

UNIVERSITY OF CALGARY

AUGMENTED REALITY: A NARRATIVE LAYER FOR HISTORIC SITES

By

ROZHEN KAMAL MOHAMMED-AMIN

A THESIS

SUBMITTED TO THE FACULTY OF ENVIRONMENTAL DESIGN

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ENVIRONMENTAL DESIGN (COMPUTATIONAL

MEDIA DESIGN)

THE FACULTY OF ENVIRONMENTAL DESIGN

CALGARY, ALBERTA

SEPTEMBER 2010

© ROZHEN KAMAL MOHAMMED-AMIN 2010



UNIVERSITY OF
CALGARY

The author of this thesis has granted the University of Calgary a non-exclusive license to reproduce and distribute copies of this thesis to users of the University of Calgary Archives.

Copyright remains with the author.

Theses and dissertations available in the University of Calgary Institutional Repository are solely for the purpose of private study and research. They may not be copied or reproduced, except as permitted by copyright laws, without written authority of the copyright owner. Any commercial use or re-publication is strictly prohibited.

The original Partial Copyright License attesting to these terms and signed by the author of this thesis may be found in the original print version of the thesis, held by the University of Calgary Archives.

Please contact the University of Calgary Archives for further information:

E-mail: uarc@ucalgary.ca

Telephone: (403) 220-7271

Website: <http://archives.ucalgary.ca>

Abstract

Augmented Reality: A Narrative Layer for Historic Sites

Rozhen Kamal Mohammed-Amin

September 2010

Prepared in partial fulfilment of the requirements of the degree in the Faculty of
Environmental Design, The University of Calgary.

Supervisor: Dr. Richard M. Levy

Today's physical spaces are becoming a hybrid (mix) of real and digital entities. Consequently, spaces have become narrative spaces where objects, buildings and streets are linked to websites, blogs and wikis. This new character of space enables everyone with a smartphone to potentially experience their worlds differently with the assistance of Augmented Reality (AR) technology. With the advancements of smartphone technology the use of AR and the number of potential applications have dramatically increased across all fields. In cultural heritage and historic resource management AR promises very interesting opportunities for narrating and presenting history. This research focuses on examining the use of smartphone-based AR for narrating history and communicating information to on-site visitors.

This research first examines the state-of-the-art of the AR technology and its systems components, interface design requirements, advancements, and its applications in architecture, urban planning and design, and cultural heritage and historic resource management. This research also considers guidelines for building AR applications that focus on presenting historic sites. Functions critical to these applications would include location-based learning, adding context, geotagging, information visualization, way-finding, and audio guiding. It is the goal of this research to create a set of guidelines that would facilitate the historic restoration and reconstruction of heritage sites and places using functions like image alignment and 3D model reconstruction and view. In this research a case study approach presents a proof of concept for an AR application that would be used to explore Erbil citadel. This proof of concept called Arbela Layers Uncovered (ALU) was developed using the design guidelines developed in this research. The final proof of concept was then assessed using the design guidelines as a checklist. A summary and future research in the field of cultural heritage and historic resource management were also recommended.

Keywords

Augmented Reality, mobile Augmented Reality, Historic Architecture, Historic Resource Management, Augmented Reality in Architecture, Augmented Reality in Urban Design and Planning, Cognitive map, Way Finding, Information Visualization and Historic Restoration, Smartphone, Interface Design.

Acknowledgements

I would like to express my deepest gratitude to all the individuals who contributed to this thesis and supported me during my master's degree studying:

- Dr. Richard Levy, my supervisor, for his extraordinary supports, encouragements, and feedback that led to finishing this thesis and also for being a great source of motivation and inspiration.
- Prof. Tang Lee, my co-supervisor, for his continuous supports and valuable advices.
- Dr. Jeffrey Boyd, my external supervisor, for all his valuable feedback and contributions in advancing this thesis.
- Prof. Denis Gadbois, the Dean's appointed examiner, for his suggestions.
- Dr. Bakr Shah, for all his great supports and care during my studying.
- Dr. Sherzad Najar, for all his supports and helps.
- Mr. Salar Omer, for all his valuable supports.
- Mr. Kanan Mufti, the General Director for Antiquities, for being a valuable resource during collecting data about Erbil citadel.
- Everyone else who didn't hesitate to help and support me throughout this academic exploration.
- And finally, my mother who always stood behind me to support, encourage, and motivate, and also for her extraordinary life scarifies to make me and my sisters happy and successful.

Dedication

“Learning never exhausts the mind”

(Leonardo da Vinci)

This work is dedicated to:

- The soul of the most wonderful, courageous, and kindest father and role model in the world, Kamal.
- The most dedicated, supportive, generous, and inspiring mother, Sabry, for whom I owe all my successes.
- The delicate little, yet most precious, pieces of my soul, Hammy, JyJy, Banoza, MiMi, Winni, ToTo, Nimo, and Mimo.
- My beloved sisters, Havin, Dereen, Gasheen, Dnya, and Esra.
- My lifetime friend and sister, Kanar.
- The rest of my family and friends.
- And finally, every little soul who suffers from cancer.

Table of Contents

Approval Page.....	ii
Abstract.....	iii
Keywords.....	iii
Acknowledgements.....	iv
Dedication.....	v
Table of Contents.....	vi
Epigraph.....	xiii
 CHAPTER ONE: INTRODUCTION.....	 1
1.1 The Research.....	1
1.2 An AR Scenario.....	2
1.3 Background.....	4
1.4 Motivation.....	5
1.5 Research Contributions.....	6
1.6 Objectives.....	6
1.7 Research Methodology.....	7
1.7.1 Literature Review.....	7
1.7.2 Design Guidelines.....	8
1.7.3 Data collection.....	9
1.7.4 Smartphone-based AR proof of concept.....	10
1.7.5 Evaluating ALU interface design.....	11
1.8 Research Limitations.....	11
1.9 Document Structure.....	12
 CHAPTER TWO: AUGMENTED REALITY.....	 13
2.1 What is AR?.....	13
2.1.1 Augmentation.....	13
2.1.2 Augmented Reality Definition.....	14
2.1.3 The Development of AR: First experiments.....	17
2.2 AR and Human Memory and Experience.....	20
2.3 Augmented Reality system.....	23
2.3.1 Display.....	24
2.3.1.1 Fusion technologies in AR displays.....	28
2.3.2 Tracking.....	40
2.3.3 Registration.....	47
2.3.4 Calibration.....	51
2.4 AR and ARToolkit.....	53
2.5 AR interface design.....	54
2.5.1 AR interface design trends.....	61
2.6 AR challenges.....	67
2.7 AR Recent developments.....	68
2.7.1 The development of mobility in AR technology.....	69
2.7.2 AR and Smartphones.....	75
2.8 Summary.....	87

