principle issues were identified. **Table 7.6** shows the themes of the general issues related to the AA principle.

By summarising the relevant issues regarding the AA design principle, it was found that this design principle may provide designers with different design alternatives for addressing the AR issues related to the following themes: user acceptance, user cognition and the accuracy and modality of the virtual content. All of the possible design alternatives are shown in **Table 7.6**. In terms of user acceptance, the participants suggested that it is difficult to justify the relationship between the AA principle and familiarity issues. This might be associated with the level of the users' familiarity. Although the position of the virtual content is relatively accurate in corresponding with physical world objects, the users may still feel confused if they are very unfamiliar with any sort of technology.

Similar to the previous design principles, the third version of Accurate Augmentation added the relevant themes of the issues and possible design alternatives under the **Benefit or Problem solving** category and also summarised the limitations of the principles.

7.2 THE THIRD VERSION OF THE AUGMENTED REALITY DESIGN PRINCIPLES

7.2.1 Hidden Reality Design Principle

The enhancement of the new AR principle (third version) is designed to complete the **Benefit or Problem solving category** by adding the relevant themes of the issues and possible design alternatives. In addition, the third version principles also added the **Trade-off category**

to discuss how to deal with the raised relevant issues and how to apply this principle in an appropriate manner (see **Table 7.7**).

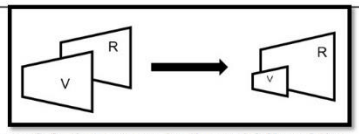
Name	**Hidden Reality (HR)**	
Definition	Virtual content overlies or hides the real content, where the real content is not required to achieve users' goals.	
Explanation	When users use the AR device, the virtual content hides or obscures some of the real content. The design of the virtual content needs to take into account what will be hidden as much as what will be shown. Although users should benefit from seeing the virtual content, the virtual content should not hide real content that might be useful.	
Diagram	In the AR system shown on the left-hand side of this diagram, the virtual content (V) is overlaid onto the real content (R) and partially obscures the real content. In order to uncover the hidden real content which is meaningful or useful, the arrow in the middle of the diagram points out the new AR system (on the right-hand side) and combines the appropriate virtual and real content by adjusting the size of the virtual content. 	
Example - Word lens (Word Lens 2012)	Word lens AR translator generates the virtually translated words, which replace the real-world words. This supports the goal of understanding what is written in Spanish. It is important to note that, if the goal were to support learning Spanish, the hidden reality in this design prevents the user from simultaneously seeing both the Spanish and its English equivalent. Design decisions that take account of hidden reality require careful consideration of which user goals to support. 	
Benefit or Problem Solving	Themes of AR Issues	Design Alternatives
	Virtual content - Modality	Vibration or audio virtual content could be applied by decreasing the amount of virtual content and revealing more real content depending on the different users' task.
	Virtual content - Accurate	Provide some ideas for designers to help users clearly to understand that the overlaid virtual content is relevant to the surrounding real content, indicating the physical world object in a particular position.
Trade-off	Weakening the impact of the virtual content, the smaller size icon (virtual content) could make it difficult for the users to touch the screen. It is important to satisfy the characteristics of older adults' physical and cognitive needs.	

Table 7.7: The Third Version of AR Design Principles - Hidden Reality

7.2.2 Modality-focus Augmentation Design Principle

Similarly to the previous design principle - Hidden Reality -, the third version of the AR design principles reworded the **Benefit or Problem solving** category by adding the relevant themes of the issues, possible design alternatives and the limitation of this principle (see **Table 7.8**).

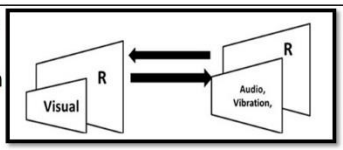
<table>
<tr><td>Name</td><td colspan="2">Modality-focus Augmentation (MfA)</td></tr>
<tr><td>Definition</td><td colspan="2">Virtual content can be provided in different modalities (such as visual, audio, vibration, etc.), depending on the users' goals.</td></tr>
<tr><td>Explanation</td><td colspan="2">When users use the AR device, the virtual content hides or obscures some of the real content. The design of the virtual content needs to take into account what will be hidden as much as what will be shown. Although users should benefit from seeing the virtual content, the virtual content should not hide real content that might be useful.</td></tr>
<tr><td>Diagram</td><td colspan="2">Figure shows a diagram of the Modality-focus Augmentation design principle. The arrow from left to right in the middle of this diagram shows that the visual-based AR system on the left-hand side of the diagram could be transformed into other modalities, including audio-based and haptic-based augmentation. The additional top arrow (from right to left) represents the meaning of the Modality-specific idea, which reduces the number of modalities from multi-modality (e.g. audio plus vibration) to a single modality (e.g. visual-based augmentation).
  </td></tr>
<tr><td>Example - The Lund Time Machine application (Szymczak 2011)</td><td colspan="2">The Lund Time Machine application (Szymczak 2011) is an AR tourist guide. This application uses both the users' location (GPS) and the orientation (compass) of the device (mobile phone) they are holding to give audio or tactile feedback.
  </td></tr>
<tr><td rowspan="3">Benefit or Problem solving</td><td>Themes of AR Issues</td><td>Design Alternatives</td></tr>
<tr><td>User - Acceptance and Cognition</td><td>Changing the modality of the virtual content (e.g. from visual to audio) might help designers to find the design alternatives, which could meet the cognitive characteristics of users.</td></tr>
<tr><td>Virtual Content - Modality</td><td>Emphasising the variety of virtual content's modality (e.g. vibration or audio reminder) might give designers different options when seeking an appropriate modality.</td></tr>
</table>

Table 7.8: The Third Version of the AR Design Principles - Modality-focus Augmentation

7.2.3 Instantaneous Augmentation Design Principle

The newly-generated virtual content could also place an additional cognitive burden on users, who might be unfamiliar with it (see the third version of the IA design principles in **Table 7.9**).

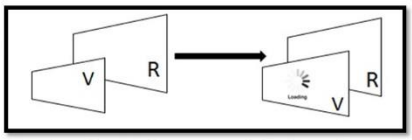
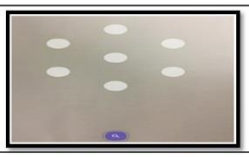
Name	Instantaneous Augmentation (IA)	
Definition	If the virtual content cannot be displayed promptly, then provide prompt and informative feedback to the users.	
Explanation	AR designers commonly aim to generate virtual content instantaneously after, say, scanning an object in the physical world. When the process of generating virtual content is delayed (due to computational complexity, poor connectivity, etc.), users can become frustrated or confused. User confusion can be reduced if feedback about any delay can be provided, thus informing users that the AR application is processing, searching, etc.	
Diagram	The V-R Augmented Reality system presents that the virtual content (V) is the overlay of real content (R) on the left-hand side of the diagram. The right-hand side of this diagram represents the formative feedback (e.g. the loading information) before the main virtual content is generated. 	
Example - Aurasma (Aurasma 2016)	If users try to scan one of the physical pictures and see the virtual content, six grey circular points will appear immediately to remind them that the AR application is ready to capture physical-world information. The virtual content will pop up next. 	
Benefit or Problem solving	Themes of AR Issues	Design Alternatives
	Virtual Content - Accuracy and Update	Designers could develop different informative reminders by employing this design principle to instruct users where the virtual content is about to appear.
Trade-off	The newly-generated virtual content might not be easy to understand for older people who are unfamiliar with using AR. Designing Informative feedback could place an additional cognitive burden on users, who might not understand what the information means. Designing simple, understandable informative feedback is an important consideration when applying this principle in practice.	

Table 7.9: The Third Version of the AR Design Principles - Instantaneous Augmentation

7.2.4 Layer-focus Augmentation Design Principle

Compared with the other research principles, both the Hidden Reality and Layer-focus Augmentation principles are relevant to the **Interaction-related** AR issues and raise issues (see the third version of the IA design principles in **Table 7.10**).

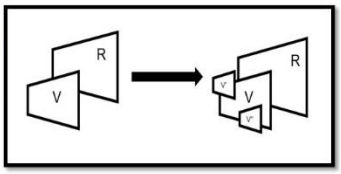
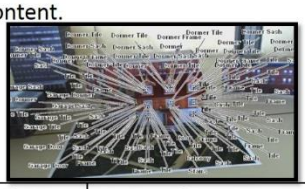
<table>
<tr><td>Name</td><td colspan="2">Layer-focus Augmentation (LfA)</td></tr>
<tr><td>Definition</td><td colspan="2">Where more than one piece of virtual content is required, these can be displayed in separate layers if that supports the users' goals.</td></tr>
<tr><td>Explanation</td><td colspan="2">Virtual content can be grouped in many ways, so it is important to ensure that the groupings match the likely needs of the users. The layer-focus principle is to consider what information should be provided collectively to support users' goals and what information should be separately accessed by the users. If this principle is not followed, users will encounter increased operational complexity with regard to finding the information they need.</td></tr>
<tr><td>Diagram</td><td colspan="2">The left-hand side of the diagram represents the AR system in which the virtual content (V) is overlaid onto the real content (R). The arrow from left to right aims to show the idea of separating a large amount of virtual content into different groups (shown on the right-hand side of this diagram V1, V2 and V3).
  </td></tr>
<tr><td>Example - Dynamic Compact (Tatzgern, Kalkofen et al. 2013)</td><td colspan="2">Unfiltered augmentations (left figure) may quickly lead to clutter and thus decrease the comprehensibility of the resulting visualisation. Similar items (right figure) have been clustered by different groups, and representatives have been selected from each cluster. This allows us to reduce the amount of augmentation while still presenting an annotation to each available piece of virtual content.
   </td></tr>
<tr><td rowspan="3">Benefit or Problem solving</td><td>Themes of AR Issues</td><td>Design Alternatives</td></tr>
<tr><td>User - Acceptance and Cognition.</td><td>Adjusting the layers of the virtual content mainly aims to enhance the user’s familiarity, make the virtual content easy to understand and reduce the cognitive overload of users.</td></tr>
<tr><td>Virtual Content - Accuracy.</td><td>Separating the virtual content into various smaller layers may help the user to understand which piece of virtual content is overlaid with the corresponding physical object.</td></tr>
<tr><td>Trade-off</td><td colspan="2">Although creating the possibility of enriching the diversity of the virtual content (e.g. a virtual image could be divided into different layers, including buttons, signs, bubbles, etc.), more dynamic and playful virtual content could be difficult for users to touch. When applying this principle, it is important to consider how to distribute the virtual content in a structured way, and work out which information needs to be kept and which is less important information, and so can be hidden.</td></tr>
</table>

Table 7.10: The Third Version of the AR Design Principles - Layer-focus Augmentation

7.2.5 Accurate Augmentation Design Principle

Similarly to the previous design principles, the third version of Accurate Augmentation added the relevant themes of the issues and possible design alternatives under the **Benefit or Problem solving** category and summarised the limitations of this principle (see **Table 7.11**).

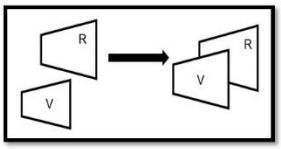
<table>
<tr><td>Name</td><td colspan="2">Accurate Augmentation (AA)</td></tr>
<tr><td>Definition</td><td colspan="2">The virtual content is displayed in the way that users would expect, given their goals.</td></tr>
<tr><td>Explanation</td><td colspan="2">Virtual content should register with real world content to satisfy the users' expectations. Registration and expectation will depend upon the users' goals. Registration refers to the correlation between virtual and real content for the users, which may be based on the physical position, information content, information needs, etc.</td></tr>
<tr><td>Diagram</td><td colspan="2">The left-hand diagram shows the augmentation breaking away from the real content, which makes it difficult to establish their inter-correlation. The right-hand side of the diagram clearly illustrates how the overlaid virtual content originated from the real content.
  </td></tr>
<tr><td>Example - Misplaced and Placed Base (Kirner, Cerqueira et al. 2012)</td><td colspan="2">Both pictures show some results of the virtual information and real content from the user's perspective. The position of the virtual content (vase and model car) in Figure (a) is misplaced on the real content (table, book, etc.). Figure (b) shows the accurate position between the virtual content (vase and model car) and the real content (AR user, book, table, etc.).
  </td></tr>
<tr><td rowspan="3">Benefit or Problem solving</td><td>Themes of AR Issues</td><td>Design Alternatives</td></tr>
<tr><td>User Acceptance and Cognition</td><td>If some of the virtual content is incorrectly placed when being overlaid onto the physical world, the burden on the users' cognition might increase and they may find it difficult to understand the relationship between the virtual content and physical world information. However, it still depends on the level of familiarity.</td></tr>
<tr><td>Virtual Content - Accuracy and Modality</td><td>The clear advantage of employing the AA design principle is that it provides a design alternatives in order to generate accurate virtual content that is in the right position after recognising the physical world objects. In addition, when providing more interactive or dynamic virtual content, it is vital to guarantee that the AR registration is accurate.</td></tr>
</table>

Table 7.11: The Third Version of the AR Design Principles - Accurate Augmentation

7.3 MATCHING THE DESIGN PRINCIPLES WITH AR APPLICATIONS FOR OLDER ADULTS

All of these AR design principles are only evaluated in terms of addressing or solving design-related issues. However, there is a lack of analysis regarding whether they are widely applicable to different AR applications. Therefore, a list of AR applications for older adults has

been created to assess how these principles may be used in practice (see **Table 7.12**).

Domain	AR Application	HR	MfA	IA	LfA	AA
Transpo rtation	Kim and Dey (2009) AR navigation system.	x				x
	Fu et al. (2013) AR indicator.	x				x
	Rusch et al. (2014) AR cues I.	x				x
	Schall et al. (2013) AR cues II.	x				x
	Peleg-Adler, Lanir et al. (2018) AR Route in public transportation.	x			x (more content)	x
Home activities .	Lera et al. (2014) AR pillbox.	x				x
	Wood and Mcrindle (2012) AR discovery and information system.	x	x		x	x
	Quintana and Favela (2013) AR annotations.		x		x	x
	Saracchini, Ortega (2014)AR pico-projector.	x	x			x
Entertai nment	McCallum and Boletsis (2013) 3D Angry Birds-like game.		x			x
	Fenu and Pittarello (2018) AR Svevo Tour.	x	x			x
	Simão and Bernardino (2017) AR project game.	x	x			x

Table 7.12: Matching the Design Principles with AR Applications for Older Adults

The indicator 'x' means that this design principle is applied in the related publication. This research selects 12 of the 17 existing AR applications for older adults that were discussed (see **Section 2.6**) because the other five are in the exploratory stage and have not been developed into concreate AR prototypes or describe how the application works. According to **Table 7.12**, the third version of the AR design principles has been initially evaluated in practice.

The Accurate Augmentation design principle has been applied to all of these applications. Although the number of AR applications for older adults is limited, this principle appears to be the basic criterion for

designing AR. If the virtual content is incorrectly placed onto the real content, users cannot understand the correspondence between the two.

Ten AR applications applied the Hidden Reality (HR) design principle, which emphasises the importance of weakening the virtual content. This principle is especially important when designing transport-related AR applications; for example, if an AR navigation system (Kim & Dey, 2009) uses a large element of virtual content to provide navigation information, the real road content might be obscured and users might find it difficult to drive. Therefore, it is important that designers apply this principle in order to adjust the virtual content to an appropriate rate.

Modality-focus Augmentation has been applied in both domains of home activities and entertainment. In the transportation domain, adding another modality of virtual content (e.g. audio or vibration) might distract users while they are driving, but might also provide helpful additional information (e.g. audio navigation) for visually-impaired users. Considering this design principle could create more design possibilities for designers to fulfil their aims, but will also increase the difficulty associated with designing an application.

Layer-focus Augmentation is applied to AR applications which contain more virtual content (e.g. a list of buttons or menu bar). If the virtual content is simple and easy to understand, it is unnecessary to separate the virtual information into different parts. Therefore, this principle could be applied to reduce the complexity of the virtual content within an AR system.

Interestingly, Instantaneous Augmentation providing the formative feedback design principle is not applied or mentioned in regard to any of the applications above. One reason for this may be that the virtual content is simply designed. The augmentation could be displayed promptly, which does not require the downloading of further data from the server. Designers do not need to develop any formative feedback (e.g. a loading page) for the users to inform them about what virtual content will be displayed next. Another factor could be that the

designers or researchers received some prompt feedback but failed to mention this in their publications. Therefore, this principle could be applied when designing complex virtual content and formative feedback could help users to understand what will happen next.

7.4 CHAPTER SUMMARY

This chapter assessed the relationship between the relevant themes of general AR issues for older adults and the second version of design principles based upon a reflection on the second focus group's participants' feedback (see **Table 7.13**). These relationships provide the evidence for determining the third version of the AR design principles.

Table 7.13 shows that, apart from the Hidden Reality principle, the other four research design principles are relevant to the user cognition- and user acceptance-related AR issues for older adults. The Instantaneous Augmentation design principle may raise these relevant issues while Modality-focus Augmentation, Layer-focus Augmentation and Accurate Augmentation could address or even solve them. In terms of the AR issues related to the virtual content higher theme, four principles (HR, IA, LFA, AA) are relevant to the **Accuracy**-related issues, which is the most relevant raw data theme of all. Modality-related issues could be solved or addressed by three principles (HR, MFA, AA), and only one principle (IA) could address or solve the update-related issues. Interestingly, no principles could address or solve the interaction-related issues and two of them (HR and LFA) could even exacerbate these. It is difficult to build a connection between the Device and Physical World-related issues using these principles, even though the participants suggested that these are two general and important categories.

Higher Theme of AR general Issues	Raw Theme of AR general Issues	HR	MFA	IA	LFA	AA
User	Acceptance		Address or solve	Raise	Address or solve	Address, solve or raise
	Cognition		Address or solve	Raise	Address or solve	Address or solve
Virtual Content	Accuracy	Address or solve		Address or solve	Address or solve	Address or solve
	Update			Address or solve		
	Modality	Address or solve	Address or solve			Address or solve
Interaction	Touch Difficulty.	Raise			Raise	
Device	Screen; Battery; Wearability	All principles are irrelevant with these themes.				
Physical World	QR Code					

Table 7.13: The Relationship between the Relevant Themes of the General AR Issues for Older Adults and the second version of Design Principles

The enhancement of the new AR principles (third version) for older adults is to complete the **Benefit or Problem solving category** by adding the relevant themes of issues and possible design alternatives. The third version of the principles also added the limitation of these principles based on analysing the raised relevant issues. In addition, after matching these principles with different AR applications for older adults, this chapter identifies that both the Hidden Reality and Accurate Augmentation design principles are widely applied. Modality-focus Augmentation could be applied to add further functions to the applications and Layer-focus Augmentation could help to arrange complex virtual content more effectively. Instantaneous Augmentation is rarely applied to AR applications because simple virtual content does not require formative feedback (e.g. a loading page).

CHAPTER 8 SECOND EMPIRICAL FOCUS GROUP CONSULTATION

The first empirical stage discussed in **Chapter 5** identified the proposed usability issues which the design principles could address or solve. However, the validity of these design principles was not assessed in practice, nor was it examined whether these principles are valuable or useful when designing AR applications for older adults. This chapter describes the second empirical stage for evaluating the third version of the Augmented Reality (AR) design principles by applying them to AR prototypes using focus groups. Within this chapter, **Section 8.1** outlines the main purpose of the empirical focus groups, while **Section 8.2** discusses how to apply these principles to AR prototypes (focused on AR Pillbox) and explains the possible benefits of using these AR prototypes for older adults. The following sections, (**Section 8.3** and **Section 8.4)** propose which data should be collected, how these focus groups should be conducted, the main activities involved and who was actually recruited for these focus groups. Finally, **Section 8.5** analyses the collected data in terms of the ease of use of the AR prototypes related to the design principles while **Section 8.6** discusses an evaluation of these AR principles by reflecting on the participants' feedback.

8.1 THE PURPOSE

The purpose of the second empirical stage is to evaluate the third AR design principles related to AR applications for older adults.

In the first empirical stage, this research identified the proposed facets of using design principles based on the feedback of designers, HCI researchers and stakeholders, but these principles were never applied in practice. The second empirical stage aims to allow the target users

(older adults) to evaluate a set of AR prototypes that are embedded with the third version of the design principles. By analysing the participants' feedback in terms of the ease of use of the AR prototypes, the evaluation of these principles will be discussed.

8.2 APPLYING DESIGN PRINCIPLES TO AR PROTOTYPES

It is difficult to apply the third version of the AR design principles in practice. These design principles are abstract in nature and some of them contradict each other; for example, Hidden Reality emphasises the diminishment of the virtual content, which impacts on developing a variety of AR modalities, mentioned in the Modality-focus principle. However, these principles involved the 'Benefit and Problem Solving' category (see **Section 7.2**), which suggests that the proposed design alternatives could be developed by applying these principles. This research developed a set of updated AR prototypes operationalised with these design principles, based on their relevant design alternatives (see **Figure 8.1**).

Hence, there are five prototypes developed in this chapter, including: Original AR Pillbox, Separated-layer AR Pillbox, Audio-based AR Pillbox, Video-based AR Pillbox and Controlled Video-based AR Pillbox. This research invited older adults to evaluate the design alternatives by comparing the prototypes with and without the application of the AR principles; for example, the main design alternative from Hidden Reality is to reveal more real content in an AR system, so by comparing the Original Pillbox with one overlaid with a big frame of virtual information (e.g. the time at which the tablets should be taken and the doctor’s instruction) (see **Figure 8.2**), older adults can be asked whether they find the real content of the Separated-layer AR Pillbox (e.g. the Gaviscon box) to be obscured (see **Figure 8.3**).