CHAPTER THREE: AR IN ARCHITECTURE, URBAN PLANNING, AND CULTURAL HERITAGE	88
3.1 AR, Architecture and Built Environment	88
3.1.1 Augmented Reality Applications in Architecture and Urban Design and Planning	93
3.1.1.1 AR as a tool in architectural design and information visualization:	94
3.1.1.2 AR for way finding, guiding, and geotagging:	101
3.1.1.3 AR for adding context into Built Environments:	104
3.1.1.4 AR for advertising and projection:	107
3.1.1.5 AR for Art Installations in architectural and urban spaces	115
3.2 AR, Cultural Heritage, and Historic Resource Management	117
3.2.1 AR applications in Cultural Heritage and Historic building representation	118
3.2.1.1 AR for information representation	119
3.2.1.2 AR for restoration, reconstruction, and visualization	130
3.3 Summary	137
CHAPTER FOUR: DESIGN GUIDELINES	139
4.1 Design guidelines for developing AR applications and prototypes	139
4.1.1 AR technology:	140
4.1.2 AR user interface:	141
4.1.2.1 The augmented virtual contents:	141
4.1.2.2 User Interface (UI) design:	144
4.1.2.3 Interactivity:	145
4.1.2.4 Connectivity with real and virtual world:	146
4.2 Summary	147
CHAPTER FIVE: THE ARBELA LAYERS UNCOVERED (ALU) PROOF OF CONCEPT	148
5.1 A Smartphone-based AR proof of concept for Erbil Citadel	148
5.2 A brief history of Erbil Citadel	149
5.3 Why develop a smartphone-based AR proof of concept for Erbil Citadel?	153
5.4 ALU Proof of concept	157
5.4.1 ALU Technology	158
5.4.2 ALU Interface design	159
5.4.2.1 History:	161
5.4.2.2 Heritage:	163
5.4.2.3 Database:	170
5.5 Evaluating the Proof of Concept Design	174
5.6 Summary	176
CHAPTER SIX: CONCLUSION	177
6.1 Summary	177
6.2 Conclusions	178
6.3 Future Research	178
REFERENCES	181

List of Figures and Illustrations

<i>Figure 2.1</i> Reality-virtuality continuums.	15
<i>Figure 2.2</i> A view from a real environment that is augmented with digital information.....	16
<i>Figure 2.3</i> A user navigating in a virtual environment in VR.	16
<i>Figure 2.4</i> Sutherland's HMD (1968).	18
<i>Figure 2.5</i> Building blocks in augmented reality system.	24
<i>Figure 2.6</i> Image-generation for augmented reality display.	26
<i>Figure 2.7</i> Head-Mounted Display. <i>Figure 2.8</i> Mobile phone display.	27
<i>Figure 2.9</i> Projector-based augmentation.	27
<i>Figure 2.10</i> Optical see-through display.	29
<i>Figure 2.11</i> Optical see-through HMD conceptual diagram.	30
<i>Figure 2.12</i> Optical see-through HMD.....	32
<i>Figure 2.13</i> Video see-through display.	33
<i>Figure 2.14</i> Video see-through HMD conceptual diagram	34
<i>Figure 2.15</i> Replacing a blue screen with a virtual set using chroma-keying technique.	35
<i>Figure 2.16</i> A view from video see-through HMD.	37
<i>Figure 2.17</i> Monitor-based technology.	39
<i>Figure 2.18</i> Monitor-based conceptual diagram.....	39
<i>Figure 2.19</i> Tracking a user in a given space.	41
<i>Figure 2.20</i> (a) The six-degree-of-freedom (6DOF). (b) A head tracker.	41
<i>Figure 2.21</i> Marker-based tracking.	44
<i>Figure 2.22</i> Tracking in an outdoor environment using Marker-less tracking.	45
<i>Figure 2.23</i> A correct registration example.	48
<i>Figure 2.24</i> ARToolKit and AR.	53

<i>Figure 2.25</i> ARToolKit tracking steps.	54
<i>Figure 2.26</i> The key interface elements.	55
<i>Figure 2.27</i> The effect of the information filter.	57
<i>Figure 2.28</i> Area feature labeling comparison in virtual reality.	58
<i>Figure 2.29</i> Area An example of the use of registration error estimation.	59
<i>Figure 2.30</i> User wields a real paddle to pick up, move, drop, and destroy models.	63
<i>Figure 2.31</i> The AR MagicLens Interface Components.	64
<i>Figure 2.32</i> Using the AR MagicLens to see different views of the earth.	65
<i>Figure 2.33</i> The virtual studio setup.	66
<i>Figure 2.34</i> A “mediated” house mock-up. A real model with virtual enhancements.	67
<i>Figure 2.35</i> Touring Machine supporting technologies.	69
<i>Figure 2.36</i> The AR-PDA project.	71
<i>Figure 2.37</i> A video see-through example on a consumer cell-phone.	73
<i>Figure 2.38</i> Processing devices comparison.	74
<i>Figure 2.39</i> A view from New York Nearest Subway iPhone application developed by Acrossair.	79
<i>Figure 2.40</i> Using Goggle for finding information about a landmark online.	81
<i>Figure 2.41</i> Using Goggle for finding information about a text online.	81
<i>Figure 2.42</i> iPhone Screenshots for two different scenarios using Wikitude World Browser.	83
<i>Figure 2.43</i> Using Layar for finding information about a restaurant.	84
<i>Figure 2.44</i> Augmented reality outdoor campaign for the new ‘Prince of Persia’ movie.	86
<i>Figure 3.1</i> Internet map represents information flow.	89
<i>Figure 3.2</i> An aerial view of the Shibuya district in Tokyo, with a large variety of LCD displays and animated screens in the cityscape.	91
<i>Figure 3.3</i> Using SecondSite to visualize a part of a project on-site before it is built.	96

<i>Figure 3.4</i> SecondSite visualization device.....	97
<i>Figure 3.5</i> Using AR4BC for on-site information visualization.	98
<i>Figure 3.6</i> AR- Scale Model application in the ARARAT project.	100
<i>Figure 3.7</i> AR- Interior application in the ARARAT project.	100
<i>Figure 3.8</i> Using Metro Paris Subway application for finding nearby Metro stations in Paris.	102
<i>Figure 3.9</i> Automatically receiving notification when a disrupted line is detected in Paris Metro (A feature in Metro Paris Subway iPhone application).....	103
<i>Figure 3.10</i> Using Metro Paris Subway application for finding businesses and POI in Paris.....	104
<i>Figure 3.11</i> GeoTravel application as a tour guiding.	105
<i>Figure 3.12</i> Mouse Reality layer for guiding in Disneyland.	106
<i>Figure 3.13</i> EyeTour layer for exploring Puerto Rico.....	107
<i>Figure 3.14</i> Using Fashionista Virtual Dressing Room for trying on clothes and navigating among selections from Tobi online retailer.	109
<i>Figure 3.15</i> Using Magic Mirror for try on clothes in online shopping.	109
<i>Figure 3.16</i> N Building in Tokyo, Japan.	112
<i>Figure 3.17</i> An augmented view of N Building from a mobile phone camera.	112
<i>Figure 3.18</i> Hague's city hall urban installation.	113
<i>Figure 3.19</i> The 555 KUBIK façade projection on Kunsthalle in Hamburg, Germany.	114
<i>Figure 3.20</i> The Energy Passages art installation.....	115
<i>Figure 3.21</i> The Augmented Sculpture project's layers.	116
<i>Figure 3.22</i> Different views from the Augmented Sculpture layers by Pablo Valbuena.	117
<i>Figure 3.23</i> Mobile phone tour at Tate Modern's David Smith: Sculptures exhibition.	120
<i>Figure 3.24</i> HU walking tour application start-up interface.....	124
<i>Figure 3.25</i> A shot of Spanio, the baker and singer, appears on the screen before the HU guide and invites the user to go inside the bakery.	125

<i>Figure 3.26</i> Launching StreetMuseum application on iPhone 3GS.	126
<i>Figure 3.27</i> A view from an iPhone showing the pins on London's map in StreetMuseum app.	128
<i>Figure 3.28</i> A view from the iPhone after tapping the pin on Carnaby Street on the map.....	128
<i>Figure 3.29</i> A view from the iPhone showing the 2D image of Carnaby Street in 1968 and appears to be aligned with the real view of the street today.	129
<i>Figure 3.30</i> A view from the iPhone showing the Carnaby Street image in 1958 enlarged with historical facts about the street.	129
<i>Figure 3.31</i> The aligned 2D image of the bombed headquarters building appears on top of the view of the renovated building today using the StreetMuseum application.	130
<i>Figure 3.32</i> An augmented view with historic buildings from ancient Olympia site using the ARCHEOGUIDE system.	132
<i>Figure 3.33</i> The ARCHEOGUIDE system's devices worn by the visitor.	133
<i>Figure 3.34</i> The ARCHEOGUIDE overall system Architecture.	134
<i>Figure 3.35</i> An AR reconstruction example: The Philippion Temple at Ancient Olympia.....	135
<i>Figure 3.36</i> A user wearing LifeClipper AR technology to navigate in St. Alban Quarter.	136
<i>Figure 3.37</i> Two view of the same spot from LifeClipper project.	137
<i>Figure 5.1</i> Erbil citadel which locates in the center of Hawler (Erbil) city.....	149
<i>Figure 5.2</i> Alexander's route to Babylon through Arbela.	151
<i>Figure 5.3</i> A 17th century painting of the battle of Gaugamela by Jan Bruegel the Elder.	152
<i>Figure 5.4</i> Running ALU application on an iPhone.	157
<i>Figure 5.5</i> Using ALU for on-site visiting of Erbil citadel.	158
<i>Figure 5.6</i> ALU's main interface and the three modes.	160
<i>Figure 5.7</i> A brief about the content of each mode appears after tapping the screen once.	160

<i>Figure 5.8</i> The main interface in history mode where the historic information is arranged according to a timeline.	162
<i>Figure 5.9</i> An illustration for the interface content after tapping Arbela Battle in the history mode.	162
<i>Figure 5.10</i> An illustration of the user's ability to select and zoom-in on an image.	163
<i>Figure 5.11</i> The main interface in heritage mode where the three functions appear.	164
<i>Figure 5.12</i> Close by pins appears on Erbil citadel's map when a user activates the 2D view function on-site. The blue circle indicates user's location.	165
<i>Figure 5.13</i> Obtaining information in camera view in heritage mode.	166
<i>Figure 5.14</i> Information appears after a circle is tapped in heritage/3D view mode.	166
<i>Figure 5.15</i> Circles indicating availability of re-construction in heritage mode.	167
<i>Figure 5.16</i> 3D model of a reconstructed part appear in its original location as the user taps the indicating circle (illustration).	168
<i>Figure 5.17</i> The user can tap more than a circle on the screen to see the re-construction.	168
<i>Figure 5.18</i> An indication of the ability to re-construct Erbil citadel's main gate in heritage/re-construct mode.	169
<i>Figure 5.19</i> Re-constructing Erbil citadel's main gate in 1918 using the image alignment technique.	170
<i>Figure 5.20</i> Accessing HCECR webpage in database mode for finding more information.	172

Epigraph

*"If you please - draw me a sheep!"
said the little Prince, thinking not
about a real sheep, but a virtual one.
For a virtual sheep requires very
little space and can live a long time.*

(Flachbart & Weibel, 2005)

Chapter One: Introduction

1.1 The Research

Augmented reality (AR) is a type of communication technology that allows extending digital media out into the physical world. It can augment the surrounding environment with virtual entities and information in a way that a person can no longer differentiate between reality and fiction. –Augmented reality is collecting headlines almost as fast as it's tagging the world around us” (Green, 2010). Advancements in mobile phone technology (such as the smartphone) have accelerated the number of "augmented reality" applications that are being developed.

As AR and its supporting technologies continue to flourish, so does its applications across different fields. The ability to augment computer generated entities (3D objects and data) into real world scenes makes AR an ideal platform for enriching historic architecture and the remains of cultural heritage. With AR technology it is possible to reconstruct and narrate the history of a site, buildings, or artefacts in an innovative way. AR provides a platform for combining representation techniques such as, text, pictures, audio, and video used to create a unique informed experience while navigating in a space.

In this research an extensive study on AR technology has been conducted. The aim was to develop design guidelines that help building mobile phone-based AR applications for representing historic architecture and the remains of cultural heritage. In developing the design guidelines, this research depended on successful AR applications and demos in

architecture, urban planning and design, and cultural heritage. The design guidelines were then used to develop a smartphone-based AR proof of concept called Arbela Layers Uncovered (ALU) which was used to develop a model of a historic settlement that is believed to be the world's most inhabited settlement, Erbil citadel in Kurdistan Region of Iraq.

1.2 An AR Scenario

The advancement of mobile phone-based AR technology today has made it is possible for someone with a smartphone to enjoy a unique and unprecedented tour of any historic site in the world regardless of any communication barriers. Imagine a scenario about an architect named Banoza from Italy who uses ALU as a tour guide for navigating in a historic site.

Last summer Banoza travelled to the Kurdistan Region of Iraq (KRG). Banoza was there as a representative of her company which has a contract with KRG to develop a tourist master plan for some resorts areas around Sulaymani city. In her free time, she visited several ancient sites, which is her favourite hobby, in Kurdistan region. She then wanted to visit a historic site which she heard a lot about from the locals living in the area. The historic site is more than 7000 years old and is called Erbil citadel. Today, the citadel is located in modern Hawler (Erbil) city.