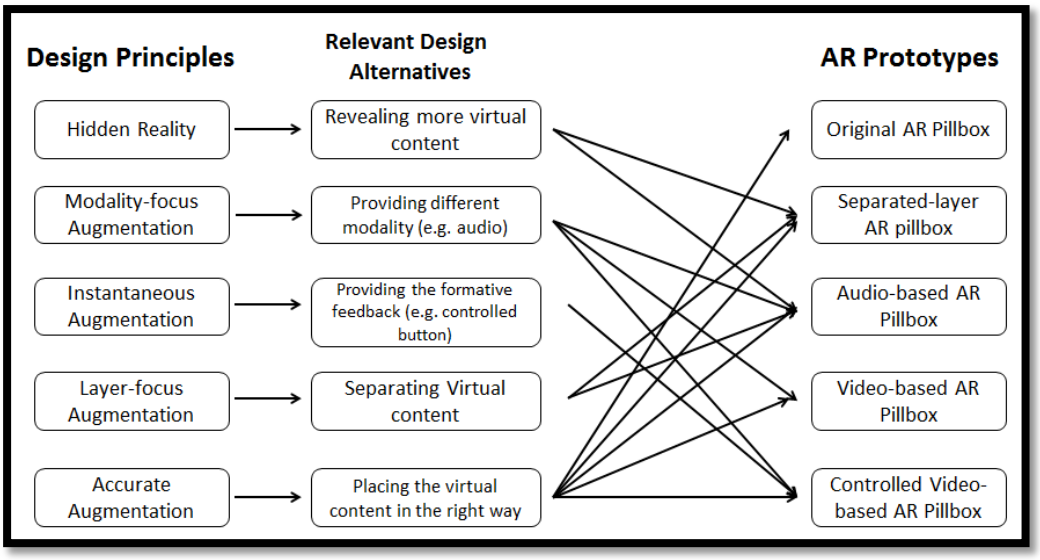


Figure 8.1: Applying the Design Principles to the AR prototypes

Two initial AR prototypes developed in **Chapter 1**, focusing on medication management and meal preparation context, were used to explore the AR-related issues for older adults. Discussing both medication and meal context in this stage makes it difficult to compare the design principles using these prototypes because the latter are used in a different way. Lawson and Nutter (2005) divided the requirements for older adults' home activities in terms of their level of essential and urgency; for example, taking medication in a strict dosage is more essential and urgent compared with preparing a meal. Therefore, these five updated prototypes mainly focus on essential and urgent activities, i.e. the taking of medication and providing additional medicine-related information.

It is necessary to design high-fidelity prototypes in order to create a more functional and diverse AR experience (see **0**). The participants also suggested, in the first empirical stage, upgrading the fidelity of the AR prototypes. Vuforia and Unity 3D platform software are used to upgrade the AR Pillbox application by providing more functions (see **Section 5.3**). Compared with other online editors (see **Figure 5.7**), Vuforia (https://www.vuforia.com/) is a well-known AR software development kit, supported on Android, iOS, UWP and Unity Editor. It can be used to recognise and track image targets, 3D objects, and

human faces, for GPS, etc. Developers could also position and orient virtual buttons, 3D models, audio, video and other modalities in relation to physical world information. In addition, the free version of Vuforia is still available, with many tutorials. Unity 3D is used to implement the AR application embedded in Vuforia SDK. This platform provides various functions that might enable comprehensive and flexible AR interactions to occur.

8.2.1 Original AR Pillbox

The Original AR Pillbox (see **Figure 8.2**) is similar to the initial AR Pillbox developed in **Chapter 1**. However, the Original AR Pillbox was developed using Vuforia and Unity 3D platform to provide more functions while the initial one used HP Reveal studio AR editor. This prototype could be seen as the 'control' application, as it applies only one design principle – Accurate Augmentation. The additional virtual information is the same at that of the initial AR Pillbox, which was displayed in an appropriate position over the real content (the Aspirin Box, see **Figure 8.2**). All of the AR Pillbox prototypes were developed based on this principle. It is the essential principle for creating a meaningful relationship between virtual and real content when designing AR applications. Developing the Original AR Pillbox aimed to help users to understand the distinction between when the design principles were applied and when they were not, by comparing this one with the other updated AR Pillbox versions.

Figure 8.2: Original AR Pillbox

8.2.2 Separated-layer AR Pillbox

Compared with the Original AR Pillbox (the 'control' prototype), the aim in designing the separated-layer AR pillbox was to assess the impact of applying two design principles: Layer-focus Augmentation and Hidden Reality (**Figure 8.1**). After selecting the design alternatives of these

No.	Requirements:	Design Alternatives (conceptual design):	Design Alternatives (physical design):
1	The correct dose of medicine	Use the virtual content to display how many tablets need to be taken every day.	Write '2 tablets per day' as the text-based virtual content.
2	The appropriate time for taking the medicine	Use the virtual content to display what time the tablets need to be taken.	The virtual content could be added in the form of text, like 'take at 18:00 --- 2 hours 24 mins next'.
3	The doctor's instructions	Use the virtual content to display how many tablets need to be taken every day.	Add relevant information about the doctor's instructions; for example: 'do not give to children under 6 years old'.
4	Detailed medicine-related information	Apply a website to describe the tablet after clicking the tablet information text.	Use the tablet's website (e.g. Aspirin) to provide information.
5	Other information.	Apply the virtual content to show the number of tablets remaining and when to request more.	Use the text-based button which could be written like '12 pills left so contact the doctor'.

principles, this prototype formulates four pieces of important information based on the No.2 requirement, for designing the original Pillbox (see

Table 5.1) including a tablet reminder, tablet taken, tablet missed and setting. Other requirements are still important. After applying these principles, however, not all of the virtual content could be displayed. The reason for choosing the design alternatives related to the No.2 requirement was that it is important information which needs to be considered when designing the Pillbox Reminder. Some of the other design alternatives related to the other requirements do not need to be displayed repeatedly, as in the AR Pillbox Reminder; for example, telling users whether they have taken a tablet on time is an essential and urgent requirement rather than them having to read the doctor's instructions every time. Therefore, these four pieces of information are shown and explained below (see **Figure 8.3**):

- Tablet reminder: this instruction aims to remind users to take a tablet at the required time. This has been shown as text-based virtual content, such as 'Take the next tablet at 12 noon'.
- Tablet taken: the Original Pillbox only tells the user what time they need to take the tablet without recording whether they actually took it. The updated Separated-layer AR Pillbox provides a record of whether or not the tablet was taken on time. After clicking on this button, the system can help users to record when they have taken a tablet.
- Tablet missed: Related to the ‘Tablet Taken’ button, users can click on the ‘Tablet missed’ button to check how many times they have missed a tablet and at what time. This is also important information for the older users or carers, which was not considered in the Original AR Pillbox.
- Setting: This text-based button can help users or carers to set the time when the tablet needs to be taken; for example, 12 noon. This information will be displayed on the top as the ‘Tablet reminder’.

It seems that a big piece of virtual content has been separated into four different parts after applying the Layer-focus Augmentation. At the same time, more real content has been revealed (the Gaviscon Box) based on the principle of Hidden Reality.

Figure 8.3: Separated-layer Pillbox

8.2.3 Audio-based AR Pillbox

Compared with the Separated-layer AR Pillbox, the aim in designing the Audio-based AR Pillbox is to examine the impact of applying the Modality-focus Augmentation principle. This principle emphasises the importance of using the alternative modality in designing the virtual content (e.g. audio, icon, vibration). Therefore, the Audio-based Pillbox prototype (**Figure 8.4**) simplifies the virtual content of the Separated-layer AR Pillbox, uses the icon-based button rather than a text-based one and provides audio feedback after users click on this button. The layout of these buttons is consistent with the Separated-layer AR Pillbox. The audio clips will be played to remind users to take their tablets. All four text-based buttons have been changed to four icon-based buttons with a one-to-one correspondence, including clock, tick, account and zigzag icon buttons:

- The clock icon ‘  ’ button reminds users what time they need to take a tablet; for example, after clicking on this button, users will hear the message: ‘Hurry up, hurry up. It’s time to take a tablet’. This icon corresponds to the text icon 'Tablet reminder' in the Separated-layer AR Pillbox.
- The tick icon ‘  ’ records whether or not users have taken a tablet; for example, after clicking on this button, users will hear the message: ‘Tablet taken. Thank you’. This icon corresponds to the text icon 'Tablet taken' in the Separated-layer AR Pillbox.
- The account icon ‘  ’ informs users how many times they have forgotten to take a tablet. By clicking on this button, users can hear this information, such as: ‘I’m sorry; you forgot to take a tablet three times,' corresponding with the 'Tablet missed' text button in the Separated-layer AR Pillbox.
- The zigzag icon ‘  ’ is also a clickable button, which could instruct users to set the reminder clock, corresponding to the 'Setting' text button in Separated-layer AR Pillbox.

Figure 8.4: Audio-based Pillbox

8.2.4 Video-based AR Pillbox

The Video-based AR Pillbox aims to examine the alternative way of applying Modality-focus Augmentation, whereby a video clip plays automatically after scanning the physical image (a Chinese herb box) rather than audio or an icon. This prototype provides an example to help users to understand how to make Chinese herbal infusions, step-by-step (**Figure 8.5**). The principles of Modality-focus Augmentation and Accurate Augmentation provide the idea of applying a video clip as the virtual content and overlaying it in an appropriate position.

Figure 8.5: Video-based Pillbox

8.2.5 Controlled Video-based AR Pillbox

The controlled Video-based Pillbox aims to assess the impact of applying the Instantaneous Augmentation principle. This AR prototype

is similar to the Video-based Pillbox, which plays a non-automatic video. After scanning the pot image (a Chinese herb), a play button (virtual content) is displayed on it (see **Figure 8.6**). Users can play the video immediately or later. Compared with the Video-based AR Pillbox, the Controlled prototype applied the principle of Instantaneous Augmentation, which adds the idea of developing an informative reminder (the play button) to instruct users on where the video is about to appear.

Figure 8.6: Controlled Video-based Pillbox

8.3 THE FOCUS GROUPS' DESIGN

In order to evaluate the AR design principles, this research conducted two focus groups that involved consulting older adults regarding their satisfaction and preferences regarding five AR prototypes (see **Section 8.2**), applied using different principles. These two focus groups were based on two institutions in Sheffield, UK: the Lai Yin Association and Sheffield Royal Society for the Blind Organisation (SRSB). These focus groups were arranged by an organiser, who observed, took notes and audio recorded the sessions. A further qualified assistant (working at the institution) was invited to support the older adults if they had any difficulties in seeing, hearing or understanding the tasks.

The two focus groups each lasted approximately 60 minutes.

At the beginning of the two focus groups, the organiser presented the consent form (**APPENDIX C.1**) and explained the purpose of this session. Each focus group consisted of three steps. In the first step, the participants were asked about their requirements with regard to using a mobile phone as the familiarity activity. The questions asked were:

- How often do you use your mobile phone?
- What do you do when using your phone?
- What are the difficulties associated with using mobile phones?

This activity inspired the participants to think their behaviour when using a mobile phone in their daily life. Because all of these AR prototypes were operated using a mobile phone, the older people's experience with mobile phones is vital for understanding the AR technology.

Then, in the second step, the organiser began to introduce the purpose of the focus group and demonstrated all of the prototypes. The participants could road-test these prototypes at the same time and were asked to comment on their preference and satisfaction with the different prototypes in relation to the design principles at the end of the second step, although the aim of these focus groups was to evaluate these AR design principles rather than evaluate the AR prototypes. Therefore, all of these questions are close to the design alternatives in the context of the prototypes.

The list of questions was:

- Regarding the original AR Pillbox, would you find it difficult if the overlaid virtual information was in the wrong position?
  This question aims to understand the effect of applying the Accurate Augmentation principle.
- Compared to the Original AR Pillbox and Separated-layer AR Pillbox, are you satisfied with the overall virtual information?

This question aims to understand the effect of applying the Hidden Reality principle.

- In the separated-layer AR Pillbox, do you feel satisfied when all of the virtual information is divided into different categories?
  This question aims to understand the effect of applying the Layer-focus Augmentation principle.
- In the Audio-based AR Pillbox, do you think it is easy to use with the audio-based information?
  This question aims to understand the effect of applying the Modality-focus Augmentation principle according to the audio format.
- Are you satisfied with the Video-based technology within the Video-based AR Pillbox?
  This question also aims to understand the effect of applying the Modality-focus Augmentation principle according to the video format.
- Are you satisfied with the Controlled video-based AR Pillbox?
  This question also aims to understand the effect of applying the Instantaneous Augmentation principle.

In the third step, all of the participants needed to complete an open-ended questionnaire (**APPENDIX C.2**), which discussed the overall comments on all of these prototypes and the focus group.

These questions included:

- Which prototype do you like or dislike the most and why?
- The overall comments on these prototypes and any other suggestions for improving them.
- The overall comments on this focus group (e.g. with which parts were you dissatisfied and what did you learn from this focus group?)

8.4 PARTICIPANTS

A total of nine older adults (Participants 1-9), ranging in age from 56 to 79 years (mean=65.67), were consulted during the two focus groups. There were three (British) participants in the first focus group, recruited from SRSB in May 2018, and six (Chinese) participants in the second, from Lai Yin, conducted in June 2018. Two participants were male and seven were female. One participant had both some form of motor disability and memory deficit. Another participant was partially-sighted. Eight participants had used mobile phones for more than a year, three between one and three years and the rest for more than three years. Only one participant had never used a mobile phone before, but still provided comments on the potential difficulties associated with using AR. Although the number of participants was limited, it was acceptable to collect qualitative feedback from these focus groups.

8.5 RESULT

Similarly to the first empirical stage (**Chapter 5**)**,** theme-based content analysis (TBCA) (Neale & Nichols, 2001) was adopted in this stage to analyse the audio and note files. The procedure included transcribing the audio files (see the raw data in **APPENDIX C.3** and transcribed files in **APPENDIX C.4**), identifying the raw data themes, selecting the higher themes and presenting them in matrix form. The themes were identified which reflected the ideas of the participants in these two focus groups. Although some divergence of opinion was noted, most of the points made were common to all. The participants' feedback mainly focused on their satisfaction and preferences regarding the design alternatives related to the AR principles among the different prototypes.

8.5.1 Ease of Use of the AR Prototypes in Relation to the Principles

After analysing the participants' feedback on the ease of use of the AR prototypes related to the AR principles, their comments were

categorised from the 11 raw data themes under five higher themes depending on the different principles (see **Figure 8.7**).

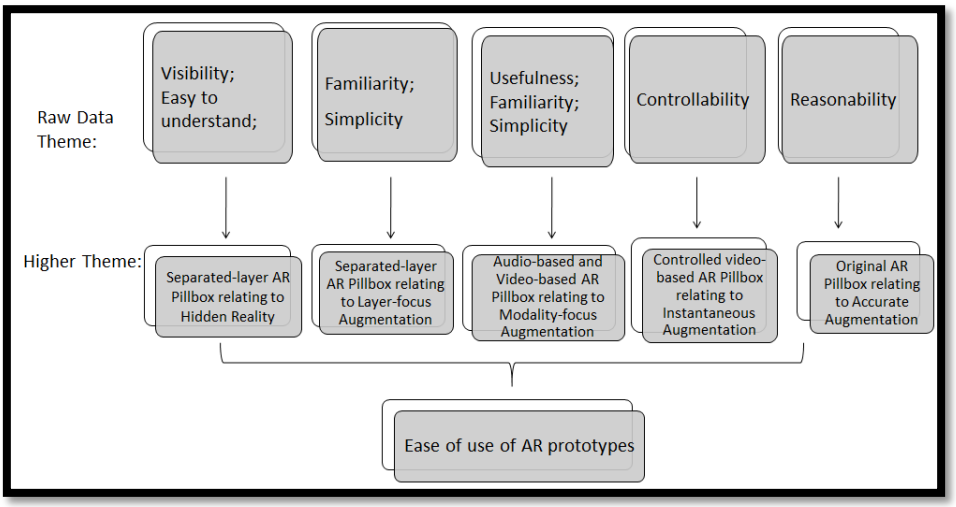


Figure 8.7: Comments Relating to the Ease of Use of the AR Prototypes

8.5.1.1 Comments relating to Hidden Reality

After comparing the difference between the Original AR Pillbox and the other Pillboxes after applying the Hidden Reality principle (e.g. the Separated-layer Pillbox and Audio-based Pillbox), two raw data themes relating to hidden reality were identified: visibility and ease of understanding. Participant 7 stated that the Pillbox that applied the Hidden Reality principle could help users to '*read what something underneath*'. In addition, if the real content was obscured (e.g. the Pillbox image); '*it is hard to tell you what you should look at*' (Participant 7). However, Participant 3 pointed out that the prototype which did not apply the Hidden Reality principle could be very clear, as it provides the information in detail.

8.5.1.2 Comments relating to Modality-focus Augmentation

Most of the participants were satisfied with the prototype Audio-based Pillbox after Modality-focus Augmentation was applied. Six of the nine participants (Participants 2-4 and 6-8) reported that the Audio-based version was the most useful one compared to the others. Three raw data themes relate to this principle: usefulness, familiarity, and simplicity. Participant 7 stated that the Audio-based Pillbox prototype

would be very helpful and useful for older adults with visual impairments, and both Participants 2 and 9 confirmed this. Interestingly, the participants also commented that they expected to hear the audio, which is their favourite music. Participant 8 stated:

'You are going to take the tablet, like the music. 6 o'clock, music starts. The noise is going off'.

Participant 9 summarised:

'Pill-taking music, something you are familiar with. That is, an alarm but musical. No buzzers. No bell. You could choose your favourite songs'.

Participant 7 also commented:

'If it is just the alarm going off, you would just think it is the alarm. You might take notes what is on it. If it is particular music, you recognise it, you know it. And the music is specific to the tablet'.

8.5.1.3 Comments relating to Instantaneous Augmentation

The Controlled Video-based Pillbox after Instantaneous Augmentation had been applied was welcomed by some of the participants (e.g. Participants 1 and 5). The raw data theme of applying the Instantaneous Augmentation principle identified in this category is Controllability. Participants 1 and 5 commented that playing a video without a control button might be a waste of time. It was seen that some of the more unfamiliar tablets need a video but others do not. Users might think it is too long and uninteresting. However, some of the participants thought that using the control button as the informative feedback might increase the complexity of the AR system. Participant 6 commented that it is better if users scan something automatically.

8.5.1.4 Comments relating to Layer-focus Augmentation

The Layer-focus Augmentation principle emphasises the idea of displaying the separated virtual content which is applied to both the Separated-layer Pillbox and Audio-based Pillbox. The former used a text-based button and the latter used an audio-based button. Two raw

data themes were identified: Familiarity and Simplicity. Participant 8 commented that the reason why he/she likes the Separated-layer Pillbox is that she/he is familiar with the form of the virtual content (a text-based button) '*like the sticker you stick on the box*'. In addition, Participant 7 pointed out that simplifying the amount of virtual content (e.g. buttons) makes it easier for older adults to use. He/she commented:

'If it is only one button to press, it will be very easy. The others could not be adopted'. Participant 8 agreed: '*do not go to complication'.*

Participant 6 also pointed out, that if the elderly are unwell, their perception might be affected and hence pressing buttons might make them feel annoyed and confused.

8.5.1.5 Comments relating to Accurate Augmentation

Accurate Augmentation as the basic principle is applied to all of the Pillboxes. However, only Participant 1 mentioned that the position of the virtual content was appropriate, which was in the centre, overlaid onto the real content. It is clear that the users would struggle to understand the meaning of an AR system if the virtual content were placed in the wrong position.

8.5.2 Additional results

The participants also made comments regarding their requirements when using a mobile phone. Because all of these AR prototypes that applied different AR design principles were developed based on a mobile phone, it is vital to understand the older adults' habits and behaviour when using mobile phones in their daily life. Under this topic, 13 raw data themes and three higher themes were selected and identified (**Figure 8.8**).

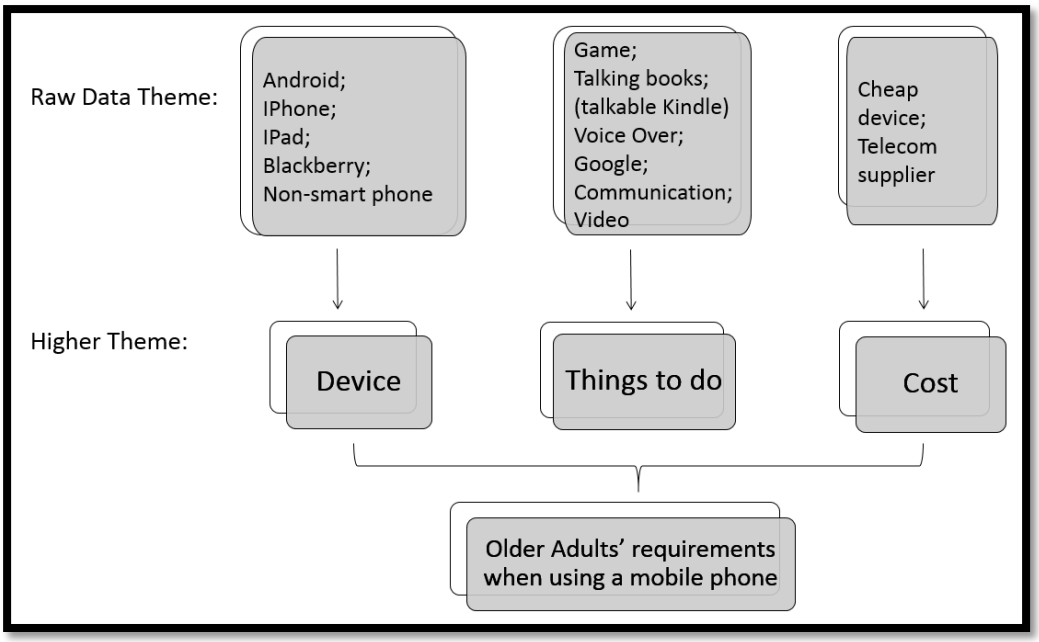


Figure 8.8: The themes of older adults' requirements of using mobile phone

There were many mobile devices used by the older adults. Participant 7 stated that he/she had used an Android phone for three years, and found it OK. He/she described a Blackberry, used previously, as *'a horrible thing'* that was hard to understand. She/he did not want to use an IPhone because it was very expensive. Participant 9, who has memory loss and partial visual impairment, stated that she/he likes to use both an IPhone and IPad. The IPad is bigger and she/he can use it to play games. She/he prefers to see the yellow and blue and is interested in talking books (she/he enquired whether a Kindle can talk). Participant 9 also mentioned the voiceover function on IPhone and showed it to the focus group. The voiceover could assist her/him to read. She/he commented: '*I have trouble with my memory. I lose very simple words, so I Google them'*. Some of the participants are satisfied with a non-smart phone, which can meet their basic requirements (e.g. sending text messages and communicating with others), but others thought it necessary to use a smart phone, which they need to communicate with their relatives using video or audio chats. Participant 6 also mentioned the price of the different telecom suppliers and which company could provide a good communication signal.