After a day of planning and preparing, Banoza finally arrived at Erbil city with her translator. Banoza's excitement to see the historic remains of the citadel from

millenniums years ago soon to become vanished as her car was approaching the citadel in the city center of Hawler city. Despite the lack of a formal education in archaeology and history, Banoza soon realized that nothing on the site indicates the citadel's long history, as she didn't realize that she is actually standing in front of a historic monument that has not sustained historic structures and remains but rather the life in it. It is when she started asking her translator that she realized Erbil citadel, in contrary to the Machu Picchu in Peru that she visited last year, is the longest continuously inhabited settlement in the world and the mound that she was standing on is not a natural mound but rather built by historic accumulation of successive civilizations occupied Erbil citadel.

Banoza became interested in finding more information about the site, so she decided to go inside and have a tour with a tourist guide. Upon hearing a suggestion by the tourist guide in the citadel, Banoza decided to make her touring experience a unique one by using ALU (Arbela Layers Uncovered) application she just downloaded on her iPhone. Banoza never regretted her decision and found the experience an excellent one as she was able to personalize her tour, learn about the things that were interesting to her, see and interact with things that did not physically exist on the citadel, listen to and read about Erbil citadel's history in her native language, and record her experience by inputting information into a database. Since then, Banoza doesn't consider Erbil citadel as a structure with a few centuries of age standing on a mound, but rather a series layers of historic events from ancient and modern history, and a strong picture for a settlement that stood the test of the millenniums.

1.3 Background

The rapid growth in information and communication technology has generated new media, such as the internet, used for accessing information in parallel to the traditional media, such as radio, TV, newspaper, and books. The information from new media are conveyed through many different types of technologies such as computers, cell phones, hand-held devices, display screens, and other new electronic devices.

These new media have affected people's life-styles and contributed in re-shaping their daily activities in accessing and processing information. Consequently the surrounding physical spaces have also changed. Today the spaces around people are a blend of information space with physical space, and this character of space offers unprecedented opportunities to merge the virtual and the real, the information landscape of the Internet with the urban landscape of the city, to transform digital animated media in storytellers, in public installations and through personal wearable technology" (Sparacino, 2002).

AR as a technology for emerging virtual and real entities provides an opportunity for adding a new layer to the surrounding spaces, information and virtual entities. This communication technology has also provided many opportunities for location-based tasks. As a result, AR applications have been used in many fields including military, medicine, education, and entertainment. AR can now accommodate people's continuous need for information in order to proceed with their daily life activities.

In cultural heritage, the potential for this technology is vast. AR is able to enhance and enrich the user's perception about a thing or environment dramatically by augmenting invisible information and data; something that cultural heritage is striving for when representing a historic building, historic site, or artefact to visitors and researchers. AR as an innovative technology provides the ability to travel through time and visualize a historic building or site during its glory time while walking around it in real time; thus reconstructing the history of a building or place. AR also facilitates learning in a right time and place for a user by its location-aware augmentation ability.

1.4 Motivation

Cultural tourism is continuously growing and it is becoming the largest industry in the world, far ahead of automobiles and chemicals as claimed by UNESCO (*Cultural tourism* : UNESCO-CULTURE.2008). According to a survey by Ludovico Solima (2000), an associate Professor of Cultural Organizations Management at the Second University of Naples, about 10 percent of the visitors to cultural sites and museums live in that city (Baltsavias, Gruen, Van Gool, & Pateraki, 2006). The remaining 90 percent are tourists looking for an enjoyable experience which mixes entertainment and education (Richards, 2001). It has also been proven by recent studies that most people spend no more than one week for their holiday" (Baltsavias et al., 2006). As such, time becomes a crucial component for visitors who plan their trips in order to obtain exhaustive information from a short but enjoyable visit" (Baltsavias et al., 2006).

In this respect AR as an innovative technology by which the real world can be tagged with virtual information and objects become a promising tool for recording, restoring, visualizing, and representing historic architecture and the remains of cultural heritage. In addition to discussing the state-of-the-art AR technology, this research also discusses AR's uses and applications for enriching the visitor's perception about the historic spaces and objects which have stories to narrate. This research also reveals AR's uses for recording and preserving a historic site or building and presenting them to researchers and the public.

1.5 Research Contributions

This research offers two contributions. The first contribution is developing design guidelines for building mobile phone-based AR applications and prototypes that will enhance people's perception about a place or artefact which has accumulated layers of information while navigating in real time. These design guidelines work best for cultural heritage purposes in representing and documenting historic remains to the public and researchers. The second contribution is applying these guidelines when developing a smartphone-based AR proof of concept, ALU.

1.6 Objectives

The objectives of this research include:

- 1- examining the state-of the-art of AR technology by reviewing the AR system components and its developments,

- 2- exploring AR as a communication tool for representing and documenting historic architecture and cultural heritage remains and narrate their story by collecting and reviewing the AR applications used in architecture, urban planning and design, and cultural heritage,
- 3- developing design guidelines for building future smartphone-based AR applications by examining the current AR technology and determining available successful AR applications. These guidelines could be used for building AR application in cultural heritage, historic site exploration, way finding, entertainment, education purposes, and many others, and
- 4- applying the design guidelines by developing a smartphone-based AR proof of concept for reconstructing the buried historic layers of Erbil citadel.

1.7 Research Methodology

1.7.1 Literature Review

In this research, an extensive literature review was conducted on AR's history, technology, interface design, challenges, advancements, and applications in architecture, urban planning and design, and cultural heritage.

The literature review included:

- Books/ journals/ periodicals/ conference proceedings/ video: examined in the fields of augmented reality, virtual reality, interface design, cognitive maps and spatial memory, AR in architecture and urban planning, and AR in cultural

heritage. Research databases such as ACM, IEEE Xplore, Avery, and ProQuest were used for this purpose.

- World Wide Web: identified web sites, research centers, projects, researchers, and developers that are using or propagating AR technology. Internet resources and website reviews were also used for identifying online products used in developing mobile phone-based AR applications and also for finding successful AR applications in architecture, urban planning and design, and cultural heritage. Google Scholar and Google were the primary search engines used.

1.7.2 Design Guidelines

The design guidelines developed in this research are based on the following:

- studying AR technology and its system components by examining and making notes on research and projects by prominent researchers and developers in the field of AR,
- identifying AR system interface design requirements from AR applications in HMDs and mobile phones and also from researches on AR interface design presented in the literature review,
- identifying AR's technological challenges and opportunities from studying the system components and supporting technology,
- examining the current state of AR's supporting technology and identifying a mobile easy use platform for future AR applications (especially for navigating in

a space) through a detailed study of the recent advancements in AR and mobile phone technologies and making a comparison among the AR's platforms,

- examining AR applications and projects, or features, in architecture, urban planning and design, and cultural heritage uses in order to intervene technological and interface design solutions used for developing an AR application which presents historic sites and cultural heritage remains in the best way.

1.7.3 Data collection

Data and resources used for developing the ALU proof of concept for Erbil citadel were collected from:

- references in Kurdish, English, and Arabic languages in the form of books, researchers, Erbil citadel's archives, and papers found in Hawler city's public library, the Ministry of Culture's library, Department of Archaeology, and Hawler museum's archives,
- high Commission for Erbil Citadel Revitalization (HCECR) database and UNESCO World Heritage Center's review on Erbil citadel,
- photographs of the citadel gathered from a personal on-site visit of the citadel and from tourists and researchers of Erbil citadel posted online,
- historic photographs obtained from the Ministry of Culture in KRG, Hawler city's public library, Hawler museum, online, and books, and
- interviewing officials from HCECR and the Ministry of Culture including the General Director for Antiquities, Mr. Kanan Mufti.

1.7.4 Smartphone-based AR proof of concept

The AR proof of concept developed in this research was based on:

- The design guidelines developed in this research for building mobile phone-based AR.
- Considering smartphones' technological abilities based on AR system's requirements.
- The collected data and resources on Erbil citadel's history.
- Using Adobe Photoshop CS4 software for generating the graphics in which information and virtual objects are overlaid onto the scenes of Erbil citadel.
- Using Sketch-Up for constructing a 3D model of a hypothesis building in Erbil citadel in order to demonstrate the 3D object augmentation of Erbil citadel's historic demolished buildings.
- Addressing the following factors:
 - AR and smartphones' interface design requirements.
 - Smartphone's size and resolution of the screen.
 - Sound overlay of the audio guide and music.
 - Navigation through the citadel's streets.
 - Visual overlay of still images, graphics, text, and 3D model.
 - Organizing historic details and backgrounds according to a timeline.
 - Language translation ability.
 - Providing location related information when navigating.
 - Connectivity with internet resources such as, Google Maps, Goggle, and HCECR database.

- Accessibility to a wide range of users such as young, old, partially sighted individuals.

1.7.5 Evaluating ALU interface design

The ALU proof of concept is evaluated by checking its interface design components against a list of interface design requirements in the developed design guidelines.

1.8 Research Limitations

This research is limited by the available resources and data needed to develop a reliable smartphone-based AR tour guide for Erbil citadel. The citadel's rich history has not been fully documented for three main reasons; a lack of archaeological excavation on the site that will start soon under UNESCO's supervision, the spread of Erbil citadel's archives and resources, and the lack of a reliable central online database when developing the ALU proof of concept. These have limited the amount of augmented information used for representing and documenting the Erbil citadel. The ALU proof of concept will need to augment more archaeological and historic information, before it reaches its full potential as a reliable source of information and guide for researchers and visitors. The final proof of concept in this research is more of an exploration of the possibilities and is a demonstration of what can be achieved. ALU is only a proof of concept and not a working application. This research has not tested the reaction to ALU's interface design with real users due to time and budgetary constraints. However, this can potentially be conducted in future research.

1.9 Document Structure

The next five chapters of this research are divided into the following discussions:

Chapter two includes a detailed discussion about the AR system, its development, system components, and the types of AR. This chapter also presents interface design principles required for developing AR applications, and it underlines AR's challenges. The last section of this chapter examines the recent advancements in AR technology in terms of changing AR's platform from HMD to mobile phones, especially smartphones. It also presents new online mobile products that support building effective AR applications. This chapter provides a full understanding about AR technology and its supporting technology. It also identifies the suitable technology (smartphones) that have become an ideal platform for building interesting AR applications.

Chapter three analyzes the different uses of AR technology in the fields of architecture, urban planning and design, and cultural heritage. This has been done by examining the various AR applications in these fields. Chapter four presents the developed design guidelines that will help developing smartphone-based AR applications for representing and documenting historic architecture and cultural heritage remains. These design guidelines are developed through; an extensive examination of AR technology and its supporting technologies in chapter one, and also by analyzing and examining various AR applications and their uses in chapter three. In Chapter five the developed design guidelines from Chapter four are used to develop an AR proof of concept for the Erbil citadel. This chapter is followed by a conclusion chapter that includes a summary and future research ideas.

Chapter Two: Augmented Reality

This chapter provides an introduction to the basics and fundamentals of Augmented Reality (AR) technology. It contains a discussion about the development of this technology and its influence on enhancing people's perception and memory in a space. In presenting the system components, this chapter also discusses the underlying technologies, components, features, and characteristics of AR systems. Finally, the current state-of-the art of AR is highlighted by presenting the recent advancements in AR technology.

2.1 What is AR?

2.1.1 Augmentation

In the Oxford dictionary, augmentation is defined as the act of increasing, enlarging, or enriching something. This definition precisely reflects the task of augmented reality, enriching reality with information and virtual content. Augmentation becomes the main theme in building an augmented reality system. The recent advancements in AR have made it possible to augment different types of data and information that is detected by the different human senses, such as sight, smell, touch, and hearing.

Currently, the most popular applications of AR are those that focus on visual augmentation. In this type of augmentation visually detected information sources such as, text, graphics, and images are used for augmenting a space or environment. Thus, the augmented information is detected through the sense of sight by humans. At the same time, the number of applications adapting other augmentation types such as, audio

augmentation is continuously increasing. As Azuma, a noted AR developer from the University of North Carolina, (1997) states, “Augmented Reality might be applied to all senses, not just sight”. In addition to augmentation, an AR system also has the potential to move or hide objects from real scenes, such as removing a window from a wall, through graphic overlaying (R. Azuma, 1997).

2.1.2 Augmented Reality Definition

Augmented Reality (AR) is “a user interface technology that augments the users’ environment with computer generated entities” (Reitmayr & Schmalstieg, 2003). The computer generated entities in an AR system are registered with real world (i.e. tagged to a geographic location). AR is a form of Mixed Reality¹ (MR) in which real and virtual objects are blended and appear in a single display in the same time and location. The dominance of the surrounding real environment is a key aspect of AR when compared to AV (Augmented Virtuality²) in Reality-Virtuality Continuum (Milgram, Takemura, Utsumi, & Kishino, 1994) (See Figure 2.1).

¹ Mixed Reality (MR) refers to blending virtual and real objects/information and presenting them together. MR covers a continuum from AR to AV (Tamura, Yamamoto, & Katayama, 2001).

² Augmented Virtuality (AV) means augmenting a virtual environment (VE) with data from the real world (Tamura et al., 2001).