In addition, the participants reported their attitudes about using the traditional Pillbox and AR Pillbox. These are useful comments for designers in terms of updating the AR Pillbox prototypes in the future. Several of the participants (e.g. Participant 6, 8 and 9) were satisfied with their current traditional tablet reminder and were concerned about using AR for this purpose:

‘*‘I have a tablet reminder in the morning, called my wife.’* – Participant 8
‘I only take one type of tablet and my daughter sets an alarm using a mobile phone.’ – Participant 6

‘I will know anyway and I will remember up to now. What I do, I keep them on the bathroom windowsill and I got one for the morning’. – Participant 9

He/she also mentioned that AR provided additional information (e.g. the doctor’s instructions), which could be *‘printed on the box you collect from the chemist’.*

Some of the participants thought that there were potential benefits from using AR Pillbox as the reminder for older adults. Participant 9 pointed out that the additional virtual information is storable and updateable. Users might lose the physical label inside the pillbox and doctors might update their instructions based on the patients’ health. Participant 3 mentioned that he/she preferred to use AR Pillbox because this system told the users how many times they had forgotten to take the tablets.

In particular, Participant 9 thought that AR Pillbox could be useful for the '*medical profession*'. Firstly, doctors can remotely monitor the patient's medication and change the prescription promptly after the end of treatment. She/he said '*tell the doctor (maybe not only the doctor) to change to another prescription*’. In addition, if the patients forget to take their tablets, the AR Pillbox could remind them immediately and doctors or nurses do not need to spend time informing the patients.

8.6 DISCUSSION

According to the feedback from these focus groups, several key points were made during the discussion with the older adults about their AR experience and the design principles.

8.6.1 Evaluation of the third version of the AR design principles

According to the feedback from these two focus groups and the existing literature (Fisk et al., 2009), the priority when designing AR applications for older adults is to accommodate their characteristics and requirements. The AR design principles provide a series of design alternatives that incorporate both AR features and older adults' characteristics and also develop AR prototypes. The following discussion focuses on a reflection on the ease of use of these prototypes and an evaluation of the design principles.

- Hidden Reality and Layer-focus Augmentation are relevant to be applied.

Visibility reflects the main ease of use AR prototype by applying Hidden Reality. When designing the virtual content, some repetitive or unnecessary virtual information could obscure the users' view. Taking the AR Pillbox as the example, the doctors' instruction (virtual content) may not need to be seen every time that the users scan the physical Pillbox. Simplifying the virtual content creates different design alternatives, which are easy for older adults to understand.

Layer-focus Augmentation is closely related to the Hidden Reality principle. Categorising and grouping the virtual content will result in the real content visible. It is difficult to separate these two principles. Layer-focus Augmentation is supposed to be the methodological principle and Hidden Reality is seen as the resultative principle.

- Modality-focus Augmentation creates a direct solution for older adults.

Modality-focus Augmentation is easy to implement in the prototype AR applications. The older adults' preferences and satisfaction with the novel technology originally arose from their basic characteristics. Most of the participants in the second empirical study were satisfied with the Audio-based prototype, which creates an alternative modality for the participants (e.g. you do not need to see, you can listen).

- Instantaneous Augmentation can be interpreted in many ways.

There are different ways to implement the Instantaneous Augmentation principle into the prototypes; for example, designers could create a button to inform the users that some virtual information is going to pop up. An arrow or tag could also be added as the informative feedback. The prerequisite for applying this principle is that the 'tag' or 'arrow' is easy to understand and will not confuse the users. The users made different comments on the Controlled-video Pillbox after Instantaneous Augmentation was applied in this empirical study. Those participants with more mobile phone experience were satisfied with this prototype while some were not, since they found it too complicated.

- Accurate Augmentation is the basic principle.

All five AR prototypes implemented the Accurate Augmentation principle. Designing misplaced virtual content is meaningless for users. Designers must guarantee that the virtual content has a corresponding position with the real content.

8.6.2 General Tips regarding Discussing Issues with the Older Adults

Compared with the previous empirical focus groups (see **Chapter 5**), the participants recruited for this empirical stage were all older adults. Care was taken to use the term 'older' rather than 'old' when interviewing or discussing issues with them, as they dislike being called 'older people' or 'the elderly', so it is important to avoid using such words. If the researchers must refer to age, terms like 'senior' could be used. This analysis also identified that older adults have different

acceptance levels regarding mobile phones. Some of the older adults are very familiar with various mobile apps and can clearly explain how to use them; for example, one of the participants with visual impairment felt very confident when explaining how to use the 'voiceover' function on an IPhone, but some of the participants had never used a mobile phone before. In addition, by comparing different applications, it is easier to understand the users' preferences and satisfaction levels. The user's feedback was hesitant when consulted about their preferences and satisfaction with only one AR prototype. However, if they were asked to compare two or more prototypes, they could make a decision quickly.

8.6.3 AR Experience for Older Adults

AR applications are still novel technology for older adults (Peleg-Adler et al., 2018). Based on the feedback from these two focus groups, it is important to explain the meaning of AR and its components in detail using simple terms; otherwise, the older users find it difficult to understand this new form of technology, especially the meaning of virtual content. Additionally, some of the tasks seem to be easy to understand, but the older adults need more time to complete them; for example, some of the participants encountered difficulty in triggering the AR system. When they scanned the physical objects using a mobile phone, they were unsure of the appropriate distance for scanning them. If the scanned the objects too close or too far away, the virtual content failed to appear. Therefore, designers need to provide more help for users who are learning how to use the new technology (e.g. clear instructions or a tutorial video on using AR). The older adults' previous experience with mobile phones also affects their understanding of Augmented Reality systems. Users with more experience of using mobile phones are familiar with more modality (e.g. buttons, images, audio and video), which are the basic functions of virtual content in an AR system. Users without this experience feel confused when using these functions. The older adults' satisfaction and preferences regarding different AR applications are related to their

characteristics; for example, all of the participants with visual impairment thought that the audio-based prototype was the ideal application for them. Some of the participants, with shaking hands, preferred to use the auto-played video because it is difficult for them to click on an button.

8.7 CHAPTER SUMMARY

The two focus groups in the second empirical stage aimed to evaluate the third version of the Augmented Reality (AR) design principles by applying them to AR prototypes. After analysing the feedback of the older adults and discussing the reflection on these data, the ease of use of this set of AR design prototypes can be summarised under the following themes: visibility, ease to understand, familiarity, simplicity, usefulness, controllability and reasonability. **Figure 8.7** showed the correspondence between the themes and the related design principles. Applying these principles might also result in negative effects; for example, users might not see the virtual content clearly if the Hidden Reality principle has been applied incorrectly. Using the Instantaneous Augmentation principle inappropriately might make the virtual content overly complex.

Moreover, the difficulty of applying these principles varies. The Modality-focus Augmentation principle could be implemented easily while it is complex to apply the Instantaneous Augmentation principle because there are many different ways to interpret this concept. Accurate Augmentation should be used in the majority of AR design. Hidden Reality and Layer-focus Augmentation are normally applied in combination.

In addition, there are some additional findings in terms of tips regarding discussing issues with older adults, their previous experience and their requirements regarding using mobile phones, pillboxes and AR. When consulting older participants, researchers and designers need to be

careful about the terms used to describe this group. The term ‘older people’ tends to be preferred to ‘old people’. It is also important to allow them extra time in which to learn about the novel technology that they have never used before. Older adults’ experience of using mobile phones varies. Users with more mobile phone experience can understand AR better. More AR prototypes could help users to make judgements more easily. Explaining the novel technology (e.g. AR) properly and its components is important if the older adults are to understand the meaning of AR. The fundamental task when designing AR applications for older adults is to clarify the characteristics of these applications and what they mean to older adults.

CHAPTER 9 CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

This chapter describes how the work presented in this thesis fulfilled the aims and objectives of the research (see **Section 9.1**) and examines the original contribution to research (see **Section 9.2**). It then examines the limitations of this research and recommendations for further work (see **Section 9.3**).

9.1 RESEARCH AIMS AND OBJECTIVES

Chapter 1 introduced the research and stated that its general aim was to establish a set of design principles to support AR designers to formulate design solutions and explore the quality of design alternatives which could potentially benefit the ageing population.

To contribute to the general aim, this research had five specific objectives:

9.1.1 Objective One

The first objective of this research was to **'Clarify the Terminology of Augmented Reality'**.

The AR-related terminology in this research included AR-related concepts (see **Chapter 2**), a conceptual AR architecture (see **Chapter 2**) and AR features (see **0**).

In **Section 2.2**, a conceptual AR architecture was explored, consisting of seven key elements, including **User**, **Interaction**, **Device**, **Server**, **Virtual Content, Real Content** and **Physical World**, by reviewing the AR-related literature and examples. From an AR design perspective, the critical aspect of this research is the process of understanding the relationship among virtual content, real content and the physical world.

In **Section 0**, five prominent features of AR were described through undertaking an in-depth analysis of the AR characteristics according to the most relevant AR elements, including virtual content, real content and the physical world. These five representative features are: **Changeability, Synchronicity**, **Partial one to one**, **Hidden Reality and Registration**.

In **Section 0**, this research reviewed 18 existing AR-related papers and selected 28 AR design recommendations for review, which is correlated to the predominant AR features. **Design recommendations** are the understanding of design-related information and the unified name for different design formats, including: design principles, patterns, design guidelines, usability principles, etc. These existing AR design recommendations are different from design principles but are the fundamental materials for formalising the AR design principles.

9.1.2 Objective Two

The second objective of this research was to '**Identify a set of first version design principles for Augmented Reality**'.

The first version of the AR design principles were formalised according to the existing design recommendations related to the features of AR based on the AR architecture. They were clearly explained at the end of **0**, including **Diminished Augmentation, Modality-rich Augmentation, Instantaneous Augmentation, Augmented Augmentation, Accurate Augmentation** and **Transparent Augmentation**. The format for explaining these AR design principles is based upon the modified approach (Saenz-Otero, 2005).

9.1.3 Objective Three

The third objective of this research was to '**Characterise and specify the design-related issues of older adults that could be addressed by AR**'.

This was achieved by reviewing the aged-related literature (see **Chapter 2**), developing the AR applications for older adults (see

Chapter 1) and evaluating the AR applications for older adults to specify the AR-related issues by conducting focus groups (see **Chapter 5**) (see **Table 9.1**).

Section 2.4 clarified the meaning of older adults, together with their characteristics, including sensation, perception, cognition and movement control. **Section 2.5** reviewed the Ageing Better Focus group, summarised older people's requirements and classified them into different categories: Transport, Technology, Communication, Pets care and Home activities.

Two AR applications (AR Pillbox and AR Reminder) were developed in **Chapter 1**, followed by a systematic design process.

In the first empirical stage (see **Chapter 5**), several of the key themes of general older adults' requirements were identified by analysing written scenarios. These could be classified by the higher themes in terms of Individual, Family and Society. Eight raw data themes were specifically described under the higher themes, including Sensation, Perception Cognition, Mobility, Interest, Treatment, Support of relatives and Social support.

The AR-related design issues were summarised by analysing the feedback after the participants used the AR prototypes. These issues were classified according to five higher themes – device, virtual content, server, user and physical world, which were defined in the AR elements of the pre-established AR architecture. Fourteen raw data themes were described, including: Text, Video, Alarm, Iconography, Accurate, Confidentiality, Trustiness, Personalisation, Complexity, Wearable, Internet, QR code, User goal and User acceptance.

Some of the higher and raw data themes of the AR usability issues for older adults were identified by employing qualitative data analysis techniques. Five higher themes were also drawn from the elements of AR architecture: Virtual content, Device, Interaction, Physical world and User, with 18 raw data themes (see **Table 9.1**).

Item	Chapter	Characteristics
The older adults' requirements.	**Chapter 2** (literature review).	Transport (Audioboom 2014)
		Technology (Audioboom 2014)
		Communication (Audioboom 2014)
		Pets Care (Audioboom 2014)
		Home Activities (Audioboom 2014)
	Chapter 6 (First Empirical Stage, focus group I).	Individual (Sensation, Perception, Cognition, Mobility, Interest and Treatment)
		Family (Support of relatives)
		Society (Support of social people and groups)
AR-related Issues for the older adults	**Chapter 6** (First Empirical Stage, focus group I).	Virtual Content (Text, Video, Alarm, Iconography, Confidentiality, Accuracy, Trustiness, Personalisation, Complexity)
		Device (Wearability)
		Server (Internet)
		Physical world (QR Code)
		User (Goal, Acceptance)
	Chapter 6 (First Empirical Stage, focus group II).	User (Cognition, Acceptance, Comfort, Sensation)
		Virtual Content (Real time, Modality, Update, Accuracy, Trustiness, Complexity, Text)
		Device (Wearability, Battery, Screen, Brightness).
		Interaction (Touch Difficulty).
		Physical world (QR code, Many objects)

Table 9.1: A Summary of the User Requirements and Design-related Issues in this Research

9.1.4 Objective Four

The fourth objective of this research was to **'Assess the relevance between AR design principles and design-related issues for older adults**'.

This research (see **Chapter 5**) assessed the relevance between the first version of the AR design principles and the various design-related issues for older adults in **Section 6.4**, and the relevance between the second version of the AR design principles and usability issues for older adults in **Section 6.8**. **Table 7.13** showed the relevant themes of the 15 AR general usability issues for older adults that matched these principles.

In addition, a comparison between all the second version of the principles and a further five existing AR design principles was shown in **Section 6.9**. The second version principles are all relevant to the AR usability issue according to simplifying the complex virtual content, enriching the modality and the interaction with the virtual content, but are limited in terms of resolving the AR issues related to the device's wearability. In contrast, the other five existing principles are more relevant to the AR usability issue in terms of user acceptance. After applying a sign test, a significant difference was found between these two sets of design principles in terms of virtual content-related issues for older adults.

9.1.5 Objective Five

The fifth objective was to '**Reflect on the assessment of the principles and iteratively develop a full set of AR design principles for older adults**'.

The first version of the AR design principles was formalised from the existing AR-related literature, which was unrelated to older adults and their requirements. After establishing the first version, this research produced a second version of AR design principles for older adults based on a reflection on the feedback of the first empirical focus

groups. However, this version still lacked validation in terms of relevant issues and possible solutions. Then, the third version of AR design principles was iteratively established (see **Chapter 5**) by analysing the feedback from the empirical stage. The names of the second and third version principles were identical, but the latter was a full set, containing relevant themes related to AR issues, possible design alternatives and solutions (for a full list, see **Chapter 6**).

9.1.6 Objective Six

The sixth objective was to 'Evaluate the third AR design principles for designing AR applications for older adults'.

This research in the second empirical stage (Chapter 7) recruited the older adults to evaluate a set of AR prototypes embedded with the third version of the design principles. The Modality-focus Augmentation principle could be implemented easily but it is complex to apply the Instantaneous Augmentation principle because there are many different ways to interpret this concept. Accurate Augmentation should be used in the majority of AR design. Hidden Reality and Layer-focus Augmentation are normally applied in combination.

9.2 ORIGINAL CONTRIBUTION

9.2.1 A set of AR design principles for the ageing population

A new set of AR design principles (see **Chapter 6**) from the perspective of older adults were established by the iterative process. Although some of the design principles (e.g. Hidden Reality) might actually exacerbate the AR-related issues for older adults (e.g. touch difficulty), these provide different possible design alternatives for addressing the relevant AR issues focusing on older adults.

Compared with the representative design principles of AR established by Dünser et al. (2007) and Kourouthanassis et al. (2013), the third

version of the design principles developed in this research were iteratively assessed by designers, HCI researchers and older adults. All of these AR design principles were formalised based on the fundamental differences between graphical user interfaces (GUIs) and AR-based interfaces.

9.2.2 An Iterative Research Strategy for establishing AR Design Principles

This research applied the modified structure of Ruru et al. (2011)'s research strategy, that includes ten stages: **Exploratory**, **Descriptive**, **Analytical**, **Formative**, **First empirical stage (focus group I)**, **First refinement**, **First empirical stage (focus group II)**, **Second refinement**, **Second empirical stage** and **Third refinement**. This research re-phrases the description of these steps associated with the contents and purposes of each stage (see **Section 3.3**).

Although there are some existing papers (Kalalahti, 2015; Ko et al., 2013) which describe practical experience of establishing usability heuristics for AR, this research strategy is a formal process or method used to establish AR design principles for older adults. This research strategy also provides an iterative process of developing the design principles and was applied to observe and record the reactions and perceptions of the participants.

9.2.3 A Conceptual AR Architecture

A conceptual AR architecture (see **Figure 2.3**) has been explored, consisting of seven key elements, including **User**, **Interaction**, **Device**, **Server**, **Virtual Content**, **Real Content** and **Physical World**, by reviewing the AR-related literature and examples. This architecture not only provides the basis work for formalising the AR design principles, but also articulates the AR-related concepts (e.g. features, design recommendations) used throughout this research; for example, four of the AR principles used 'Augmentation' as a title, which was clearly described in the AR architecture.

In addition, there is a possibility of applying the elements of this AR architecture in describing the AR issues during the focus groups.

9.2.4 AR Issues for Older Adults

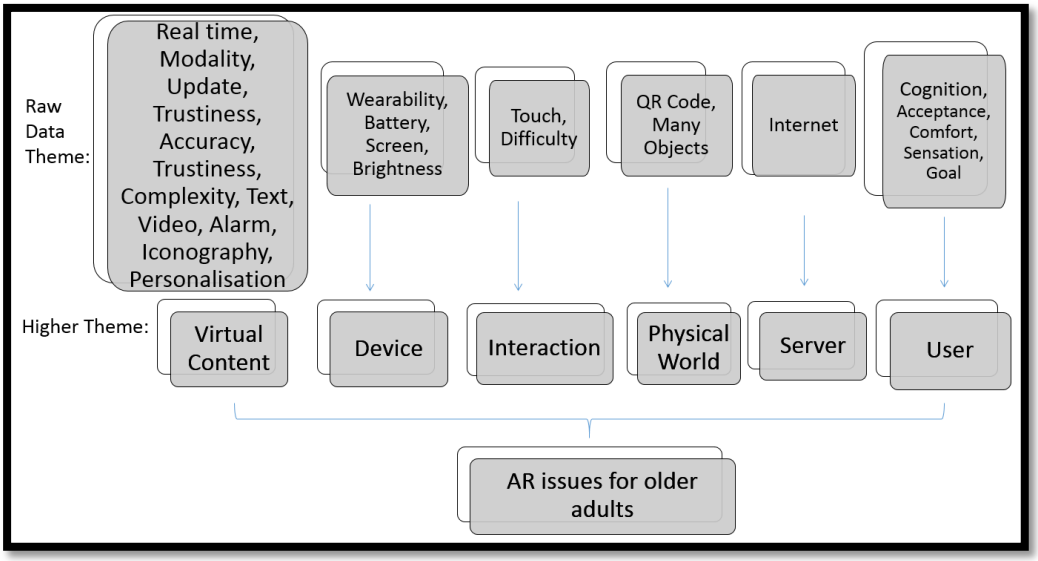


Figure 9.1: Overall Themes of AR Issues for Older Adults

Combining the design and usability issues for older people, this research generates the overall AR issues and relevant themes, focusing on the ageing population (see **Figure 9.1**).

As mentioned in the literature review (see **Chapter 2**), few researches provide theoretical solutions that could support designers to develop suitable AR applications for older adults. These issues play an important role in terms of investigating older people's experience when interacting with specific AR technology. These issues are structured by raw data and higher themes, which are very different from the general issues of older people with regard to HCI (e.g. anxiety, alienation, being too busy to learn and the need for the new tools) (Turner et al., 2007).

9.3 RECOMENDATIONS FOR FUTURE WORK

A number of new research questions emerged during the course of this thesis. These questions provide the basis for further work.

9.3.1 Further Testing of the Final Version of the AR Design Principles

The third version of the AR design principles (see **Chapter 6**) are formalised through an iterative process, but without any formal validation. A study with novice or experienced designers could be conducted to assess how the final version of AR design principles improve designers' skills in terms of deciding design alternatives, broadening the design space, communicating with other designers, etc. However, recruiting a wider group of participants is difficult. This PhD research only recruited 15 participants, who attended the first empirical stage, from different backgrounds (HCI reader, researcher, ageing population researcher, HCI and psychology PhD student), with nine older participants in the second empirical stage.

9.3.2 Validating the Principles with regard to Further AR Applications

After formulating a set of AR design principles and adapting them to suit five AR prototypes, it is important to validate them further by using more AR applications; for example, researchers could re-design different AR applications and draw a usability comparison between the AR application with and without the design principles. In addition, the third version of the AR design principles for this research was developed for use on a mobile phone or iPad platform, which is considered a primary illustration of AR. Researchers could evaluate the applicability of these principles on other platforms (e.g. Smart Glass) as a method for assessing further the effectiveness of the design principles. However, although the explored AR principles and solutions are sufficiently clear, finding accessible technology remains challenging because of the hardware and software limitations.

9.3.3 Expanding the Group of Users

This research only focuses on AR design principles from the perspective of designing for older adults, so the possibility that these principles may be applicable to other groups of people (e.g. children) might also be explored.

REFERENCES

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20*, 1-11.

Al-Khalifa, A. S., & Al-Khalifa, H. S. (2012). *Do-it-yourself object identification using augmented reality for visually impaired people* Springer.

Andrew, L., Davis, T., & Johnson, C. (2017). The impact of visual impairments on mobility performance in community-dwelling older adults.

Aston, L., Hilton, A., Moutela, T., Shaw, R., & Maidment, I. (2017). Exploring the evidence base for how people with dementia and their informal carers manage their medication in the community: A mixed studies review. *BMC Geriatrics, 17*(1), 242.

Audioboom. (2014). Audio materials of ageing better in sheffield (last access 14/07/2017). Retrieved from https://audioboom.com/users/2156794/posts

Azuma, R. (1993). Tracking requirements for augmented reality. *Communications of the ACM, 36*(7), 50-51.

Azuma, R. (2017). (2017). Making augmented reality a reality. Paper presented at the *Applied Industrial Optics: Spectroscopy, Imaging and Metrology,* JTu1F. 1.

Azuma, R. T. (1997). A survey of augmented reality. *Presence, 6*(4), 355-385.

Balcisoy, S., Kallmann, M., Fua, P., & Thalmann, D. (2000). (2000). A framework for rapid evaluation of prototypes with augmented reality. Paper presented at the *Proceedings of the ACM Symposium on Virtual Reality Software and Technology,* 61-66.

Barrie, P., Komninos, A., & Mandrychenko, O. (2009). (2009). A pervasive gesture-driven augmented reality prototype using wireless sensor body area networks. Paper presented at the *Proceedings of the 6th International Conference on Mobile Technology, Application & Systems,* 61.

Bederson, B. B. (1995). (1995). Audio augmented reality: A prototype automated tour guide. Paper presented at the *Conference Companion on Human Factors in Computing Systems,* 210-211.

Benyon, D., Turner, P., & Turner, S. (2005). *Designing interactive systems: People, activities, contexts, technologies* Pearson Education.