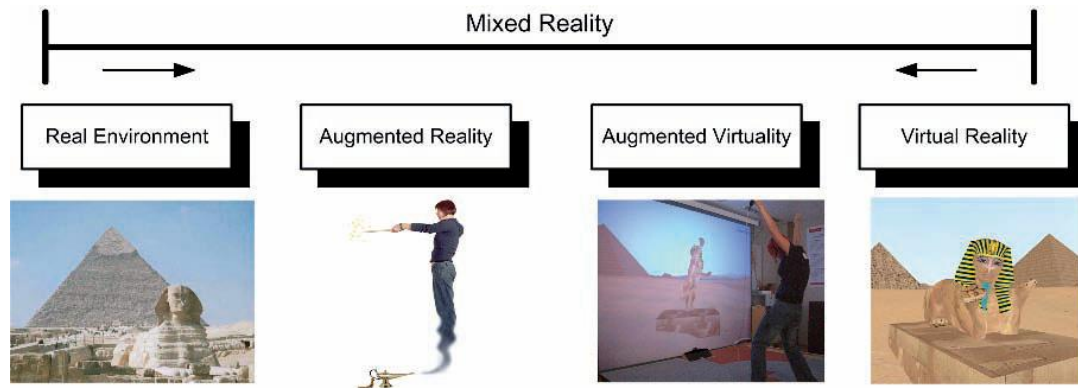


Figure 2.1 Reality-virtuality continuums.
(Gutiérrez A., Vexo, & Thalmann, 2008c)

Augmented reality doesn't replace reality, as is the case in Virtual Reality³ (VR), but rather supplements a real environment with digital information, virtual and computer-generated graphics, and/or virtual objects (2D or 3D) (See Figure 2.2). In VR, users navigate through a computer simulated or imaginary environment called a virtual environment, which has suppressed the real environment. In this environment all the users' senses are controlled by a computer and immersed in a simulated environment (See Figure 2.3).



Figure 2.2 A view from a real environment that is augmented with digital information.
(Contactum.n.d.)



Figure 2.3 A user navigating in a virtual environment in VR.
(CGV - computer graphics and knowledge visualization.2010)

In contrast to VR, in AR the real environment plays a dominant role (Bimber & Raskar, 2005). Consequently, the user's senses are not fully detached from the real environment. This character provides opportunities for interaction with the objects within a real

³ Virtual Reality (VR) uses computers to create 3D environments in which a user can navigate and interact (Gutiérrez A., Vexo, & Thalmann, 2008c).

environment. The augmented information in AR system has a strong spatial relationship with the superimposed real environment or object.

The aim of augmented reality is to enhance and enrich real images, objects, and/ or environments by providing information, digital objects, contextual data, background, and meaning for those objects or scenes in a real environment.

2.1.3 The Development of AR: First experiments

Although the term of augmented reality was coined in the early 1990s, the first augmented reality functional system appeared in the late 1960s. In 1965, Ivan Sutherland, an early pioneer in the field of Virtual Reality systems and a professor of Electrical Engineering from Harvard University, published a paper entitled “The Ultimate Display”. In his paper, Sutherland introduced the notion of the *Ultimate Display*, and described it as —a room within which the computer can control the existence of matter” in which the users should be able to interact with the virtual environment (Sutherland, 1965).

Consequently, in 1968 Sutherland and his colleagues were able to develop the first functioning *Head-Mounted Display* (HMD), which is considered the first augmented reality display. Feiner & Höllerer (2004), two computer science researchers from Columbia University, state that, “Ivan Sutherland and colleagues (1968) built a mechanically tracked 3D see-through head-worn display, through which the user could see computer-generated information mixed with physical objects, such as signs on a laboratory wall” (See Figure 2.4).



*Figure 2.4 Sutherland's HMD (1968).
(Gutiérrez A., Vexo, & Thalmann, 2008c)*

According to Bimber and Raskar (2005), two renowned AR researchers and professors, “Sutherland had used half-silvered mirrors as optical combiners that allowed the user to see both computer-generated images reflected from *cathode ray tubes* (CRTs) and objects in the room, simultaneously”. In order to give the illusion of being in a virtual world, the computer-generated images need to be updated according to the user's head movement. In measuring the position of the user's head (tracking) in the system, Sutherland had used mechanical and ultrasonic head position sensors to ensure the correct registration of the real environment and the graphical overlays (Bimber & Raskar, 2005). Also, the computer-generated images in Sutherland's example ~~were~~ were far from being realistic; they were simple line drawings. However, the stereoscopic view produced the impression of a real looking at solid 3D objects” (Gutiérrez A., Vexo, & Thalmann, 2008c).

Sutherland's first AR system was refined over the next decade. In the late 1970s, photorealistic computer-generated images became an area of research. In particular, progress in tracking technology furthered the hopes to create the ultimate simulation machine" (S. K. Feiner & Höllerer, 2004).

In early 1990s, the notion of overlaying computer graphics on top of the real world was created in the research labs of Boeing Corporation. It was Thomas Caudell, an engineer from Boeing at the time, who coined the term "Augmented Reality". Later on, in the mid-1990s, computing and tracking devices had become sufficiently powerful, and small enough, to support registered computer-generated graphical overlays in a dynamic mobile setting." (S. K. Feiner & Höllerer, 2004).

Furthermore, augmenting virtual content into a real environment raises two issues that are unique to augmented reality:

- 1- Establishing 3D geometric relationships between physical and virtual objects:
 - The locations of virtual objects must be initialized in the user's environment before user interaction can take place" (Kutulakos & Vallino, 1998).
- 2- Virtual objects rendering: —Realistic augmentation of a 3D environment can only be achieved if objects are continuously rendered in a manner consistent with their assigned location in 3D space and the camera's viewpoint" (Kutulakos & Vallino, 1998).

In the last decade, a variety of different technologies and techniques have been developed for advancing tracking, registration, and rendering techniques in AR systems.

2.2 AR and Human Memory and Experience

The first impression a person feels when navigating in a new environment are often ones of confusion, disorientation, feeling overwhelmed, and feeling excited or uncomfortable (Wagner, 2006). This occurs from a lack of understanding the spatial layout of an environment. This feeling is diminished with the formation of a cognitive map⁴ of the area. People start to form cognitive maps or mental maps for a place through experience and spending time in the place. This will occur when knowledge is acquired about movement patterns and spatial relationships among the objects in a place (Montello, Hegarty, Richardson, & Waller, 2004). The acquired knowledge is stored in memory and then translated to spatial memory, creating cognitive maps. As a result, people become familiar with the place/environment and can find the place again and navigate it easily (Montello et al., 2004).

Cognitive maps help people in moving around an environment efficiently, so that they can quickly acquire food, clothing, and other necessities of life (Wagner, 2006). As Wagner (2006), a psychology professor from Wagner College in New York, further explains —Without them [cognitive maps], we would be reduced to the level of primitive robots that move about at random, searching until they find what they need.”

⁴ Cognitive map is a concept introduced and coined by Edward Tolman in 1948 in psychology. It is the knowledge of spatial layout, which develops across time. —Thus, unlike other spatial literatures, cognitive mapping is concerned with knowledge accumulated across time” (Wagner, 2006).

In an attempt to explore cognitive map learning, Moeser (1998), a psychology professor from Memorial University, conducted research in a hospital with a complex layout in which the rooms and corridors had irregular sizes without any set pattern. In this research, Moeser (1988) found that ~~n~~nurses who had worked in this environment for more than two years had poorer knowledge of its spatial layout than did naive subjects who were merely asked to learn the buildings layout after a half-hour experience studying maps of the building” (Wagner, 2006). As it appears, it is not the frequent moving in an environment that creates better cognitive maps, but rather prior knowledge or desire to explore the environment. As Wagner (2006) summarized Paul Ellen’s study (1980), a psychology professor from Georgia State University, ~~h~~ocomotion without engagement of higher mental processes leads to little learning.”