Blackwell, A. F., Britton, C., Cox, A., Green, T. R., Gurr, C., Kadoda, G., . . . Petre, M. (2001). Cognitive dimensions of notations: Design tools for cognitive technology. *Cognitive technology: Instruments of mind* (pp. 325-341) Springer.

Bryman, A. (2015). *Social research methods* Oxford university press.

Camburn, B., Viswanathan, V., Linsey, J., Anderson, D., Jensen, D., Crawford, R., . . . Wood, K. (2017). Design prototyping methods: State of the art in strategies, techniques, and guidelines. *Design Science, 3*

Carvajal, R. I. (2012). Usability heuristics for touchscreen-based mobile devices. *Pontificia Universidad,*

Caudell, T. P., & Mizell, D. W. (1992). (1992). Augmented reality: An application of heads-up display technology to manual manufacturing processes. Paper presented at the *System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on, , 2* 659-669.

Challis, B. P. (2000). Design principles for tactile communication within the human-computer interface.

Chang, C., Yang, S., Chern, J., & Yang, T. (2017). (2017). Visual role in the dynamic postural balance due to aging-assessment by using an augmented reality perturbation system. Paper presented at the *Computer-Based Medical Systems (CBMS), 2017 IEEE 30th International Symposium on,* 446-451.

Chattratichart, J. (2003). *Usability issues and design principles for visual programming languages*

Chen, X., Xu, L., Wang, Y., Wang, H., Wang, F., Zeng, X., . . . Egger, J. (2015). Development of a surgical navigation system based on

augmented reality using an optical see-through head-mounted display. *Journal of Biomedical Informatics, 55*, 124-131.

Chung, C., & Chen, C. (2017). Augmented reality based social stories training system for promoting the social skills of children with autism. *Advances in ergonomics modeling, usability & special populations* (pp. 495-505) Springer.

Chung, N., Han, H., & Joun, Y. (2015). Tourists' intention to visit a destination: Role of augmented reality application for heritage site. *Computers in Human Behavior, 50*, 588-599.

Clark, V. L. P., Huddleston-Casas, C. A., Churchill, S. L., Green, D. O., & Garrett, A. L. (2008). Mixed methods approaches in family science research. *Journal of Family Issues, 29*(11), 1543-1566.

Collazos, C. A., Rusu, C., Arciniegas, J. L., & Roncagliolo, S. (2009). (2009). Designing and evaluating interactive television from a usability perspective. Paper presented at the *Advances in Computer-Human Interactions, 2009. ACHI'09. Second International Conferences on,* 381-385.

Collis, J., & Hussey, R. (2013). *Business research: A practical guide for undergraduate and postgraduate students* Palgrave macmillan.

Connolly, E., & Hoskins, J. (2014). Using iPads to teach year 7 induction with aurasma. *The School Librarian, 62*(1), 6.

Courage, C., & Baxter, K. (2005). *Understanding your users: A practical guide to user requirements methods, tools, and techniques* Gulf Professional Publishing.

Cowley, N., & Wesson, J. (2005). An experiment to measure the usefulness of patterns in the interaction design process. *Human-Computer Interaction-INTERACT 2005,* , 1142-1145.

Craig, A. B. (2013). *Understanding augmented reality: Concepts and applications* Newnes.

Craik, F. I., & Salthouse, T. A. (2011). *The handbook of aging and cognition* Psychology Press.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches* Sage publications.

Czaja, S. J. (1990). *Human factors research needs for an aging population* National Academy Press Washington, DC.

Dawson, C. W. (2005). *Projects in computing and information systems: A student's guide* Pearson Education.

de Sá, M., & Churchill, E. (2012). (2012). Mobile augmented reality: Exploring design and prototyping techniques. Paper presented at the *Proceedings of the 14th International Conference on Human-Computer Interaction with Mobile Devices and Services,* 221-230.

Dinis, F. M., Guimarães, A. S., Carvalho, B. R., & Martins, J. P. P. (2017). (2017). Virtual and augmented reality game-based applications to civil engineering education. Paper presented at the *Global Engineering Education Conference (EDUCON), 2017 IEEE,* 1683-1688.

Dix, A. (2009). *Human-computer interaction* Springer.

Domegan, C., & Fleming, D. (2007). Market research in ireland.

Dunleavy, M. (2014). Design principles for augmented reality learning. *TechTrends, 58*(1), 28-34.

Dünser, A., Grasset, R., Seichter, H., & Billinghurst, M. (2007). (2007). Applying HCI principles to AR systems design. Paper presented at the *2nd International Workshop on Mixed Reality User Interfaces: Specification, Authoring, Adaptation (MRUI '07),* Charlotte, North Carolina, USA.

Endsley, T. C., Sprehn, K. A., Brill, R. M., Ryan, K. J., Vincent, E. C., & Martin, J. M. (2017). (2017). Augmented reality design heuristics: Designing for dynamic interactions. Paper presented at the *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, , 61*(1) 2100-2104.

Farage, M. A., Miller, K. W., Ajayi, F., & Hutchins, D. (2012). Design principles to accommodate older adults. *Global Journal of Health Science, 4*(2), 2-25. doi:10.5539/gjhs.v4n2p2 [doi]

Feiner, S. K. (1999). (1999). The importance of being mobile: Some social consequences of wearable augmented reality systems. Paper presented at the *Augmented Reality, 1999.(IWAR'99) Proceedings. 2nd IEEE and ACM International Workshop on,* 145-148.

Feiner, S., MacIntyre, B., Haupt, M., & Solomon, E. (1993). (1993). Windows on the world: 2D windows for 3D augmented reality. Paper presented at the *Proceedings of the 6th Annual ACM Symposium on User Interface Software and Technology,* 145-155.

Fenu, C., & Pittarello, F. (2018). Svevo tour: The design and the experimentation of an augmented reality application for engaging visitors of a literary museum. *International Journal of Human-Computer Studies, 114*, 20-35.

Fisk, A. D., Rogers, W. A., Charness, N., Czaja, S. J., & Sharit, J. (2009). *Designing for older adults: Principles and creative human factors approaches* CRC press.

Fu, W., Gasper, J., & Kim, S. (2013). (2013). Effects of an in-car augmented reality system on improving safety of younger and older drivers. Paper presented at the *Mixed and Augmented Reality (ISMAR), 2013 IEEE International Symposium on,* 59-66.

Gabbard, J. (2001). Researching usability design and evaluation guidelines for augmented reality (ar) systems. *Laboratory for Scientific Visual Analysis, Virginia Tech, USA,*

Gartner. (2017). Hype cycle for emerging technologies. Retrieved from https://www.gartner.com/en/newsroom/press-releases/2017-08-15-gartner-identifies-three-megatrends-that-will-drive-digital-business-into-the-next-decade

Giladi, N. (2017). Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training. *Journal of Alternative Medicine Research, 9*(2), 171.

Goddard, W., & Melville, S. (2004). *Research methodology: An introduction* Juta and Company Ltd.

Green, T., & Blackwell, A. (1998). (1998). Cognitive dimensions of information artefacts: A tutorial. Paper presented at the *BCS HCI Conference, , 98*

Griffiths, R. N., & Pemberton, L. (2005). Don't write guidelines write patterns. *Retrieved August, 4*, 2006.

Guba, E. G. (1990). *The paradigm dialog* Sage Publications.

Gutiérrez, F., Cardoso, B., & Verbert, K. (2017). (2017). PHARA: A personal health augmented reality assistant to support decision-making at grocery stores. Paper presented at the *Second International Workshop on Health Recommender Systems,* 10.

Han, D., tom Dieck, M. C., & Jung, T. (2018). User experience model for augmented reality applications in urban heritage tourism. *Journal of Heritage Tourism, 13*(1), 46-61.

Henning, E., Van Rensburg, W., & Smit, B. (2004). *Finding your way in qualitative research* Van Schaik Pretoria.

Hilton, D. (2008). *Virtual Reality and Stroke Rehabilitation: A Mixed Reality Simulation of an Everyday Task,*

Hix, D., & Hartson, H. R. (1993). *Developing user interfaces: Ensuring usability through product & process* John Wiley & Sons, Inc.

Hollerbach, J. M., & Wampler, C. W. (1996). The calibration index and taxonomy for robot kinematic calibration methods. *The International Journal of Robotics Research, 15*(6), 573-591.

Homans, N. C., Metselaar, R. M., Dingemanse, J. G., van der Schroeff, Marc P, Brocaar, M. P., Wieringa, M. H., . . . Goedegebure, A. (2017). Prevalence of age-related hearing loss, including sex differences, in older adults in a large cohort study. *The Laryngoscope, 127*(3), 725-730.

Howitt, D., & Cramer, D. (2007). *Introduction to research methods in psychology* Pearson Education.

Huang, W., Alem, L., & Livingston, M. (2012). *Human factors in augmented reality environments* Springer Science & Business Media.

Hudson, L. A., & Ozanne, J. L. (1988). Alternative ways of seeking knowledge in consumer research. *Journal of Consumer Research, 14*(4), 508-521.

Ihuah, P. W., & Eaton, D. (2013). The pragmatic research approach: A framework for sustainable management of public housing estates in nigeria. *Journal of US-China Public Administration, 10*(10), 933-944.

Isaacs, E., & Walendowski, A. (2002). *Designing from both sides of the screen: How designers and engineers can collaborate to build cooperative technology* Sams Publishing.

Jacobs, M. C., & Livingston, M. A. (1997). (1997). Managing latency in complex augmented reality systems. Paper presented at the *Proceedings of the 1997 Symposium on Interactive 3D Graphics,* 49-ff.

Jiménez, C., Rusu, C., Roncagliolo, S., Inostroza, R., & Rusu, V. (2012). (2012). Evaluating a methodology to establish usability heuristics. Paper presented at the *Chilean Computer Science Society (SCCC), 2012 31st International Conference of the,* 51-59.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112-133.

Kalalahti, J. (2015). *Developing usability evaluation heuristics for augmented reality applications*

Kaplan, B., & Maxwell, J. A. (2005). Qualitative research methods for evaluating computer information systems. *Evaluating the*

organizational impact of healthcare information systems (pp. 30-55) Springer.

Karlsson, J., & Li, H. (2010). (2010). Augmented reality to enhance visitors experience in a digital zoo. Paper presented at the *Proceedings of the 9th International Conference on Mobile and Ubiquitous Multimedia,* 7.

Kim, S., & Dey, A. K. (2009). (2009). Simulated augmented reality windshield display as a cognitive mapping aid for elder driver navigation. Paper presented at the *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* Boston, MA, USA. 133-142. doi:10.1145/1518701.1518724 Retrieved from http://doi.acm.org/10.1145/1518701.1518724

Ko, S. M., Chang, W. S., & Ji, Y. G. (2013). Usability principles for augmented reality applications in a smartphone environment. *International Journal of Human-Computer Interaction, 29*(8), 501-515.

Kondo, H. M., & Kochiyama, T. (2017). Normal aging slows spontaneous switching in auditory and visual bistability. *Neuroscience,*

Kourouthanassis, P. E., Boletsis, C., & Lekakos, G. (2013). Demystifying the design of mobile augmented reality applications. *Multimedia Tools and Applications, 74*(3), 1045-1066.

Kujala, S. (2002). *User studies: A practical approach to user involvement for gathering user needs and requirements* Helsinki University of Technology.

Kurz, D., Fedosov, A., Diewald, S., Guttier, J., Geilhof, B., & Heuberger, M. (2014). (2014). [Poster] towards mobile augmented reality for the elderly. Paper presented at the *Mixed and Augmented Reality (ISMAR), 2014 IEEE International Symposium on,* 275-276.

Lawson, S., & Nutter, D. (2005). Augmented reality interfaces to support ageing-in-place.

Lazar, J., Feng, J. H., & Hochheiser, H. (2010). *Research methods in human-computer interaction* John Wiley & Sons.

Lee, C., Su, Y., & Chen, L. (2012). (2012). An intelligent depth-based obstacle detection system for visually-impaired aid applications. Paper presented at the *Image Analysis for Multimedia Interactive Services (WIAMIS), 2012 13th International Workshop on,* 1-4.

Lee, G. A., Yang, U., Kim, Y., Jo, D., Kim, K., Kim, J. H., & Choi, J. S. (2009). (2009). Freeze-set-go interaction method for handheld mobile augmented reality environments. Paper presented at the *Proceedings of the 16th ACM Symposium on Virtual Reality Software and Technology,* 143-146.

Lee, L., Ng, G., Tan, K., Shaharuddin, S., & Wan-Busrah, S. (2018). Integrating interactive multimedia objects in mobile augmented

reality for sarawak tourism. *Advanced Science Letters, 24*(2), 1017-1021.

Leitão, R. A. (2013). Creating mobile gesture-based interaction design patterns for older adults: A study of tap and swipe gestures with portuguese seniors.

Lera, F. J., Rodríguez, V., Rodríguez, C., & Matellán, V. (2014). Augmented reality in robotic assistance for the elderly. *International technology robotics applications* (pp. 3-11) Springer.

Liang, S. (2016). Important things of the first PhD Workshop (last access 22/01/2018). Retrieved from https://shaliang.wordpress.com/2016/04/07/important-thing-of-the-workshop/

Liang, S. (2017). Animation of augmented reality design principles (last access 22/01/2018). Retrieved from http://homepages.shu.ac.uk/~b2047406/

Liang, S., & Roast, C. (2014). Five features for modeling augmented reality. *HCI international 2014-posters' extended abstracts* (pp. 607-612) Springer.

Liarokapis, F., & De Freitas, S. (2010). A case study of augmented reality serious games. *Looking Toward the Future of Technology-Enhanced Education: Ubiquitous Learning and the Digital Native.IGI Global,* , 178-191.

Lin, C., Fei, S., & Chang, S. (2013). An analysis of social interaction between older and children: Augmented reality integration in table game design. *Human factors in computing and informatics* (pp. 835-838) Springer.

Lincoln, Y. S., & Denzin, N. K. (2003). *Turning points in qualitative research: Tying knots in a handkerchief* Rowman Altamira.

Lindley, S. E., Harper, R., & Sellen, A. (2008). (2008). Designing for elders: Exploring the complexity of relationships in later life. Paper presented at the *Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction-Volume 1,* 77-86.

Löwgren, J., & Stolterman, E. (2004). Thoughtful interaction design.

Mackay, W. E. (1996). Augmenting reality: A new paradigm for interacting with computers. *La Recherche, 3*

Mackay, W. E., & Fayard, A. (1997). (1997). HCI, natural science and design: A framework for triangulation across disciplines. Paper presented at the *Proceedings of the 2nd Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques,* 223-234.

MacWilliams, A., Reicher, T., Klinker, G., & Bruegge, B. (2004). (2004). Design patterns for augmented reality systems. Paper presented at the

International Workshop Exploring the Design and Engineering of Mixed Reality Systems-MIXER,

Madden, L. (2011). *Professional augmented reality browsers for smartphones: Programming for junaio, layar and wikitude* John Wiley & Sons.

Malik, S. A., Abdullah, L. M., Mahmud, M., & Azuddin, M. (2013). (2013). Mobile applications using augmented reality to support older people. Paper presented at the *Research and Innovation in Information Systems (ICRIIS), 2013 International Conference on,* 374-379.

Maxwell, D. G. (1998). Can qualitative and quantitative methods serve complementary purposes for policy research? *International Food Policy Research Institute (IFPRI),*

McCallum, S., & Boletsis, C. (2013). Augmented reality & gesture-based architecture in games for the elderly. *Studies in Health Technology and Informatics, 189*, 139-144.

McLaughlin, A. C., Matalenas, L. A., & Coleman, M. G. (2018). Design of human centered augmented reality for managing chronic health conditions. *Aging, technology and health* (pp. 261-296) Elsevier.

Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review, 85*(3), 207.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems, 77*(12), 1321-1329.

Mirelman, A., Rochester, L., Reelick, M., Nieuwhof, F., Pelosin, E., Abbruzzese, G., . . . Hausdorff, J. M. (2013). V-TIME: A treadmill training program augmented by virtual reality to decrease fall risk in older adults: Study design of a randomized controlled trial. *BMC Neurology, 13*, 15-2377-13-15. doi:10.1186/1471-2377-13-15 [doi]

Mitzner, T. L., Boron, J. B., Fausset, C. B., Adams, A. E., Charness, N., Czaja, S. J., . . . Sharit, J. (2010). Older adults talk technology: Technology usage and attitudes. *Computers in Human Behavior, 26*(6), 1710-1721.

Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical Sciences Education, 10*(6), 549-559.

Morris, A., Goodman, J., & Brading, H. (2007). Internet use and non-use: Views of older users. *Universal Access in the Information Society, 6*(1), 43-57.

Muñoz, R., Barcelos, T., & Chalegre, V. (2011). (2011). Defining and validating virtual worlds usability heuristics. Paper presented at the *Chilean Computer Science Society (SCCC), 2011 30th International Conference of the,* 171-178.

Mynatt, E. D., Back, M., Want, R., & Frederick, R. (1997). (1997). Audio aura: Light-weight audio augmented reality. Paper presented at the *Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology,* 211-212.

Neale, H., & Nichols, S. (2001). Theme-based content analysis: A flexible method for virtual environment evaluation. *International Journal of Human-Computer Studies, 55*(2), 167-189.

Neuman, L. W. (2002). Social research methods: Qualitative and quantitative approaches.

Nguyen, N. Q., Ramjist, J. M., Jivraj, J., Jakubovic, R., Deorajh, R., & Yang, V. X. (2017). (2017). Preliminary development of augmented reality systems for spinal surgery. Paper presented at the *Clinical and Translational Neurophotonics, , 10050* 100500K.

Nielsen, J. (2005). Ten usability heuristics (last access 22/01/2018). Retrieved from https://www.nngroup.com/articles/ten-usability-heuristics/

Nielsen, J. (2008). Usability ROI declining, but still strong. *Http://www.Useit.com/alertbox/roi.Html, Last Retrieved August, 15*, 2010.

Nielsen, J., & Molich, R. (1990). (1990). Heuristic evaluation of user interfaces. Paper presented at the *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 249-256.

Norman, D. A., & Draper, S. W. (1986). *User centered system design; new perspectives on human-computer interaction* L. Erlbaum Associates Inc.

Novikov, A. M., & Novikov, D. A. (2013). *Research methodology: From philosophy of science to research design* CRC Press.

Novotný, M., Lacko, J., & Samuelčík, M. (2013). Applications of multi-touch augmented reality system in education and presentation of virtual heritage. *Procedia Computer Science, 25*, 231-235.

Okuno, S., Ito, T., Suzuki, M., & Tani, S. (2017). (2017). Gait diagnosis for elderly people to prevent fall and development of training assist tool using augmented reality. Paper presented at the *Micro-NanoMechatronics and Human Science (MHS), 2017 International Symposium on,* 1-6.

Olga, K. (2014). *Adaptive User Interface Patterns for Mobile Applications,*

Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing, 49*, 215-228.

Papegaaij, S., Morang, F., & Steenbrink, F. (2017). Virtual and augmented reality based balance and gait training.

Peleg-Adler, R., Lanir, J., & Korman, M. (2018). The effects of aging on the use of handheld augmented reality in a route planning task. *Computers in Human Behavior, 81*, 52-62.

Pu, M., Abd Majid, N. A., & Idrus, B. (2017). Framework based on mobile augmented reality for translating food menu in thai language to malay language. *International Journal on Advanced Science, Engineering and Information Technology, 7*(1), 153-159.

Quesenbery, W. (2003). Dimensions of usability. content and complexity: Information design in technical communication.

Quiñones, D., & Rusu, C. (2017). How to develop usability heuristics: A systematic literature review. *Computer Standards & Interfaces, 53*, 89-122.

Quintana, E., & Favela, J. (2013). Augmented reality annotations to assist persons with alzheimers and their caregivers. *Personal and Ubiquitous Computing, 17*(6), 1105-1116.

Richard, P., Birebent, G., Coiffet, P., Burdea, G., Gomez, D., & Langrana, N. (1996). Effect of frame rate and force feedback on virtual object manipulation. *Presence: Teleoperators & Virtual Environments, 5*(1), 95-108.

Rogers, W., & Fisk, A. (2006). Cognitive support for elders through technology. *Generations, 30*(2), 38-43.

Rogers, Y., Sharp, H., & Preece, J. (2011). *Interaction design: Beyond human-computer interaction* John Wiley & Sons.

Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8*(3), 382-439.

Rosson, M. B., & Carroll, J. M. (2009). Scenario based design. *Human-computer Interaction.Boca Raton, FL,* , 145-162.

Rusch, M. L., Schall Jr, M. C., Lee, J. D., Dawson, J. D., & Rizzo, M. (2014). Augmented reality cues to assist older drivers with gap estimation for left-turns. *Accident Analysis & Prevention, 71*, 210-221.

Rusu, C., Roncagliolo, S., Rusu, V., & Collazos, C. (2011). (2011). A methodology to establish usability heuristics. Paper presented at the *Proc. 4th International Conferences on Advances in Computer-Human Interactions (ACHI 2011), IARIA,* 59-62.

Rusu, C., Roncagliolo, S., Tapia, G., Hayvar, D., Rusu, V., & Gorgan, D. (2011). (2011). Usability heuristics for grid computing applications. Paper presented at the *Proceedings of the 4th International Conferences on Advances in Computer-Human Interactions ACHI,*

Saenz-Otero, A. (2005). Design principles for the development of space technology maturation laboratories aboard the international

space station. *Massachusetts Institute of Technology, Department of Aeronautics and Astronatucis, Ph.D.Thesis, Cambridge, MA,*

Sahin, N. T., Keshav, N. U., Salisbury, J. P., & Vahabzadeh, A. (2017). An augmented reality social communication aid for children and adults with autism: User and caregiver report of safety and lack of negative effects. *BioRxiv,* , 164335.

Santos, M. E. C., Taketomi, T., Yamamoto, G., Rodrigo, M. M. T., Sandor, C., & Kato, H. (2015). (2015). Toward guidelines for designing handheld augmented reality in learning support. Paper presented at the *Proceedings of the 23rd International Conference on Computers in Education. China: Asia-Pacific Society for Computers in Education*

Saracchini, R. (2015). Tecnología asistencial móvil, con realidad aumentada, para las personas mayores: A mobile augmented reality assistive technology for the elderly. *Comunicar, 23*(45), 65-74.

Saracchini, R. F., & Ortega, C. C. (2014). (2014). An easy to use mobile augmented reality platform for assisted living using pico-projectors. Paper presented at the *International Conference on Computer Vision and Graphics,* 552-561.

Saunders, M. N. (2011). *Research methods for business students, 5/e* Pearson Education India.

Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B., & Schmalstieg, D. (2009). Handheld augmented reality for underground infrastructure visualization. *Personal and Ubiquitous Computing, 13*(4), 281-291.

Schall, M. C.,Jr, Rusch, M. L., Lee, J. D., Dawson, J. D., Thomas, G., Aksan, N., & Rizzo, M. (2013). Augmented reality cues and elderly driver hazard perception. *Human Factors, 55*(3), 643-658.

Schega, L., Hamacher, D., & Wagenaar, R. C. (2011). Poster 150 A comparison of effects of augmented reality and verbal information based interventions in elderly women after hip replacement. *Archives of Physical Medicine and Rehabilitation, 92*(10), 1734-1735.

Scholz, J., & Smith, A. N. (2016). Augmented reality: Designing immersive experiences that maximize consumer engagement. *Business Horizons, 59*(2), 149-161.

Shneiderman, B. (1992). *Designing the user interface: Strategies for effective human-computer interaction* Addison-Wesley Reading, MA.

Simão, H., & Bernardino, A. (2017). (2017). User centered design of an augmented reality gaming platform for active aging in elderly institutions. Paper presented at the *Proceedings of the 5th International Congress on Sport Sciences Research and Technology Support (icSPORTS 2017),*

Squires, D. (2017). Augmented reality application classroom development: New technology and new media, education and intelligent classrooms. *I-Manager's Journal of Educational Technology, 14*(1), 1.

Stanton, N., Salmon, P. M., & Rafferty, L. A. (2013). *Human factors methods: A practical guide for engineering and design* Ashgate Publishing, Ltd.

Stone, D., Jarrett, C., Woodroffe, M., & Minocha, S. (2005). *User interface design and evaluation* Morgan Kaufmann.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory .* Sage Publications, Inc.

Suijkerbuijk, S., Brankaert, R., de Kort, Y. A., Snaphaan, L. J., & den Ouden, E. (2015). Seeing the first-person perspective in dementia: A qualitative personal evaluation game to evaluate assistive technology for people affected by dementia in the home context. *Interacting with Computers, 27*(1), 47-59.

Summers, V. A., Booth, K. S., Calvert, T., Graham, E., & MacKenzie, C. L. (1999). (1999). Calibration for augmented reality experimental testbeds. Paper presented at the *Proceedings of the 1999 Symposium on Interactive 3D Graphics,* 155-162.

Thimbleby, H. (1990). *User interface design* ACM.

Thomas, P. Y. (2010). *Towards developing a web-based blended learning environment at the university of botswana*

Turner, P., Turner, S., & Van de Walle, G. (2007). How older people account for their experiences with interactive technology. *Behaviour & Information Technology, 26*(4), 287-296.

Vasylchenko, M., & Baskhanov, G. (2018). Best tools for building augmented reality mobile apps. Retrieved from https://rubygarage.org/blog/best-tools-for-building-augmented-reality-mobile-apps

Ventä-Olkkonen, L., Posti, M., Koskenranta, O., & Häkkilä, J. (2014). (2014). Investigating the balance between virtuality and reality in mobile mixed reality UI design: User perception of an augmented city. Paper presented at the *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational,* 137-146.

Vredenburg, K., Mao, J., Smith, P. W., & Carey, T. (2002). (2002). A survey of user-centered design practice. Paper presented at the *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 471-478.

Wagner, D., & Schmalstieg, D. (2003). *First steps towards handheld augmented reality* IEEE.

Wang, C., Feng, Y., Guo, Q., Li, Z., Liu, K., Tang, Z., . . . Zheng, Y. (2017). ARShop: A cloud-based augmented reality system for shopping. *Proceedings of the VLDB Endowment, 10*(12), 1845-1848.

Ware, C., & Balakrishnan, R. (1994). Reaching for objects in VR displays: Lag and frame rate. *ACM Transactions on Computer-Human Interaction (TOCHI), 1*(4), 331-356.

Wickens, C. D. (2004). An introduction to human factors engineering.

Wickens, C. D., & Baker, P. (1995). Cognitive issues in virtual reality.

wikipedia. (2016). Google glass (last access 22/01/2018). Retrieved from https://en.wikipedia.org/wiki/Google_Glass

Williams, M., Yao, K. K., & Nurse, J. R. (2017). ToARist: An augmented reality tourism app created through user-centred design.

Wloka, M. M., & Anderson, B. G. (1995). (1995). Resolving occlusion in augmented reality. Paper presented at the *Proceedings of the 1995 Symposium on Interactive 3D Graphics,* 5-12.

Wood, S., & McCrindle, R. J. (2012). Augmented reality discovery and information system for people with memory loss.(9th Intl Conf. Disability, Virtual Reality & Associated Technologies, Laval, France)

Word Lens. (2012). The iTunes app store (last access 22/01/2018). Retrieved from https://en.wikipedia.org/wiki/Word_Lens

Wu, P., Hwang, G., Yang, M., & Chen, C. (2018). Impacts of integrating the repertory grid into an augmented reality-based learning design on students' learning achievements, cognitive load and degree of satisfaction. *Interactive Learning Environments, 26*(2), 221-234.

Xu, Y., Barba, E., Radu, I., Gandy, M., Shemaka, R., Schrank, B., . . . Tseng, T. (2011). (2011). Pre-patterns for designing embodied interactions in handheld augmented reality games. Paper presented at the *Mixed and Augmented Reality-Arts, Media, and Humanities (ISMAR-AMH), 2011 IEEE International Symposium on,* 19-28.

Yamamoto, G., Hyry, J., Krichenbauer, M., Taketomi, T., Sandor, C., Kato, H., & Pulli, P. (2015). (2015). A user interface design for the elderly using a projection tabletop system. Paper presented at the *Virtual and Augmented Assistive Technology (VAAT), 2015 3rd IEEE VR International Workshop on,* 29-32.

Yilmaz, R. M. (2016). Educational magic toys developed with augmented reality technology for early childhood education. *Computers in Human Behavior, 54*, 240-248.

Yoo, H., Chung, E., & Lee, B. (2013). The effects of augmented reality-based otago exercise on balance, gait, and falls efficacy of elderly women. *Journal of Physical Therapy Science, 25*(7), 797.

Yu, L., Ong, S., & Nee, A. Y. (2016). A tracking solution for mobile augmented reality based on sensor-aided marker-less tracking and panoramic mapping. *Multimedia Tools and Applications, 75*(6), 3199-3220.

Zhou, F., Duh, H. B., & Billinghurst, M. (2008). (2008). Trends in augmented reality tracking, interaction and display: A review of ten years of ISMAR. Paper presented at the *Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality,* 193-202.

APPENDICES

APPENDIX A.1

THE INVITATION LETTER FOR THE FIRST FOCUS GROUP

Designing Alternative Realities

(Cantor Building, Sheffield Hallam University, 8th of June, 3.00pm onwards)

We'd like to announce an afternoon demonstrating recent research and development work looking at designing alternative realities, in the areas of: healthcare, packaging, education, cultural heritage and design for the ageing population. This will include work by the Culture, Communication and Computing Research Institute (https://www.shu.ac.uk/research/c3ri/) in the areas of: virtual worlds, virtual reality, augmented reality and augmented user experience. The afternoon will finish with a collaborative workshop: "Salt or pepper? What suits the tastes of the user? - Augmented reality design principles for the ageing population"

This will be an open event intended to disseminate and promote a range of work to designers and developers interested in such 'alternative reality technologies'.

If you'd like to join us at any time in the afternoon, please contact: Sha Liang (PhD student). E: b2047406@my.shu.ac.uk T: 01142254680Event website: https://shaliang.wordpress.com/

APPENDIX A.2

AR PILLBOX SCENARIO

AR Pillbox Scenario

Sue 65 years old and had the experience of using smart phone. She got headache last week. When see her doctor who writes prescription of ASPIRIN into her virtual account and tells her information about doses, when and how to take and hospital contact details. When she went back home, she cannot remember what the doctor said and she logs in her AR app and scans the QR code overlaid onto medicine box, some of the virtual bubble pop up. Sue could easily see how many pills taken every day and the doctor's instructions.

APPENDIX A.3

AR REMAINDER SCENARIO

AR Reminder Scenario

Alicia is the primary caregiver of her father Tom, who was recently diagnosed with AD, but is still fairly independent. Alicia is at work and realises that she won't be able to be home on time to have lunch with her father. She uses AR Reminder system to create a tag to indicate her father that she left his lunch in the fridge. As Tom gets hungry he enters the kitchen but gets overwhelmed by the number of objects available. As he looks around, the mobile phone in a hanging from his neck starts to vibrate, signaling that it has found an annotation for him. In addition, the video clip recorded by his daughter is played, indicating him that she has left his lunch in the fridge and how to make them. Tom looks at the display in the mobile phone, which shows a video of the recipient where the food was placed, he takes the recipient from the fridge, make and eats lunch.

APPENDIX A.4

THE SECOND ACTIVITY TASK FOR THE FIRST FOCUS GROUP

Task: "Help our designers"

- Choose one of the AR design for elderly you want to help with. **Produce a list of design issues for when old people are using the prototypes**.

- Talking by group produce three agreed design issues and rate the seriousness of design issues, give us a group name

APPENDIX A.5

THE QUESTIONNAIRE FOR THE FIRST FOCUS GROUP

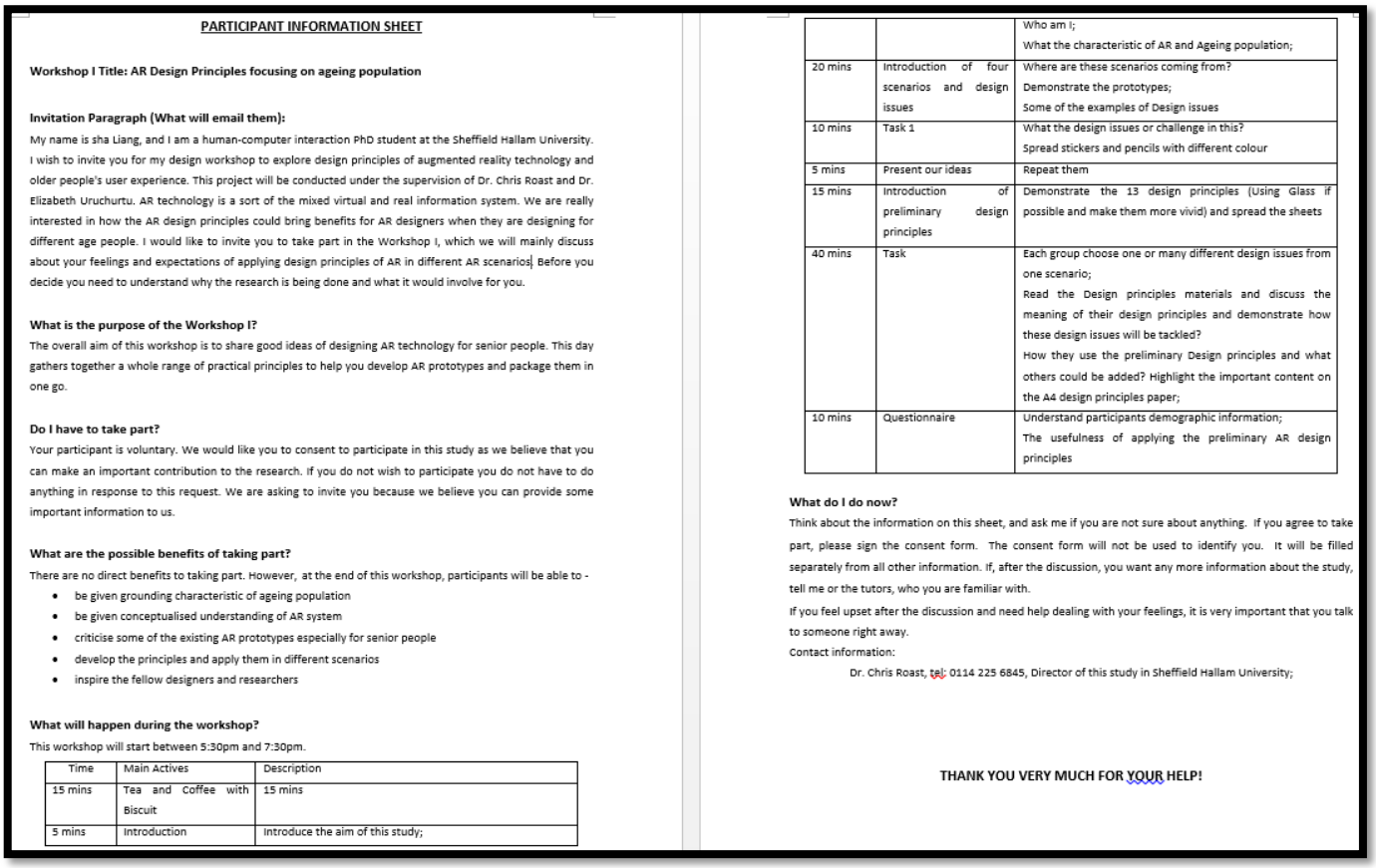
Thank you for your participation! We'd be grateful if you could provide some feedback on the event and the workshop

1.	What is your current work? a) Student; b) Teacher; c) Designer; d) Other_____
2.	How much experience of technology design do you have? a) none; b) less than 1 year; c) 1-3 years; d) more than 3 years
3.	How often have you used Augmented reality technology before? a) never; b) once a month; c) once a week; d) every day
4.	Have you any comments about today's event?
5.	What was the best thing about this workshop, for you?
6.	How could the workshop be improved?

Your Email address: _____

APPENDIX A.6

THE INFORMATION SHEET FOR THE FIRST FOCUS GROUP



PARTICIPANT INFORMATION SHEET

Workshop I Title: AR Design Principles focusing on ageing population

Invitation Paragraph (What will email them):

My name is sha Liang, and I am a human-computer interaction PhD student at the Sheffield Hallam University. I wish to invite you for my design workshop to explore design principles of augmented reality technology and older people's user experience. This project will be conducted under the supervision of Dr. Chris Roast and Dr. Elizabeth Uruchurtu. AR technology is a sort of the mixed virtual and real information system. We are really interested in how the AR design principles could bring benefits for AR designers when they are designing for different age people. I would like to invite you to take part in the Workshop I, which we will mainly discuss about your feelings and expectations of applying design principles of AR in different AR scenarios. Before you decide you need to understand why the research is being done and what it would involve for you.

What is the purpose of the Workshop I?

The overall aim of this workshop is to share good ideas of designing AR technology for senior people. This day gathers together a whole range of practical principles to help you develop AR prototypes and package them in one go.

Do I have to take part?

Your participant is voluntary. We would like you to consent to participate in this study as we believe that you can make an important contribution to the research. If you do not wish to participate you do not have to do anything in response to this request. We are asking to invite you because we believe you can provide some important information to us.

What are the possible benefits of taking part?

There are no direct benefits to taking part. However, at the end of this workshop, participants will be able to -

- be given grounding characteristic of ageing population
- be given conceptualised understanding of AR system
- criticise some of the existing AR prototypes especially for senior people
- develop the principles and apply them in different scenarios
- inspire the fellow designers and researchers

What will happen during the workshop?

This workshop will start between 5:30pm and 7:30pm.

Time	Main Actives	Description
15 mins	Tea and Coffee with Biscuit	15 mins
5 mins	Introduction	Introduce the aim of this study; Who am I; What the characteristic of AR and Ageing population;
20 mins	Introduction of four scenarios and design issues	Where are these scenarios coming from? Demonstrate the prototypes; Some of the examples of Design issues
10 mins	Task 1	What the design issues or challenge in this? Spread stickers and pencils with different colour
5 mins	Present our ideas	Repeat them
15 mins	Introduction of preliminary design principles	Demonstrate the 13 design principles (Using Glass if possible and make them more vivid) and spread the sheets
40 mins	Task	Each group choose one or many different design issues from one scenario; Read the Design principles materials and discuss the meaning of their design principles and demonstrate how these design issues will be tackled? How they use the preliminary Design principles and what others could be added? Highlight the important content on the A4 design principles paper;
10 mins	Questionnaire	Understand participants demographic information; The usefulness of applying the preliminary AR design principles

What do I do now?

Think about the information on this sheet, and ask me if you are not sure about anything. If you agree to take part, please sign the consent form. The consent form will not be used to identify you. It will be filled separately from all other information. If, after the discussion, you want any more information about the study, tell me or the tutors, who you are familiar with.

If you feel upset after the discussion and need help dealing with your feelings, it is very important that you talk to someone right away.

Contact information:

Dr. Chris Roast, tel: 0114 225 6845, Director of this study in Sheffield Hallam University;

THANK YOU VERY MUCH FOR YOUR HELP!

APPENDIX A.7

THE CONSENT FORM FOR THE FIRST FOCUS GROUP

PARTICIPANT CONSENT FORM

1) Thank you for your time. Your participation is very important to the success of this workshop. The aim of this study is to share good ideas of designing AR technology for older people. Please be aware that your participation in this study is completely voluntary and you can withdraw at any time. Please feel free to ask any questions during this workshop, or email me after the workshop if you have any concerns.

2) In reporting my research all materials or data will be kept strictly confidential in accordance with Sheffield Hallam University's ethical regulations and data management requirements. No details identifying you as an individual will be revealed in the reporting of this research.

3) Please sign below to indicate your understanding and acceptance of these conditions.

Name of Participant: _____

Signature of Participant: _____

Date: _____**8/6/2016**_____

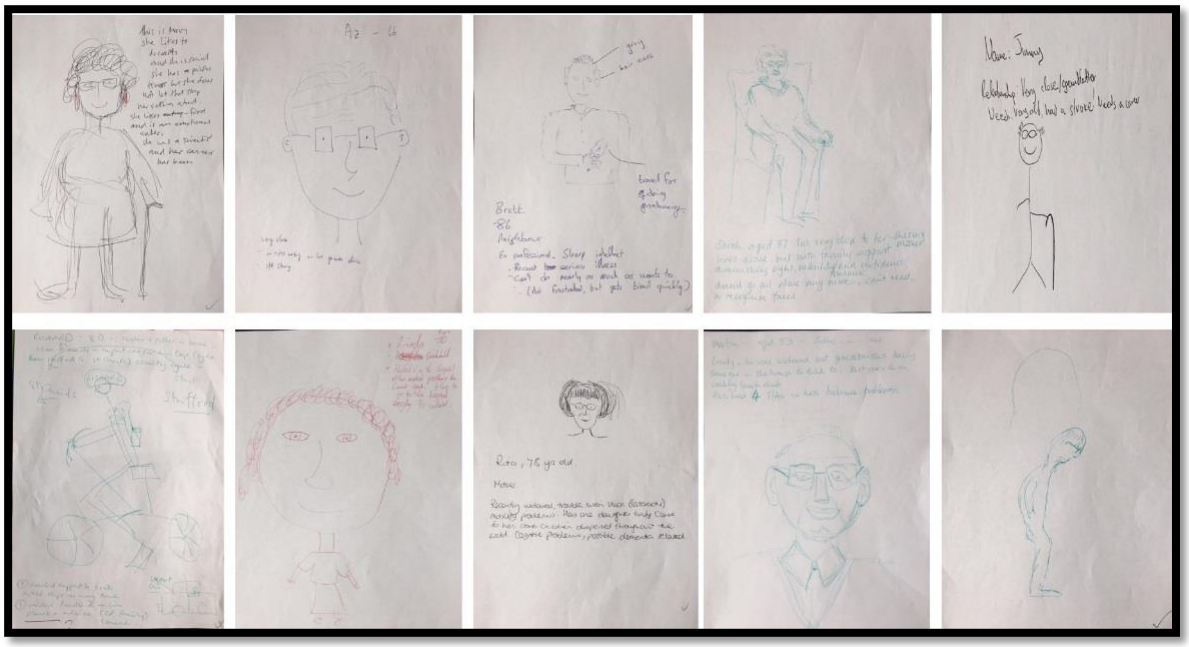
Researcher contact information
Sha Liang, PhD Student
Email: b2047406@my.shu.ac.uk

Supervisor contact information
Dr Chris Roast, Reader
Email: c.r.roast@shu.ac.uk

Sheffield Hallam University, 153 Arundel Street, Sheffield, S1 2NU, UK

APPENDIX A.8

TEN DIFFERENT PORTRAITS OF THE FIRST FOCUS GROUP



APPENDIX A.9

THE TABLE OF TEN DIFFERENT STORIES OF THE FIRST FOCUS GROUP IN FAMILIARISATION ACTIVITY

No.	Old people name	Age	How close to you	Story
1	Rita	78 years old	mother	Recently widowed, trounble with vision (cataracts), mobility problems, Has one daughter living close to her, two children dispersed throughout the world, cognitive problems, possible dementia related
2	Mavy	None	None	This is Mavy, she likes to do crafts and she is social. She has a painful knees but she does not let that stop her getting a boot. She likes food and is an emotional eater. She was a scientist and her career has been.
3	Richard	80	sister's father in law	Needs a support car for his trip (cycle from Stafford to St Dabids) charity cycle; needed support to book hotel stays on way there; needed feedback on his + advice (GP, family, carer); anxiety; link to previous
4	Jimmy	none	very close / grandfather	Very old, had a stroke; needs a career
5	Az	66	very close / grandfather	He is still working on his private clinic; still strong
6	Brett	86	neighbour	Ex: professional. Sharp intellect/ Recent serious illness/ can not do nearly as much as wants to - not frustrated, but gets tired quickly/ (with picture) trowel for doing gardening.
7	Martin	83	father-in-law	kibekym he was widowed last year. So missess having someone in the house to talk to. But goes to a weekly lunch club. Has had 4 TIAs so has balance problems.
8	Linda	70	grand	husband is in the hospital after medical problems that he cannot address. Has to go to the hospital everyday. he bit isolated.
9	n/a	n/a	n/a	To draw an elderly person would be to draw personality traits as well as physical and it just is not possible
10	Sarah	87	very close / mother	She is my mother lives alone, but with family support. Diminishing sight, mobility / balance and confidence; does not go out alone any more; can not read a recognise faces

APPENDIX A.10

THE RELATIONSHIP BETWEEN DESGIN PRINCIPLES AND ISSUES TRANSCRIBED BY EXCEL FOR THE FIRST FOCUS GROUP

No.	Prototype	Design Issue	Seriousness	Principles(DA)	Confident/comments	Principles(MA)	Confident/comments	Principles(IA)	Confident/comments	Principles(AuA)	Confident/comments	Principles(AcA)	Confident/comments	Principles(TA)	Confident/comments
1	AR Reminder	personalised content		Irrelevant		Solve		Relevent	3	Solve		Relevent	4	be	4
2	AR Reminder	How many tasks should be shown on the fridge		irrelevant		Irrelevent		Relevant	4	minus	cause confusion and mistake	Solve	Important	Relevent	4
3	AR Reminder	user can control the speed of the information been played		Irrelevant		Solve	4	Relevant	3	Relevant	3	1	4	Irrelevent	
4	AR Pillbox	User doesn't realise that the augmentation connotes to the QR code being given. (Put in to other words) Do people realise that pressing the button to read the QR code will lead to extra information				modality-specific augmentation									
5	AR Pillbox	The software generates an AR layer that covers the scanned object. Now when there is something next to it, it is covered by the layer and its not visible. For example, if there are 2 packages next to each other and one of them is scanned. The AR layer will cover them both with into for one. (with picture)	high	Relevent	1	Irrelevant	1	Irrelevent	1		1		1	Relevent/Solve	This solves the issue!
6	AR Pillbox	accessibility for visually impaired screen readers will not read the 2D image, false colours may also be a problem	medium	Irrelevant		Relevent	5	To scan the object someone may not see when recognised perhaps a beep or vibration when successful		Irrelevant		Minus	4, The angle of text can make it harder to read	Irrelevent	
7	AR Pillbox	Making People reduce it can be augmented (ignore)		Minus		Solve		Relevent				Relevent		Relevent	

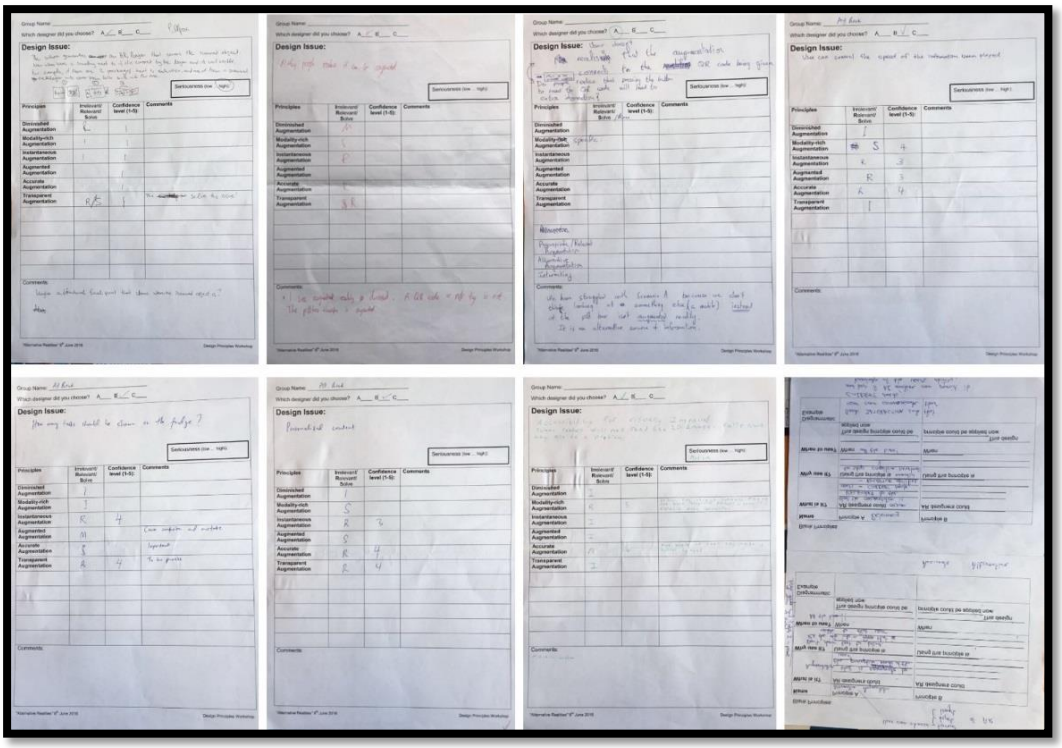
APPENDIX A.11

THE TABLE OF AR DESIGN ISSUES IN THE FIRST FOCUS GROUP

Prototype	content		content
AR Pillbox	use the device (parkinsons? not strong etc)	did not mention which prototype	spped of tasks
	difficult to hold IPad - iphone too small		some thing wareable
	navigate to launch app		how to personilization (make by family members/who is going to make contents)
	vision?		what kinds of device for you to use
	if loading a video, what about sound		QR: not obvious that you follow some instructions
	small type fonts on the website?		audible alarm - vibrating alarm: are you conntected to the device - watch confuse with alert button
	how to get access to the internet?		message - icongraphy of information - indicator of being helped
AR Reminder	Caregivers should create a video		prompts
	Piad is not suitable for elderly. Should think about the devices.		updates
	Should be divided into several steps that they can control their pace.		interface design
			confidentiality!
			information should be heavily situated
			time
			related to meal times
			tailored information
			who supplies the information
			Trusting the process : is the information true?

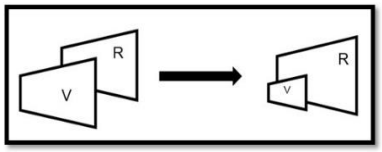
APPENDIX A.12

THE RAW DATA OF MTACHING FORMS AND NEW PRINCIPLES DEVELOPMENT FORMS



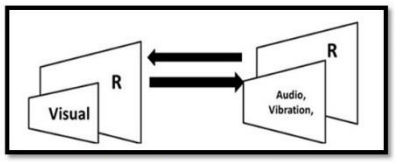
APPENDIX A.13

SECOND VERSION OF AR DESIGN PRINCIPLES – HIDDEN REALITY

Name	**Hidden Reality (HR)**
Definition	Virtual content overlays or hides the real content, where the real content is not required to achieve users' goals.
Explanation	When users use the AR device, the virtual content hides or obscures some of the real content. The design of virtual content needs to take into account what will be hidden as much as what will be shown. Although users should benefit from seeing the virtual content, virtual content should not hide real content that might be useful.
Diagram	In an AR system in the left-hand side of this diagram, the virtual content (V) overlaid onto the real content (R) and partially obscured the real content. In order to uncover the hidden real content which is meaningful or useful, the arrow in the middle of the diagram pointed out the new AR system (in the right-hand side) combines the appropriate virtual and real content by adjusting the size of the virtual content. 
Example - Word lens (Word Lens 2012)	Word lens AR translator generates the virtually translated words, which replace the real-world words. This supports the goal of understanding what is written in Spanish. It is important to note that if the goal were to support learning Spanish, the hidden reality in this design prevents the user from simultaneously seeing both the Spanish and its English equivalent. Design decisions taking account of hidden reality require careful consideration of what user goals to support. 
Benefit or Problem solving	Hidden Reality is an important concept to help designers realise the importance of obscured content which won't be needed by users. If important real contents have been hidden, diminishing the virtual content (such as decreasing the size of the virtual content boundary) could assist users improving the awareness of matching real and virtual content. Alternatively, changing the transparency of the virtual content could be another way to help users see through the meaningful real content.

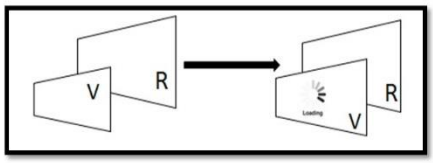
APPENDIX A.14

SECOND VERSION OF AR DESIGN PRINCIPLES – MODALITY-FOCUS AUGMENTATION

Name	**Modality-focus Augmentation (MfA)**
Definition	Virtual content can be provided in different modalities (such as visual, audio vibration, etc.) depending on the users' goals.
Explanation	When users use the AR device, the virtual content hides or obscures some of the real content. The design of virtual content needs to take into account what will be hidden as much as what will be shown. Although users should benefit from seeing the virtual content, virtual content should not hide real content that might be useful.
Diagram	**Figure** shows the diagram of Modality-focus Augmentation design principle. The arrow From left to right in the middle of this diagram shows that the visual-based AR system on the left side of the diagram could be transformed into other modalities including audio-based and haptic-based augmentation. The additional top arrow (from right to left) represents the meaning of Modality-specific idea, which reducing the number of modality from multi-modality (e.g. audio plus vibration) to one single modality (e.g. visual-based augmentation). 
Example - The Lund Time Machine application (Szymczak 2011)	The Lund Time Machine application (Szymczak 2011) is an AR tourist guide. This application uses both the users' location (GPS) and the orientation (compass) of the device (mobile phone) they are holding to give audio or tactile feedback. 
Benefit or Problem solving	Modality-focus augmentation could bring benefits for personalising content. Different modalities may address the elderly's different issues (e.g. audio-visual problems) and create audio or vibration content to reach elderly's requirements. For example, the accessibility for visually impaired screen readers will not read the 2D image; false colours may also be a problem. Modality-focus augmentation provides these people the opportunity to perceive the additional information.

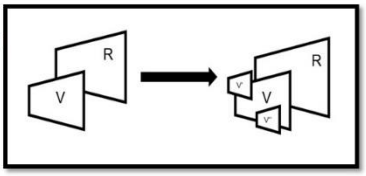
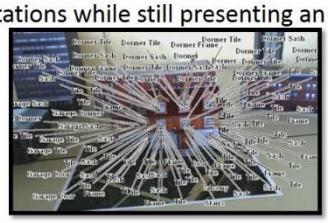
APPENDIX A.15

SECOND VERSION OF AR DESIGN PRINCIPLES – INSTANTANEOUS AUGMENTATION

Name	**Instantaneous Augmentation (IA)**
Definition	If the virtual content cannot be displayed promptly then provide prompt and informative feedback to the users.
Explanation	AR designers commonly aim to generate the virtual content instantaneously after, say, scanning an object of physical world. When the process of generating virtual content is delayed, (due to computational complexity, poor connectivity, etc.) users can be frustrated or confused. User confusion can be reduced if feedback about any delay can be given, thus informing the users that the AR application is processing, searching, etc..
Diagram	V-R augmented reality system presents that the virtual content V is the overlay of real content R in the left side of the diagram. The right-hand side of this diagram represents the formative feedback (e.g. the loading information) before generating the main virtual content. 
Example - Aurasma (Aurasma 2016)	If users try to scan one of the physical pictures and see the virtual content, six grey circular points will appear immediately to users and remind them the AR capture the physical-world information. The virtual content will pop up next. 
Benefit or Problem solving	The informative feedback could support the user realise there are some additional virtual information behind the particular physical tag. Perhaps a beep or vibration could be also useful to help users understand the trigger point.

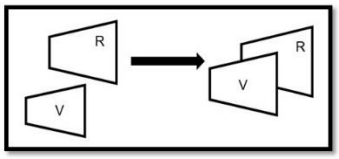
APPENDIX A.16

SECOND VERSION OF AR DESIGN PRINCIPLES – LAYER-FOCUS AUGMENTATION

Name	**Layer-focus Augmentation (LfA)**
Definition	Where more than one piece of virtual content is required, these can be displayed in separate layers if that supports the users' goals.
Explanation	Virtual content can be grouped in many ways. Ensure the groupings match the likely needs of users. The layer-focus principle is to consider what information should be provided collectively to support users' goals and what information should be separately accessed by the user. If the principle is not followed, users will have increased operational complexity finding the right information that they need.
Diagram	The left side of the diagram represents the AR system that the virtual content (V) overlaid onto the real content (R). The arrow from left to right aims to show the idea of separating a large number of virtual content into different groups (expressed in the right side of this diagram V1, V2 and V3). 
Example - Dynamic Compact (Tatzgern, Kalkofen et al. 2013)	Unfiltered augmentations (**left figure**) may quickly lead to clutter and thus decrease the comprehensibility of the resulting visualisation. Similar items (**right figure**) have been clustered by different groups and representatives have been selected from each cluster. This allows us to reduce the amount of augmentations while still presenting an annotation to each available virtual content.  
Benefit or Problem solving	One potential benefit of employing this principle is to support designers or stakeholders to design the personalised content. Compared with single-layer augmentation, Multi-layer virtual content could provide more opportunities for designers to choose different tailored information to meet the users' needs.

APPENDIX A.17

SECOND VERSION OF AR DESIGN PRINCIPLES – ACCURATE AUGMENTATION

Name	**Accurate Augmentation (AA)**
Definition	The virtual content is displayed in the way that users would expect given their goals.
Explanation	Virtual content should register with real world content satisfying users' expectations. Registration and expectation will depend upon users goals. Registration refers to the correlation between virtual and real content for the users, this may be based of physical position, information content, information need, etc.
Diagram	The left diagram shows the augmentation breaking away from the real content, which makes hard to establish the correlation between each other. The right side of the diagram clearly illustrates the overlaid virtual content is originated from the real content. 
Example - Misplaced and Placed Base (Kirner, Cerqueira et al. 2012)	Both pictures showed some results of the virtual information and real content in the user's viewpoint. The position of virtual content (vase and model car) in **Figure (a)** is misplaced in the real content (table, book and etc.). The **Figure (b**) presents the accurate position between the virtual content (vase and model car) and real content (AR user, book, table and etc.). 
Benefit or Problem solving	Accurate Augmentation could provide more precise task instruction. Sometimes, users feel confused about the correspondence between virtual and real content (e.g. this video clip overlaying on the hot chocolate image is the instruction of making a cup of hot chocolate rather than making a burger or frying chips). Additionally, the virtual reality designer stated that directional focal point.

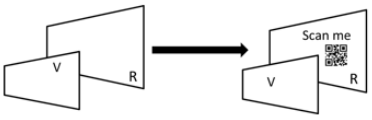
APPENDIX A.18

The overall comments of first focus group

No. Participant	Comments of today's focus group	Best thing for this focus group	How to improve
1	Learning to understand augmented reality was very useful.	Seeing projects in process interpersonal discussion around the subject.	Move time for the focus groups to evolve the ideas: simplify the forms, capture the discussions in different ways - audio? Found the blank principles form problematic.
2	Good. Could do with audio record.	Activities.	None.
3	Great but needed some more preparation.	Explaining the principles very interesting and this should have been introduced first so we could have time to ask questions.	Better management of topics. The first drawing task was irrelevant, think.
4	Great.	Really engaged.	None.
5	None.	Generate idea on solving design issues.	More time.
6	Time control.	Specific terms were explained in a good way, help participants easier to understand.	None.
7	Good mix of tasks and talks.	Looking at the different apps.	More time to look at each app.
8	None.	Meeting people with different perspectives.	None
9	Sha's focus group new my head but not feeling convenient to help.	Seeing work carried out and thinking how is going to do with my research.	Simplify the tasks section.

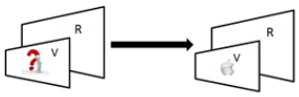
APPENDIX A.19

AFFORDABILITY

Name	Affordability **(AF)**
Definition	There is an inherent connection between users' goals and the functionality of real content (Dünser, et al. 2007).
Explanation	AR systems incorporate new ways of interacting with digital media by overlaying meaning onto the real world. Accordingly, designers use interaction metaphors derived from real world examples. Affordance, as such, provides a conceptual model describing a subject-object relationship (Dünser, et al. 2007). Integrating this model in the design principle for AR requires an extension to the notion of the subject-object relation. A clear physical indicator will remind the users about the existence of virtual content and what the virtual content will be.
Diagram	

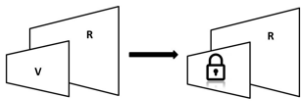
APPENDIX A.20

FAMILIARITY-FOCUS AUGMENTATION

Name	**Familiarity-focus augmentation (FA)**
Definition	Employ familiar virtual content to communicate with the application intended functionality and ensure smooth users' goals. (Kourouthanassis, Boletsis and Lekakos 2013)
Explanation	When designing the virtual content, designers could use some of well-known metaphors for frequent interaction tasks (i.e. scrolling, focusing on an object, selecting an object, etc). Additionally, designers could also use the popular or self-explanatory icons (i.e. icons that have been widely used in closely related application to communicate the system functionality. (Kourouthanassis, Boletsis and Lekakos 2013)
Diagram	

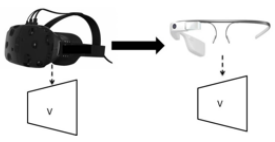
APPENDIX A.21

PRIVACY AUGMENTATION

Name	**Privacy augmentation (PA)**
Definition	Design the functionality around different privacy-related content (i.e. public versus private content) (Kourouthanassis, Boletsis and Lekakos 2013).
Explanation	The non-personalised version, no preferences, recommendations or any other data would be going public. Whereas, the personalised version, their point of interest's (POI) recommendations would be publicly available to users of the same cluster (Kourouthanassis, Boletsis and Lekakos 2013).
Diagram	

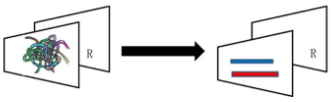
APPENDIX A.22

PHYSICAL-FOCUS AUGMENTATION

Name	**Physical-focus augmentation (PFA)**
Definition	Users should be able to accomplish a task with a minimum of Interaction steps with minimised physical load (Dünser, et al. 2007).
Explanation	Using the systems should not involve making "unnecessary" interventions by the user. A system should react efficiently reducing the likelihood of fatigue. In order to facilitate a rewarding experience with the system and to decrease chances of fatigue, user worn parts of the system should be as lightweight and comfortable as possible. (Dünser, et al. 2007, Kaufmann 2004)
Diagram	

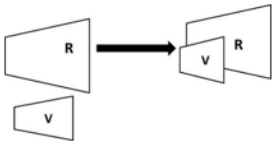
APPENDIX A.23

REDUCING COGNITIVE OVERHEAD

Name	**Reducing cognitive overhead (RCO)**
Definition	Designing the virtual content strives to enable the user to focus on the actual goal and to reduce cognitive overhead needed to interact with the application. (Dünser, et al. 2007)
Explanation	Cognitive overhead can reduce training and learning effects in virtual learning environments (Dede, Salzman and Loftin 1996, Stedmon and Stone 2001). If perceptual and cognitive load are too great, it is unlikely that AR will prove to be an effective aid. Especially for the elderly, a large number of complex virtual content will seriously exacerbate their cognitive burden.
Diagram	

APPENDIX A.24

ACCURATE AUGMENTATION

Name	**Accurate augmentation (AA)**
Definition	The virtual content is displayed in the way that users would expect given their goals.
Explanation	Virtual content should register with real world content satisfying users' expectations. Registration and expectation will depend upon users goals. Registration refers to the correlation between virtual and real content for the users, this may be based of physical position, information content, information need, etc.
diagram	

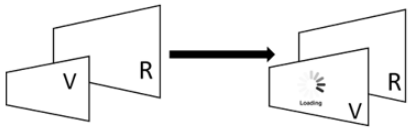
APPENDIX A.25

HIDDEN REALITY

Name	**Hidden Reality (HR)**
Definition	Virtual content overlays/hides the real content, where the real content is not required to achieve users' goals.
Explanation	When users use the AR device, the virtual content hides or obscures some of the real content. The design of virtual content needs to be take account of what will be hidden as much as what will be shown. Although users should benefit from seeing the virtual content, virtual content should not hide real content that might be useful.
Diagram	

APPENDIX A.26

INSTANTANEOUS AUGMENTATION

Name	**Instantaneous augmentation (IA)**
Definition	If the virtual content cannot be displayed promptly then provide prompt and informative feedback to the users.
Explanation	AR designers commonly aim to generate the virtual content instantaneously after, say, scanning an object of physical world. When the process of generating virtual content is delayed (due to computational complexity, poor connectivity, etc.), users can be frustrated or confused. User confusion can be reduced if feedback about any delay can be given, thus informing the users that the AR application is processing, searching, etc.
diagram	

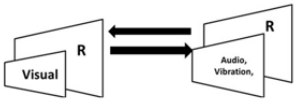
APPENDIX A.27

LAYER-FOCUS AUGMENTATION

Name	**Layer-focus augmentation (LA)**
Definition	Where more than one piece of virtual content is required, these can be displayed in separate layers if that supports the users' goals.
Explanation	Virtual content can be grouped in many ways. Ensure the groupings match the likely needs of users. The layer-focus principle is to consider what information should be provided collectively to support users' goals and what information should be separately accessed by the user. If the principle is not followed, users will have increased operational complexity finding the right information that they need.
diagram	

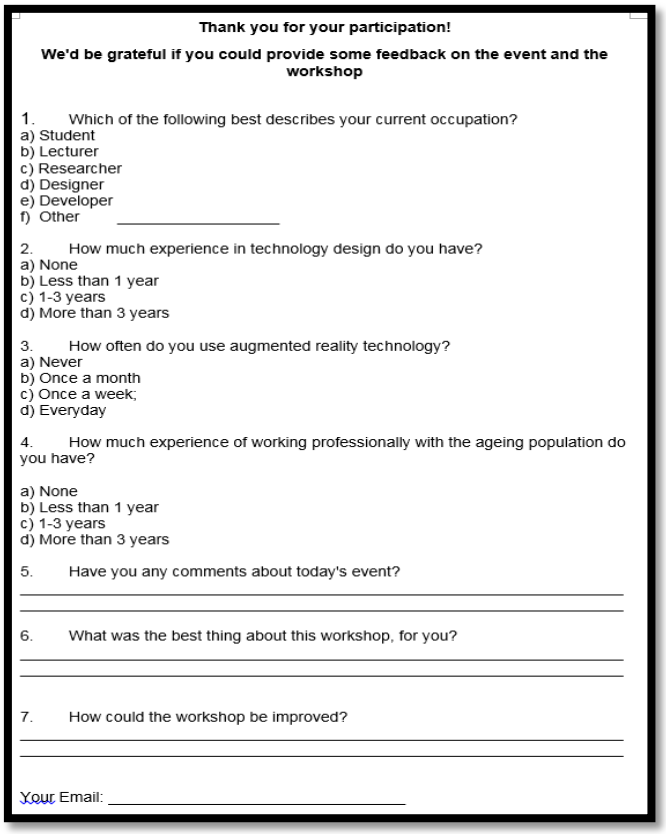
APPENDIX A.28

MODALITY-FOCUS AUGMENTATION

Name	**Modality-focus augmentation (MA)**
Definition	Virtual content can be provided in different modalities (such as visual, audio vibration, etc.) depending on the users' goals.
Explanation	The virtual content should be designed to make best advantage of the modalities that can be used. The advantages that may be gained for two reasons: 1) Modality-Specific. The modality choices may be appropriate for the user goal and context of use: for example using audio augmentation, when visual real content should not be covered at all. 2) Modality-Rich. Mixed modalities can be used with redundancy to reduce the risk of augmented content going unnoticed. For example, visual and audio modalities can be combined to ensure information is available to users who may prefer or attend to either mode of communication. These two rationales can conflict with one another, however designers should consider which rationale is being applied.
diagram	

APPENDIX A.29

QUESTIONNAIRE FOR THE SECOND FOCUS GROUP



Thank you for your participation!