In general, there are two ways for acquiring spatial information about an environment, a place, or an object: directly ~~v~~ia perceptual-motor interaction with the world”, and indirectly ~~v~~ia external representations of the world and its spatial layout” (Montello et al., 2004). The direct sources for acquiring spatial knowledge refer to a direct involvement of human senses (such as, sight, touch, and vestibular) with the environment/place and objects in it; thus directly experiencing the environment. Among the human senses, vision or sight proves to dominate the other senses (Millar, 2008). Vision provides more than 70% of the total sensory information (Kiyokawa, 2007). When conflicting cues occur between the different senses, for example sight and touch, the

visual sense dominates. This phenomenon is known as “visual capture”⁵. An example of this phenomenon occurs “When watching a television program, a viewer believes the sounds come from the mouths of the actors on the screen, even though they actually come from a speaker in the TV. Ventriloquism works because of visual capture” (R. Azuma, 1997).

The indirect sources for acquiring spatial information and knowledge about an environment/place, on the other hand, include “static pictorial representations” such as maps and pictures, and also “various dynamic pictorial representations” such as, movies, animation, dynamic computer graphics (virtual reality or virtual environment), and language (speaking and writing) (Montello et al., 2004). As indicated in Moeser’s (1988) research, using indirect sources for revealing spatial information can facilitate the creation of cognitive maps. As additional information obtained about a place, the more memorable the place becomes.

Various technologies, which allow combining both direct and indirect sources of information, have been used to enrich a person’s experience in a place. Audio guides used in museums for guiding visitors and tourists are a good example of combining an indirect source with movement. The aim is to increase a visitor’s experience and knowledge about the museums and the pieces in them.

⁵ Visual capture is “the tendency of the brain to believe what it sees rather than what it feels, hears, etc. That is, visual information tends to override all other senses” (R. Azuma, 1997).

AR technology provides promising opportunities for emerging the direct and indirect sources of information. AR can deepen people's experience and memory about a place or object in the place by augmenting almost any representation technique, text, map, video, picture, 2D or 3D virtual objects, etc, to the place or object. AR enriches the human senses, sight and hearing with its current technology, and enable us to see and/or hear beyond what already exists in the physical world. By supplementing a place or an object with information that cannot be detected or predicted, AR increases our understanding and knowledge about that place or object, making it more memorable. AR gives the illusion that the real and virtual world coexist (R. Azuma, 1997). It also allows us to query information while navigating through the physical world. Finally, AR can also help in forming a cognitive map of a place by revealing spatial information about the place, which otherwise may have been revealed across time through experiencing the place. Thus, AR doesn't only enhance and enrich an observer's experience in a place but also reduces the time needed to develop a cognitive map of the place.

2.3 Augmented Reality system

An AR system has three main features: combining real and virtual objects in a real environment, running interactively in real time, and aligning real and virtual objects with each other (Haller, Billinghurst, & Thomas, 2007). An AR system includes several different components: display, tracking, registration, and calibration (R. Azuma et al., 2001).

An augmented reality system consists of what Bimber & Raskar (2005) define as “building blocks”. These major components include tracking and registration, display technology, rendering, interaction devices and techniques, presentation, authoring, application, and user. These blocks are layered into four main layers (See Figure 2.5). The blocks which are located in the upper layers are more visible to the end-users. The base layer blocks, tracking and registration, display technology, and rendering, “represent fundamental components” for building an AR system (Bimber & Raskar, 2005) .

In general, building an AR system is more challenging than building a virtual reality (VR) because of the challenges that AR system faces in registration, display, and rendering.

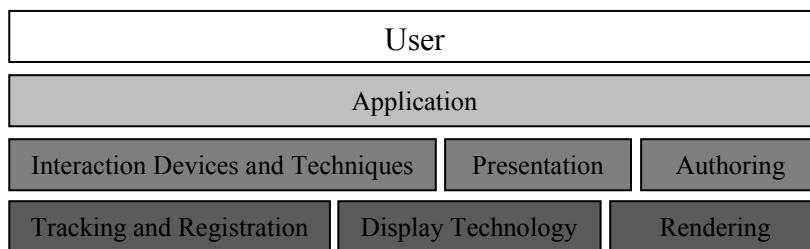


Figure 2.5 Building blocks in augmented reality system.
(Bimber & Raskar, 2005)

2.3.1 Display

Display is one of the fundamental building blocks in the base layer of an AR system. It represents the output of the AR system, which is a blended outcome from the layering of virtual objects onto the real world. Displays can be designed for either single or group use. AR displays are “image-forming systems that use a set of optical, electronic, and mechanical components to generate images somewhere on the *optical path* in between the observer’s eyes and the physical object to be augmented” (Bimber & Raskar, 2005).

In general there are three main types of displays in AR, depending on the position of the display technology in relation to the user:

- 1- Head-attached displays: These types of displays are attached to the users' body (head area), and are considered mobile displays since they allow users to move while attached to this type of display. Head Mounted Display (HMD) is a popular example of this type of displays. A typical HMD consists of one or two small displays with lenses and semi-transparent mirrors embedded in a helmet, eye-glasses or visor (Kiyokawa, 2007). There are two main categories of HMDs: Optic-see – through or video-see through displays. The size and resolution of a HMD differs depending on the category of the HMD. HMD displays are commonly used for military training purposes.
- 2- Hand- held displays: These types of displays are similar to head-attached displays in term of attachment to the users' body and their mobility. However, these displays are attached to hand-held devices, PDAs and mobile phones, instead of head worn devices.
- 3- Spatially aligned displays: These types of displays are detached to the users' body, and the displays are attached to the environment such as, light projectors. With this kind of display, users don't need to wear or hold anything to view the augmentation. In this type of display ~~the~~ user's physical environment is augmented with images that are integrated directly in the user's environment, not

simply in their visual field. The images could appear in 2D, aligned on a flat display surface, or they could be 3D and floating above a planar or non-planar surface” (Raskar & Low, 2001). Thus, the virtual or computer generated images ~~are~~ aligned within the physical environment. They do not follow the users’ movements but rather support moving around them” (Bimber & Raskar, 2005). Projector-based augmentation is an approach used for augmenting an environment in spatially aligned displays. This approach uses ~~front-~~ projection to seamlessly project images directly on a physical objects’ surface instead of displaying them on an image plane (or surface) somewhere within the viewer’s visual field” (Bimber & Raskar, 2005).