We'd be grateful if you could provide some feedback on the event and the workshop

1. Which of the following best describes your current occupation?
a) Student
b) Lecturer
c) Researcher
d) Designer
e) Developer
f) Other _____

2. How much experience in technology design do you have?
a) None
b) Less than 1 year
c) 1-3 years
d) More than 3 years

3. How often do you use augmented reality technology?
a) Never
b) Once a month
c) Once a week;
d) Everyday

4. How much experience of working professionally with the ageing population do you have?

a) None
b) Less than 1 year
c) 1-3 years
d) More than 3 years

5. Have you any comments about today's event?
_____
_____

6. What was the best thing about this workshop, for you?
_____
_____

7. How could the workshop be improved?
_____
_____

Your Email: _____

APPENDIX A.30

PARTICIPANT INFORMATION SHEET FOR THE SECOND FOCUS GROUP

PARTICIPANT INFORMATION SHEET

Workshop Title: AR Design Principles Workshop for the ageing population (24/01/2017)

Invitation Paragraph (What will email them):

My name is sha Liang, and I am a human-computer interaction PhD student at the Sheffield Hallam University. I wish to invite you for my design workshop to explore design principles of augmented reality technology and older people's user experience. This project will be conducted under the supervision of Dr. Chris Roast and Dr. Elizabeth Uruchurtu. AR technology is a sort of the mixed virtual and real information system. We are really interested in how the AR design principles could bring benefits for AR designers when they are designing for different age people. I would like to invite you to take part in this Workshop, which we will mainly discuss about your feelings and expectations of design issues in different AR scenarios and design principles of AR for preventing the issues. Before you decide you need to understand why the research is being done and what it would involve for you.

What is the purpose of this Workshop?

The overall aim of this workshop is to share good ideas of designing AR technology for senior people. This day gathers together a whole range of usability issues to help you evaluate the practical principles and package them in one go.

Do I have to take part?

Your participant is voluntary. We would like you to consent to participate in this study as we believe that you can make an important contribution to the research. If you do not wish to participate you do not have to do anything in response to this request. We are asking to invite you because we believe you can provide some important information to us.

What are the possible benefits of taking part?

There are no direct benefits to taking part. However, at the end of this workshop, participants will be able to -

- be given grounding characteristic of ageing population
- be given conceptualised understanding of AR system
- criticise some of the existing AR prototypes especially for senior people
- develop the principles and apply them in different scenarios
- inspire the fellow designers and researchers

What will happen during the workshop?

This workshop will start between 4pm and 5pm.

Time	Main Actives	Description
15 mins	Introduction	• Introduce the aim of this study; • What the characteristic of AR and Ageing population; • Two AR prototypes with scenarios
15 mins	Task 1: Find the usability issues	• Choose one prototype and write down three usability issues as elderly see them (using a few words) • Discuss with your partner and write down three general usability issues
10 mins	Introduction of 10 design principles	Demonstrate the 10 design principles (Using more visible and vivid examples to bring you a quick understanding of them and then)
20 mins	Task 2: Matching the design principles with general usability issues	This activity aims to assess the relevance between principles and issues by comparing our principles and others. There are five different numbers to rate. 1 = strongly irrelevant; 2 = irrelevant; 3 = either Irrelevant or relevant; 4 = relevant; 5 = strongly relevant
5 mins	Summary and Questionnaire	• Understand participants demographic information; • Workshop evaluation

What do I do now?

Think about the information on this sheet, and ask me if you are not sure about anything. If you agree to take part, please sign the consent form. The consent form will not be used to identify you. It will be filled separately from all other information.

Contact information:

Dr. Chris Roast, tel: 0114 225 6845, Director of this study in Sheffield Hallam University;

THANK YOU VERY MUCH FOR YOUR HELP!

APPENDIX A.31

COSENT FORM SHEET FOR THE SECOND FOCUS GROUP

PARTICIPANT CONSENT FORM

1) Thank you for your time. Your participation is very important to the success of our workshop. The aim of this study is to evaluate existing AR design principles focusing on elder people. Please be aware that your participation in this study is completely voluntary and you can withdraw at any time. Please feel free to ask any questions during this workshop, or email me after the study if you have any concerns.

2) We will recorder your views and comments. In reporting my research all recording and data will be kept strictly confidential in accordance with Sheffield Hallam University's ethical regulations and data management requirements. No details identifying you as an individual will be revealed in the reporting of this research.

3) Please sign below to indicate your understanding and acceptance of these conditions.

Name of Participant: _____

Signature of Participant: _____

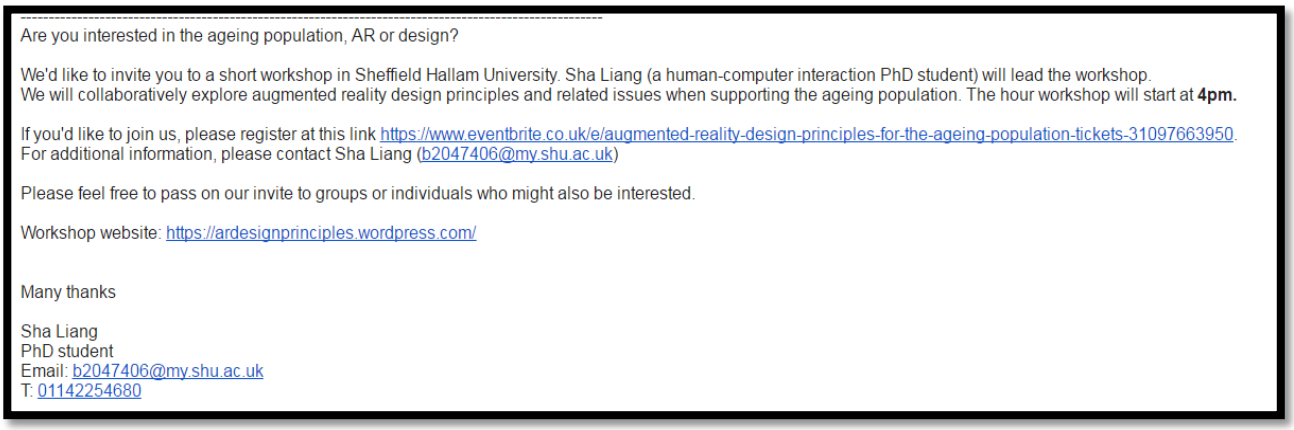
Date: **24th January 2017**

Researcher contact information
Sha Liang, PhD Student
Email: b2047406@my.shu.ac.uk
Communication and Computing Research Centre, Sheffield Hallam University

Supervisor contact information
Dr Chris Roast, Reader
Sheffield Hallam University, 153 Arundel Street, Sheffield, S1 2NU, UK.
Email: c.r.roast@shu.ac.uk

APPENDIX A.32

INVITATION LETTER FOR THE SECOND FOCUS GROUP



Are you interested in the ageing population, AR or design?

We'd like to invite you to a short workshop in Sheffield Hallam University. Sha Liang (a human-computer interaction PhD student) will lead the workshop.
We will collaboratively explore augmented reality design principles and related issues when supporting the ageing population. The hour workshop will start at **4pm.**

If you'd like to join us, please register at this link https://www.eventbrite.co.uk/e/augmented-reality-design-principles-for-the-ageing-population-tickets-31097663950.
For additional information, please contact Sha Liang (b2047406@my.shu.ac.uk)

Please feel free to pass on our invite to groups or individuals who might also be interested.

Workshop website: https://ardesignprinciples.wordpress.com/

Many thanks

Sha Liang
PhD student
Email: b2047406@my.shu.ac.uk
T: 01142254680

APPENDIX A.33

USABILITY ISSUES COLLATION FOR THE SECOND FOCUS GROUP

No.	Participant	Category	Issues
1	P1	A	If there are several pill boxes, might I missaaociate the information
2	P1	A	the information provided has to be realtime relevant (when will the system know I have taken a pill)
3	P2	A	There is no distinguishable mark on the box to remind the user that they can use the app to find out more infomration
4	P2	A	When a user has a headache they may not want to be looking at a screen maybe have audio?
5	G1	General	How can the user recognise that they can use AR (If there is nothing like a QR code)
6	G1	General	Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well
7	G1	General	Issues in targeting the correct AR (what if the wrong pillbox was shown?)
8	P3	A	Have to see enough to find the QR code
9	P3	A	If they can not remember what the doctor has said . There is a good chance they won not remember login details
10	P3	A	If user is shaking while holding the tablet it could be extremely hard to read
11	P4	B	Tom might not feel hungry - so an audible prompt / alarm might be necessary to get him to seek out hish luch + possibly medication - confusion
12	P4	B	Is there a specific way of wearing the phone comfortably at all times? - it may get lost/mislaid, but the user may not want to wear it.
13	P4	B	Visual impairment issues - will there be a voice over / ovice activated input / audio described element for someone who has poor vision? I think it could be a simpler device than a smart phone
14	G2	General	Engadgment with object celiant on at lease some memory
15	G2	General	Physical accessibility; seeing the device/where the device issued being able to use a touch screen device.
16	G2	General	Acceptence: they have to accept / understand to some level that sort of technology
17	P5	B	Weight - Heavy, difficult to carry around and focus
18	P5	B	Difficulty with hearing / sound not playing. Maybe needs subtitles.
19	P5	B	Updating apps /errors. Causing worries as you can not then get into content. May be find for younger generation. Depends if problems with elderly stun from eye or lack of experience
20	P6	A	This will depend on the type of te problems the vier has. Only useful in certain cases
21	P6	A	Will need to be comfortable with technology. Who develope + upto date. Also depends on how patient gets the pills
22	P6	A	Information overload - being able to access to many details about dr could cause anxiety.
23	G3	General	Physical Activity: Depends on what issues the patient has. e.g. - parkinsons/Dementia
24	G3	General	Technology - issues with software/hardware. Apps crash + also need updating
25	G3	General	How the information is presented. Is video the best format? It could depend on what is being trtated. (Who will recipt this (GP/CARER/ Patient))
26	P7	A	Phone battery reliant, stuck if it runs
27	P7	A	Getting used to new technology
28	P7	A	Screen size - reading small text
29	P8	A	Drifting from subject due to weight and or unsteady hands
30	P8	A	Maybe too dark to identify
31	P8	A	how to pick one box, when there are many available
32	P9	A	too much writing - this could be simpler. More 'dynamic' and play full rather than informative; using signs and simbples (more interactive) + sound
33	P9	General	IPaD - 'weight' - maybe a little bit heavy
34	P9	B	it might open up the video by proxy of the IPaD - not by touchs the video on the screen?
35	G4	General	Screen size of device (readability); appropriate view - icon?
36	G4	General	Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon
37	G4	General	Reliance on a single device (battery could be that - may not be familiar with it's use

APPENDIX A.34

RAW DATA THEME OF USABILITY ISSUES FOR THE SECOND FOCUS GROUP

Participant	Category	Issues	lower theme (the theme could either come from the raw or define by the author)
P1	A	If there are several pill boxes, might I **missaaociate** the information	Compelxicty of real content
P1	A	the information provided has to be **realtime** relevant (when will the system know I have taken a pill)	realtime feedback
P2	A	There is **no distinguishable mark** on the box to remind the user that they can use the app to find out more infomration	indicator (QR code)
P2	A	When a user has a **headache** they may not want to be looking at a screen maybe have audio?	illness
G1	General	How can the user recognise that they can use AR (If there is nothing like a **QR code**)	indicator (QR code)
G1	General	**Floating virtual content** might distress the aged user (unfamiliar) especially if they are interacting as well	floating virtual content
G1	General	Issues in targeting the **correct AR** (what if the wrong pillbox was shown?)	incorrect information
P3	A	Have to see enough to find the **QR code**	indicator (QR code)
P3	A	If they can not remember what the doctor has said . There is a good chance they won not **remember login details**	Won not remember login
P3	A	If user is shaking while holding the tablet it could be extremely **hard to read**	hard to read (cause shaking the tablet)
P4	B	Tom might not feel hungry - so an **audible prompt / alarm** might be necessary to get him to seek out hish luch + possibly medication - confusion	modality of augmentation
P4	B	Is there a specific way of wearing the phone **comfortably** at all times? - it may get lost/mislaid, but the user **may not want to wear** it.	difficult to wear the device
P4	B	**Visual impairment issues** - will there be a voice over / ovice activated input / audio described element for someone who has poor vision? I think it could be a simpler device than a smart phone	Visual impairment issues
G2	General	Engadgment with **object celiant** on at lease some memory	object reliant
G2	General	**Physical accessibility**; seeing the device/where the device issued being able to use a touch screen device.	accessibility
G2	General	**Acceptence**: they have to accept / understand to some level that sort of technology	Acceptence
P5	B	Weight - Heavy, **difficult to carry** around and focus	Difficult to carry
P5	B	**Difficulty with hearing** / sound not playing. Maybe needs subtitles.	Difficult with hearing (maybe subtitles) - modality
P5	B	**Updating apps** /errors. Causing worries as you can not then get into content. May be find for younger generation. Depends if problems with elderly stun from eye or lack of experience	updating
P6	A	This will depend on the type of te problems the vier has. Only useful in certain cases	n/a
P6	A	Will need to be **comfortable with technology**. Who develope + upto date. Also depends on how patient gets the pills	comfortable with technology
P6	A	**Information overload** - being able to access to many details about dr could cause anxiety.	Compelxicty of virtual content
G3	General	Physical Activity: Depends on what issues the patient has. e.g. - **parkinsons/Dementia**	parkinsons/Dementia
G3	General	Technology - issues with software/hardware. Apps crash + **also need updating**	updating
G3	General	How the information is presented. Is **video the best format**? It could depend on what is being trtated. (Who will recipt this (GP/CARER/ Patient))	modality
P7	A	Phone **batery reciant**, stuck if it runs	battery
P7	A	Getting used to **new technology**	unfamiliar with new technology
P7	A	Screen size - reading **small text**	small text/screen size
P8	A	Drifting from subject due to weight and or **unsteady hands**	unsteady hands (cause weight of the device) drifting - floating
P8	A	Maybe **too dark** to identify	brightness
P8	A	**how to pick one box**, when there are many available	Compelxicty of real content
P9	A	too much writing - this could be simpler. More 'dynamic' and play full rather than informative; using signs and simbples **(more interactive) + sound**	modality(signs, symbol, sound, dynaimc)
P9	General	**IPaD - 'weight'** - maybe a little bit heavy	weight of Ipad
P9	B	it might open up the video by proxy of the IPaD - not by touchs the **video** on the screen?	video pop up
G4	General	**Screen size** of device (readability); appropriate view - icon?	screen size
G4	General	Finding/locating the subject object (?!) (**drifting focus**, many objects, light/dark) + icon	drifting focus many objects/Compelxicty
G4	General	**Reliance** on a single device (battery could be that - may not be familiar with it's use	reliance

APPENDIX A.35

HIGHER THEME OF USABILITY ISSUES FOR THE SECOND FOCUS GROUP

Participant	Category	Issues	lower theme (the theme could either come from the raw or define by the author)	higher Theme (based on the AR framework)
P1	A	If there are several pill boxes, might I **missaaociate** the information	Compelxicty of real content	Real content
P1	A	the information provided has to be **realtime** relevant (when will the system know I have taken a pill)	realtime feedback	virtual content
P2	A	There is **no distinguishable mark** on the box to remind the user that they can use the app to find out more infomration	indicator (QR code)	physical world
P2	A	When a user has a **headache** they may not want to be looking at a screen maybe have audio?	illness	user's comfort
G1	General	How can the user recognise that they can use AR (If there is nothing like a **QR code**)	indicator (QR code)	physical world
G1	General	**Floating virtual content** might distress the aged user (unfamiliar) especially if they are interacting as well	floating virtual content	virtual content (interaction)
G1	General	Issues in targeting the **correct AR** (what if the wrong pillbox was shown?)	incorrect information	virtual content
P3	A	Have to see enough to find the **QR code**	indicator (QR code)	physical world
P3	A	If they can not remember what the doctor has said . There is a good chance they won not **remember login details**	Won not remember login	user's cognition
P3	A	If user is shaking while holding the tablet it could be extremely **hard to read**	hard to read (cause shaking the tablet)	interaction
P4	B	Tom might not feel hungry - so an **audible prompt / alarm** might be necessary to get him to seek out hish luch + possibly medication - confusion	modality of augmentation	virtual content
P4	B	Is there a specific way of wearing the phone **comfortably** at all times? - it may get lost/mislaid, but the user **may not want to wear** it.	difficult to wear the device	user's comfort
P4	B	**Visual impairment issues** - will there be a voice over / ovice activated input / audio described element for someone who has poor vision? I think it could be a simpler device than a smart phone	Visual impairment issues	user's visual impairment
G2	General	Engadgment with **object celiant** on at lease some memory	object reliant	user's acceptence
G2	General	**Physical accessibility**; seeing the device/where the device issued being able to use a touch screen device.	accessibility	user's accessibility
G2	General	**Acceptence**: they have to accept / understand to some level that sort of technology	Acceptence	user's acceptence
P5	B	Weight - Heavy, **difficult to carry** around and focus	Difficult to carry	user's comfort
P5	B	**Difficulty with hearing** / sound not playing. Maybe needs subtitles.	Difficult with hearing (maybe subtitles) - modality	virtual content
P5	B	**Updating apps** /errors. Causing worries as you can not then get into content. May be find for younger generation. Depends if problems with elderly stun from eye or lack of experience	updating	Virtual content
P6	A	This will depend on the type of te problems the vier has. Only useful in certain cases	n/a	n/a
P6	A	Will need to be **comfortable with technology**. Who develope + upto date. Also depends on how patient gets the pills	comfortable with technology	user's comfort
P6	A	**Information overload** - being able to access to many details about dr could cause anxiety.	Compelxicty of virtual content	Virtual content
G3	General	Physical Activity: Depends on what issues the patient has. e.g. - **parkinsons/Dementia**	parkinsons/Dementia	user's cognition
G3	General	Technology - issues with software/hardware. Apps crash + **also need updating**	updating	Virtual content
G3	General	How the information is presented. Is **video the best format**? It could depend on what is being trtated. (Who will recipt this (GP/CARER/ Patient))	modality	Virtual content
P7	A	Phone **batery reciant**, stuck if it runs	battery	device
P7	A	Getting used to **new technology**	unfamiliar with new technology	user's acceptence
P7	A	Screen size - reading **small text**	small text/screen size	device and virtual content
P8	A	Drifting from subject due to weight and or **unsteady hands**	unsteady hands (cause weight of the device)	user's comfort
			drifting - floating	virtual content
P8	A	Maybe **too dark** to identify	brightness	device
P8	A	**how to pick one box**, when there are many available	Compelxicty of real content	real content
P9	A	too much writing - this could be simpler. More 'dynamic' and play full rather than informative; using signs and simbples **(more interactive) + sound**	modality(signs, symbol, sound, dynaimc)	virtual content
P9	General	**IPaD - 'weight'** - maybe a little bit heavy	weight of Ipad	device
P9	B	it might open up the video by proxy of the IPaD - not by touchs the **video** on the screen?	video pop up	interaction
G4	General	**Screen size** of device (readability); appropriate view - icon?	screen size	device
G4	General	Finding/locating the subject object (?!) (**drifting focus**, many objects, light/dark) + icon	drifting focus	virtual content
			many objects/Compelxicty	real content
G4	General	**Reliance** on a single device (battery could be that - may not be familiar with it's use	reliance	user's acceptence

APPENDIX A.36

RAW QUNATITATIVE DATA FOR THE SECOND FOCUS GROUP

Issues Number	Participants	AA	AF	FA	HR	IA	LA	MA	PA	PFA	RCO
General issue 1	P1	4	4	2	3	3	1	5	1	3.5	4
General issue 2	P1	2	3	4	5	4	4	4	1	3	2
General issue 3	P1	5	2	2	1	4	5	3	2	3.5	4
General issue 1	P2	2	4	5	2	3	2	2	1	1	4
General issue 2	P2	4	3	3	3	3	3	4	1	4	4
General issue 3	P2	4	4	3	4	5	4	2	1	4	4
General issues 4	P3	5	5	5	2	5	3	5	4	3	5
General issues 5	P3	1	5	2	3	1	2	4	2	5	3
General issues 6	P3	5	5	5	4	5	5	3	5	4	5
General issues 4	P4	5	5	5	2	5	3	5	4	3	5
General issues 5	P4	2	5	2	3	1	2	4	1	5	3
General issues 6	P4	5	5	5	4	4	5	4	5	5	5
General issues 7	P5/6	5	2	5	3	5	4	5	2	5	5
General issues 8	P5/6	2	5	4	3	4	4	4	4	5	4
General issues 9	P5/6	2	4	5	5	4	5	5	2	5	5
General issues 10	P7	4	4	4	5	2	5	5	2	3	5
General issues 11	P7	5	4	4	3	5	4	5	2	3	5
General issues 12	P7	2	2	1	1	1	2	1	3	5	3
General issues 10	P8	1	2	5	3	4	5	5	2	4	4
General issues 11	P8	5	2	5	5	5	5	5	5	5	5
General issues 12	P8	1	1	4	1	4	3	4	4	4	4
General issues 13	P9	5	5	4	5	5	5	5	1	2	5
General issues 14	P9	1	2	1	1	1	1	2	1	5	1
General issues 15	P9	4	3	3	5	5	3	3	1	2	5

APPENDIX A.37

BINOMIAL TABLES (N=23)

n	x	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
23	0	0.793614	0.307357	0.088629	0.005903	0.000274	7.9E-06	1.19E-07	7.04E-10	9.41E-13	8.39E-17	1E-23	1.19E-30	1E-46
	1	0.184375	0.372064	0.226497	0.033942	0.002698	0.000121	2.74E-06	2.43E-08	5.05E-11	7.72E-15	2.07E-21	5.21E-28	2.28E-43
	2	0.020486	0.215405	0.27683	0.093341	0.012718	0.000888	3.02E-05	4.01E-07	1.3E-09	3.4E-13	2.05E-19	1.09E-25	2.48E-40
	3	0.001449	0.07936	0.215312	0.163346	0.038154	0.004144	0.000211	4.21E-06	2.12E-08	9.51E-12	1.29E-17	1.45E-23	1.72E-37
	4	7.32E-05	0.020884	0.119618	0.204182	0.081759	0.013813	0.001056	3.15E-05	2.47E-07	1.9E-10	5.81E-16	1.38E-21	8.51E-35
	5	2.81E-06	0.004177	0.050505	0.193973	0.133151	0.034994	0.004011	0.00018	2.19E-06	2.89E-09	1.99E-14	9.93E-20	3.2E-32
	6	8.51E-08	0.000659	0.016835	0.14548	0.171194	0.069988	0.012034	0.000809	1.53E-05	3.47E-08	5.36E-13	5.66E-18	9.5E-30
	7	2.09E-09	8.43E-05	0.004543	0.088327	0.178181	0.113314	0.029225	0.002948	8.69E-05	3.37E-07	1.17E-11	2.61E-16	2.29E-27
	8	4.22E-11	8.87E-06	0.00101	0.044164	0.152727	0.151086	0.05845	0.008843	0.000406	2.7E-06	2.11E-10	9.93E-15	4.52E-25
	9	7.1E-13	7.78E-07	0.000187	0.018401	0.10909	0.167873	0.097417	0.022107	0.001577	1.8E-05	3.17E-09	3.14E-13	7.47E-23
	10	1E-14	5.74E-08	2.91E-05	0.006441	0.065454	0.156681	0.136383	0.046424	0.005152	0.000101	3.99E-08	8.36E-12	1.03E-20
	11	1.2E-16	3.57E-09	3.82E-06	0.001903	0.033152	0.123446	0.16118	0.082297	0.014208	0.000476	4.24E-07	1.88E-10	1.21E-18
	12	1.21E-18	1.88E-10	4.24E-07	0.000476	0.014208	0.082297	0.16118	0.123446	0.033152	0.001903	3.82E-06	3.57E-09	1.2E-16
	13	1.03E-20	8.36E-12	3.99E-08	0.000101	0.005152	0.046424	0.136383	0.156681	0.065454	0.006441	2.91E-05	5.74E-08	1E-14
	14	7.47E-23	3.14E-13	3.17E-09	1.8E-05	0.001577	0.022107	0.097417	0.167873	0.10909	0.018401	0.000187	7.78E-07	7.1E-13
	15	4.52E-25	9.93E-15	2.11E-10	2.7E-06	0.000406	0.008843	0.05845	0.151086	0.152727	0.044164	0.00101	8.87E-06	4.22E-11
	16	2.29E-27	2.61E-16	1.17E-11	3.37E-07	8.69E-05	0.002948	0.029225	0.113314	0.178181	0.088327	0.004543	8.43E-05	2.09E-09
	17	9.5E-30	5.66E-18	5.36E-13	3.47E-08	1.53E-05	0.000809	0.012034	0.069988	0.171194	0.14548	0.016835	0.000659	8.51E-08
	18	3.2E-32	9.93E-20	1.99E-14	2.89E-09	2.19E-06	0.00018	0.004011	0.034994	0.133151	0.193973	0.050505	0.004177	2.81E-06
	19	8.51E-35	1.38E-21	5.81E-16	1.9E-10	2.47E-07	3.15E-05	0.001056	0.013813	0.081759	0.204182	0.119618	0.020884	7.32E-05
	20	1.72E-37	1.45E-23	1.29E-17	9.51E-12	2.12E-08	4.21E-06	0.000211	0.004144	0.038154	0.163346	0.215312	0.07936	0.001449
	21	2.48E-40	1.09E-25	2.05E-19	3.4E-13	1.3E-09	4.01E-07	3.02E-05	0.000888	0.012718	0.093341	0.27683	0.215405	0.020486
	22	2.28E-43	5.21E-28	2.07E-21	7.72E-15	5.05E-11	2.43E-08	2.74E-06	0.000121	0.002698	0.033942	0.226497	0.372064	0.184375
	23	1E-46	1.19E-30	1E-23	8.39E-17	9.41E-13	7.04E-10	1.19E-07	7.9E-06	0.000274	0.005903	0.088629	0.307357	0.793614

APPENDIX B.1

Table for AR issues for older adults relating to the relevance and irrelevant of Hidden Reality Design Principle

Issue No.	Relevant Issues	Raw Data Theme	Higher Theme	Comments
2.	*'Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.'*	Floating.	Virtual Content.	Irrelevant. (hard to build relationship)
6.	*'Acceptance: they have to accept / understand to some level that sort of technology.'*	Acceptance.	User.	Irrelevant. (hard to build relationship)
9.	*'How the information is presented. Is video the best format? It could depend on what is being treated. (Who will receipt this (GP/CARER/Patient)'*	Modality.	Virtual Content.	Relevant.
10.	*'Screen size of device (readability); appropriate view - icon?'*	Screen.	Device.	Irrelevant. (hard to build relationship)
11.	*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + Icon'.*	Accurate.	Other.	Relevant.
13.	*'Too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound'*	Modality.	Virtual Content.	Relevant.
15.	*'It might open up the video by proxy of the IPad - not by touch's the video on the screen?'*	Difficulty.	Interactio n.	Relevant.
	Irrelevant Issues			
1.	*How can the user recognise that they can use AR (If there is nothing like a QR code)?*	QR Code.	Physical World.	Irrelevant.
3.	*Issues in targeting the correct AR (what if the wrong pillbox was shown?)*	Accurate.	Other.	Relevant.
4.	*'Engagement with object reliant on at least some memory.'*	Cognition.	User.	Irrelevant.
12.	*'Reliance on a single device (battery could be that - may not be familiar with it's use'*	Battery.	Device.	Irrelevant.
14.	*'IPad - 'weight' - maybe a little bit heavy'*	Wearability.	Device.	Irrelevant.
	Either Irrelevant or relevant Issues			
5.	Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.	Acceptance.	User.	Irrelevant.
7.	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*	Cognition.	User.	Irrelevant.
8.	*'Technology issues with software/hardware. Apps crash + also need updating'.*	Update.	Virtual Content.	Irrelevant.

APPENDIX B.2

Table for AR issues for older adults relating to the relevant and irrelevant of Modality-focus Augmentation Design Principle

Issue Number	General Issues	Raw Data Theme	Higher Theme	Comments
General Issue 1.	'*How can the user recognise that they can use AR (If there is nothing like a QR code)?*'	QR Code.	Phyiscal World.	Irrelevant
General Issue 2.	'*Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.*'	Acceptance	User.	Relevent
General Issue 5.	*'Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.'*			
General Issue 6.	*'Acceptance: they have to accept / understand to some level that sort of technology.'*			
General Issue 4.	*'Engagement with object reliant on at lease some memory.'*	Cognition.	User.	Relevant
General Issue 7.	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*			
General Issue 3.	*'Issues in targeting the correct AR (what if the wrong pillbox was shown?)'*	Accuracy.	Virtual Content.	Irrelevant
General Issue 11.	*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon.'*			Irrevant
General Issue 8.	*'Technology issues with software/hardware. Apps crash + also need updating.'*	Update.	Virtual Content.	Irrelevant
General Issue 9.	*'How the information is presented. Is video the best format? It could depend on what is being treated. (Who will receipt this (GP/CARER/ Patient)'*	Modality.	Virtual Content.	Relevant
General Issue 13.	*'too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound.'*			Relevant
General Issue 10.	*'Screen size of device (readability); appropriate view - icon?'*	Screen.	Device.	Irrelevant
General Issue 12.	*'Reliance on a single device (battery could be that - may not be familiar with it's use.'*	Battery.		Irrelevant
General Issue 14.	*'IPad - 'weight' - maybe a little bit heavy.'*	Wearability.		Irrelevant
General Issue 15.	*'it might open up the video by proxy of the IPad - not by touch's the video on the screen?'*	Touch Difficulty.	Interaction.	Irrelevant

APPENDIX B.3

Table for AR issues for older adults relating to the relevant and irrelevant of Instantaneous Augmentation Design Principle

Issue Number	General Issues	Raw Data Theme	Higher Theme	Comments
General Issue 1.	'*How can the user recognise that they can use AR (If there is nothing like a QR code)?*'	QR Code.	Phyiscal World.	Irrelevant
General Issue 2.	'*Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.*'	Acceptance	User.	Relevant: raise or address
General Issue 5.	*'Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.'*			Relevant
General Issue 6.	*'Acceptance: they have to accept / understand to some level that sort of technology.'*			Relevant:
General Issue 4.	*'Engagement with object reliant on at lease some memory.'*	Cognition.	User.	Relevant
General Issue 7.	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*			
General Issue 3.	*'Issues in targeting the correct AR (what if the wrong pillbox was shown?)'*	Accuracy.	Virtual Content.	Relevant
General Issue 11.	*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon.'*			Irrevant
General Issue 8.	*'Technology issues with software/hardware. Apps crash + also need updating.'*	Update.	Virtual Content.	Irrelevant
General Issue 9.	*'How the information is presented. Is video the best format? It could depend on what is being treated. (Who will receipt this (GP/CARER/ Patient)'*	Modality.	Virtual Content.	Relevant
General Issue 13.	*'too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound.'*			
General Issue 10.	*'Screen size of device (readability); appropriate view - icon?*'	Screen.	Device.	Irrelevant
General Issue 12.	*'Reliance on a single device (battery could be that - may not be familiar with it's use.'*	Battery.		Irrelevant
General Issue 14.	*'IPad - 'weight' - maybe a little bit heavy.'*	Wearability.		Irrelevant
General Issue 15.	*'it might open up the video by proxy of the IPad - not by touch's the video on the screen?*'	Touch Difficulty.	Interaction.	Irrelevant

APPENDIX B.4

Table for AR issues for older adults relating to the relevant and irrelevant of Layer-focus Augmentation Design Principle

Issue Number	**General Issues**	**Raw Data Theme**	**Higher Theme**	**Comments**
General Issue 2.	'*Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.*'	Acceptance	User.	Relevant
General Issue 5.	*'Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.'*			
General Issue 6.	*'Acceptance: they have to accept / understand to some level that sort of technology.'*			
General Issue 4.	*'Engagement with object reliant on at lease some memory.'*	Cognition.	User.	Relevant
General Issue 7.	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*			
General Issue 3.	*'Issues in targeting the correct AR (what if the wrong pillbox was shown?)'*	Accuracy.	Virtual Content.	Relevant
General Issue 11.	*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon.'*			
General Issue 8.	*'Technology issues with software/hardware. Apps crash + also need updating.'*	Update.	Virtual Content.	Relevant
General Issue 10.	*'Screen size of device (readability), appropriate view - icon?'*	Screen.	Device.	Relevant
General Issue 12.	*'Reliance on a single device (battery could be that - may not be familiar with it's use.'*	Battery.		Irrelevant
General Issue 14.	*'IPad - 'weight' - maybe a little bit heavy.'*	Wearability.		Irrelevant
General Issue 15.	*'it might open up the video by proxy of the IPad - not by touch's the video on the screen?'*	Touch Difficulty.	Interaction.	Relevant

APPENDIX B.5

Table for AR issues for older adults relating to the relevant and irrelevant of Accurate Augmentation Design Principle

Issue Number	General Issues	Raw Data Theme	Higher Theme	Comments by this research
General Issue 1.	'*How can the user recognise that they can use AR (If there is nothing like a QR code)?*'	QR Code.	Phyiscal World.	Irrelevant (hard to build the connection)
General Issue 2.	'*Floating virtual content might distress the aged user (unfamiliar) especially if they are interacting as well.*'	Acceptance	User.	Hard to say, depending on the level of their familarity
General Issue 5.	*'Physical accessibility: seeing the device/where the device issued being able to use a touch screen device.'*			Irrelevant (hard to build the connection)
General Issue 6.	*'Acceptance: they have to accept / understand to some level that sort of technology.'*			Relevant (address or solve: easy-to-understand)
General Issue 4.	*'Engagement with object reliant on at lease some memory.'*	Cognition.	User.	Relevant: Address or solve
General Issue 7.	*'Physical Activity: Depends on what issues the patient has. e.g. Parkinson's/Dementia.'*			Relvant: Address or solve
General Issue 3.	*'Issues in targeting the correct AR (what if the wrong pillbox was shown?)'*	Accuracy.	Virtual Content.	Relevant: Address or solve
General Issue 11.	*'Finding/locating the subject object (?!) (drifting focus, many objects, light/dark) + icon.'*			Relevant: Address or solve
General Issue 8.	*'Technology issues with software/hardware. Apps crash + also need updating.'*	Update.	Virtual Content.	Irrelevant
General Issue 9.	*'How the information is presented. Is video the best format? It could depend on what is being treated. (Who will receipt this (GP/CARER/ Patient)'*	Modality.	Virtual Content.	Irrelevant
General Issue 13.	*'too much writing - this could be simpler. More 'dynamic' and playful rather than informative; using signs and symbols (more interactive) + sound.'*			Relevant
General Issue 10.	*'Screen size of device (readability); appropriate view - icon?'*	Screen.	Device.	Irrelevant
General Issue 12.	*'Reliance on a single device (battery could be that - may not be familiar with it's use.'*	Battery.		Irrelevant
General Issue 14.	*'IPad - 'weight' - maybe a little bit heavy.'*	Wearability.		Irrelevant
General Issue 15.	*'it might open up the video by proxy of the IPad - not by touch's the video on the screen?'*	Touch Difficulty.	Interaction.	Irrelevant

APPENDIX C.1

PARTICIPANT CONSENT FORM

1) Thank you for your time. Your participation is very important to the success of our focus group. The aim of this study is to evaluate AR applications focusing on elder people. Please be aware that your participation in this study is completely voluntary and you can withdraw at any time. Please feel free to ask any questions during this focus group, or email me after the study if you have any concerns.

2) We will recorder your voice, views and comments. In reporting my research all recording and data will be kept strictly confidential in accordance with Sheffield Hallam University's ethical regulations and data management requirements. No details identifying you as an individual will be revealed in the reporting of this research.

3) Please sign below to indicate your understanding and acceptance of these conditions.

Signature of Participant: _____

Date: **16th May 2018**

Researcher contact information
Sha Liang, PhD Student
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Communication and Computing Research Centre, Sheffield Hallam University

APPENDIX C.2

We'd be grateful if you could provide some feedback on this focus group

1. How much experience in using mobile phone, tick please?

a) None
b) Less than 1 year
c) 1-3 years
d) More than 3 years

2. Please try each of the technologies on the table and rate them against the following questions. In each box, please put a number from 1 (strongly disagree) to 5 (strongly agree).

	version A (Aspirin):	version B (Gaviscon):	Version C (Strepsils):	Version D (video-based I)	Version E (video-based II)
I would imagine this system is easy to use.					

3. The overall comments for these applications and any suggestions of improving them:

_____

_____

_____

4. The overall comments for this focus group:

_____

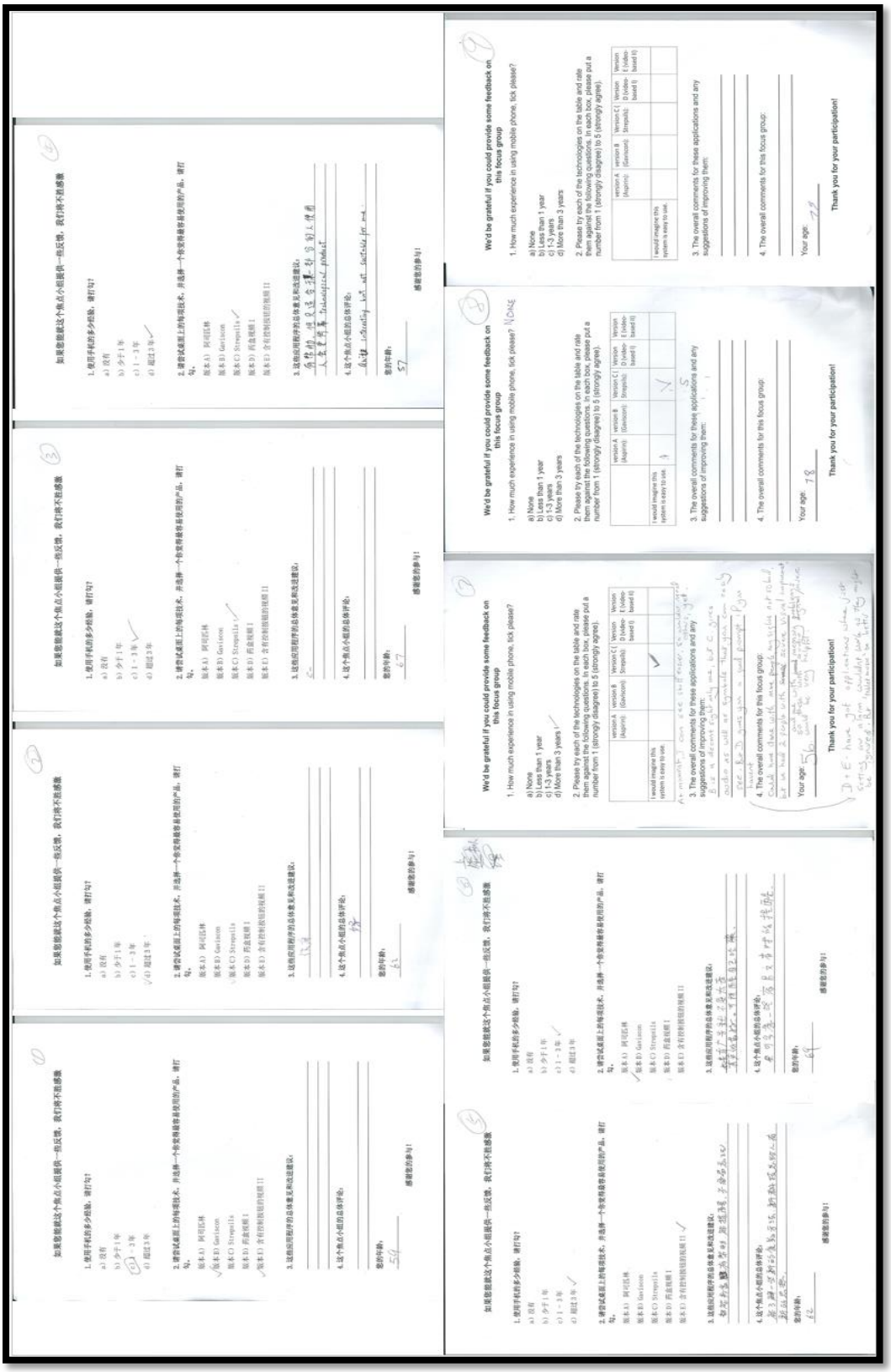
_____

Your age:

_____

Thank you for your participation!

APPENDIX C.3



(When someone said I might leave because of phone call, I need clearly reply them it is definitely OK)

Q1: What is your experience of using mobile phone? How often you use them?

Jin: The answer is yes. 30-40 times a day (iphone).

Roy: No, I do not. My wife uses the mobile phone. The difficulty is I could not see what was on the screen, (Ann) what is exactly about.

Ann: I got an Android phone now, and I had it for three years. Three years ago I used blackberry, but I do not understand that a lot. That is a horrible thing. That nearly pull all my phone together. But I got this a couple of years ago. (Jin, are you happy with that). It is all right. But would not spend too much money one time. I will not buy a really good iPhone or something like that. But I tend to do everything I want to do. I not want to play games or so.

Jin: I also got IPad. I use it as same as IPhone. IPad is bigger, that is why I like it. I also use IPad to play games. Somebody said something and you do not know what that means, like Google. (Jin shows me an APP)

Ann: I got a pain killer and trouble with memory. I lose very simple words, so I google them. (Feel interested in talking books)

Jin: I forgot names sometimes and it comes to me later. Can we use Kindle to read to you? See that TV is not good for me. Personally I cannot see it. (I have to look at them very close to me). But, anyway, it is talking all the time. I like yellow one and blue.

Q2: What do you think of the additional information?

Jin: (Use mobile phone) something cover the print out. Some of the information printed on the box you collected from the chemistry. I cannot see it and will not use it, unless it is really near to me. In your tablet, you got a piece of paper, and the instruction tells you why are you taking this and what the side effect.

Ann: That 3 version becomes better, the first one is confusing. The 3 one could see what it is. This could tell you how many you have got and able to tell the doctor you need more. It is very easy to … (14:22) a tablet. (Show a tablet box for me.) But, that does not tell you how many you take them and how many left in your packet. Might tell the doctor (maybe not only doctor) change to another description.

Jin: When we hid some information, there will be a label inside.

Ann: Sometimes you might lose them (debating time).

Q3: Compared with the divided category additional information, which one do you prefer?

Ann: V2, that is better. It is like the sticker you stick on the box. You can read what something underneath. The first one obscure your box, hard to tell you what you should look at.

Jin: From my point of view, it is very good for the medical profession. You have to take the tablet from the original packages, when you in there. That will be ideal for them. What time you take it? How many you take in? I will know anyway and I will remember up to now. What I will do, I keep them in the bathroom window and I got one for morning, one for evening, which is what I do, which is easy. There is no set time for me. But when we in the hospital, they do not know. That is valuable for them. I think that would be a boom. (20 min)

Q4: What do you think of the audio version?

Jin: I will look at the time, and the box will tell you. That is the best. That is better for me personally. We have to talk ourselves.

Ann: If you cannot see clearly, you can listen. (She just ask me the meaning of these icons).

Roy: I have a tablet reminder in the morning, called my wife. (Ann worried, if she is not at home. Benefit). She will write something down for me.

Jin: I got a friend, when she went to hospital, even buzzer (no idea what she means, 25:24) her husband bread for the next day. How bad is that? Ann, did she learn to do that, when she was younger. Some people they do not know. Jin: They just helpless.

(After demonstrating the next version)

Ann: That could be like, if you got a tablet, and you got to dissolve the tablet in water or a mixture a water.

(Would you like that? Jin asked)

Roy: when I have my stroke, I lost my short term memory. Memory is a big thing for me. I have problems with remembering things. (Ann asks, If you press the button and it tells you what to do?)

If I can remember which button to press.

Jin: If it is only one button to press, it will be very easy. The others could not be adopted. (maybe used by other careers)

Ann: You don't have to turn the thing on. It is just on your phone and come up.

Q5: Make a comparison between auto and non-auto?

Jin: The auto one is far better.

Roy: Something demand you, you are going to take the tablet, like the music. 6 o'clock, a music start. The noisy is going off.

Jin: Pill taking music, something you familiar. That is the alarm but musically. No buzzers. No bell. You could choose your favourite songs.

Ann: if it is just the alarm going on, you would just think it is the alarm. you might take notes what is on it. (Integrity the alarm with the reminder.) If it is a particular music you recognise it, you know it. And the music is specific to the tablet.

Q6: Overall comments?

Jin: How you get your phone to do it? If we forget the number? Can I see through them

Roy: Can they tell you the amount of the tablet? (36:50) Donot go to complication. It could be used. How to programme it (could be difficult).

Ann: You might take the wrong number of the tablet. How many you got left. Usually you know your instruction said it is all right and it will be all right. If you had this all set up to your daughters notes, and what you have it and automatically saying your things. Deaf or not (cannot hear clearly).