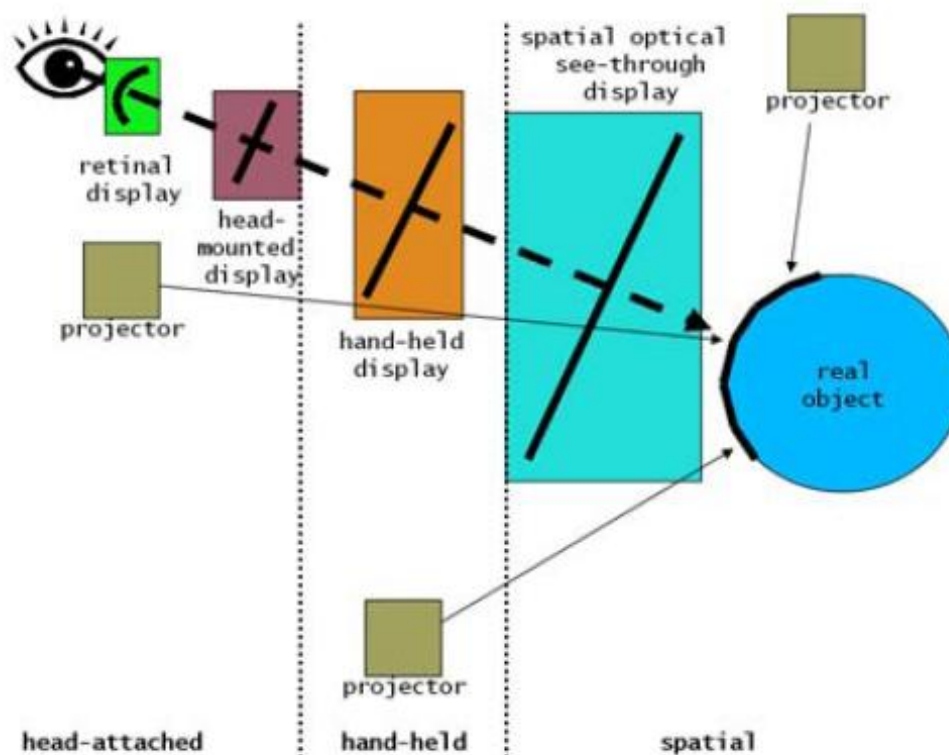


Figure 2.6 Image-generation for augmented reality display.
(Bimber & Raskar, 2005)



Figure 2.7 Head-Mounted Display.
(Broll et al., 2004)



Figure 2.8 Mobile phone display.
(Alternate_reality.jpg.2010)

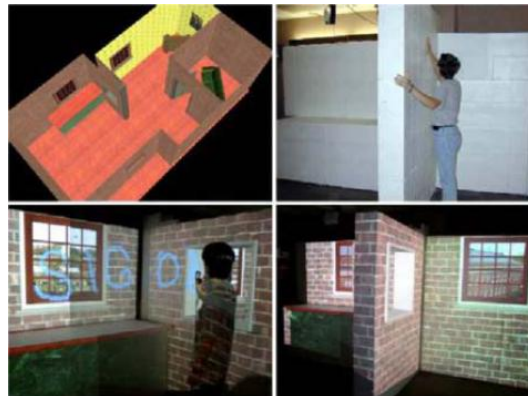


Figure 2.9 Projector-based augmentation.
(Bimber & Raskar, 2005)

Each displays type has its own characteristics, advantages, and limitations depending on the type of applications they are used with. Selecting the right type of display depends on the purpose and need of an AR system. For instance, head-attached and hand-held displays support mobile applications, while spatial displays do not and are used in limited or controlled environment. Also, the hand-held displays can address the mass-market as they are available in consumer devices such as cell phones and PDAs (Bimber, 2006).

In addition to the opportunities that come with body attached displays, there are limitations that compromise the use of these types of displays for certain applications. High quality computer-generated images are more achievable with spatial displays than with body attached displays (mobile displays) using current technology. As Bimber & Raskar (2005) state ~~→~~ “a limited environment with a fixed display can be controlled better than a large environment with a moving display.” Also, Calibration is easier and more stable in spatial displays. Power consumption is another challenge for the mobile type displays. Mobile displays (attached to the users’ body) have a smaller field of view and generally use lower resolution displays. Finally, spatial displays have improved the ergonomic design factors more than hand-held or head-attached displays (Bimber & Raskar, 2005).

2.3.1.1 Fusion technologies in AR displays

There are three main fusion technologies for mixing the real world with the virtual in AR: optical combination, video mixing, and direct augmentation. The first two technologies are recognized as optical see-through and video see-through. The third technology is direct augmentation and it relies on the use of projection-based displays or spatial display systems.

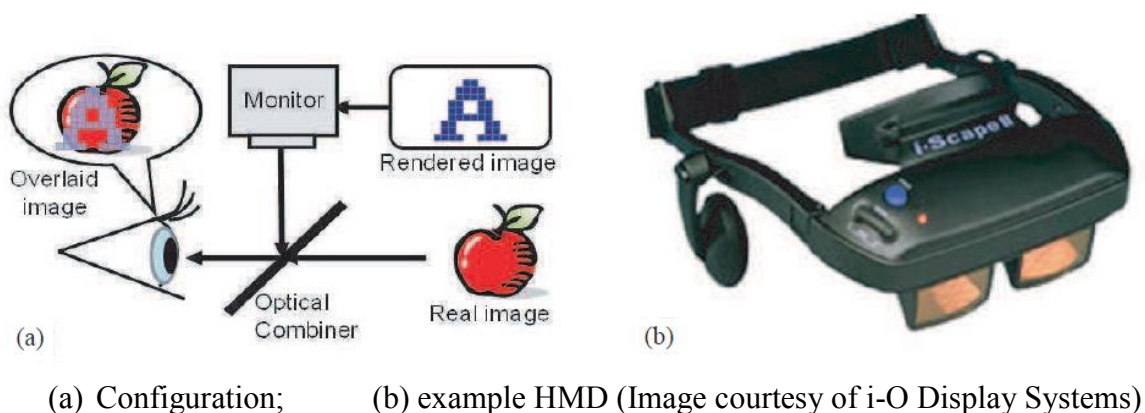
In video mixing, live recorded video streams are emerged with computer-generated objects or graphics; the combination is displayed on the display screen, head attached, hand attached, or spatial displays. In contrast, to optical combination —~~the~~ real and synthetic imagery are combined with a partially transmissive and reflective optical

device, typically a half-silvered mirror. The real world is left almost intact through the optical combiner, while the synthetic imagery is optically overlaid on the real image.”(Kiyokawa, 2007) . Thus the computer-generated images appear in the real environment or within the viewer’s visual field while observing the real environment.

In the following paragraphs, the fundamental differences between these three fusion technologies, optical see-through, video see-through and monitor-based technologies with HMD are addressed.

2.3.1.1.1 Optical see-through technology in HMD

In this technology, the user has direct visual access to the real world by wearing a head mounted optical see-through display that works like glass lenses. The virtual contents are then overlaid on the see-through display. This technique allows direct augmentations to the real world by “using mirrors to superimpose computer generated graphics optically onto directly viewed real-world scenes” (Milgram et al., 1994) (See Figure 2.10).



*Figure 2.10 Optical see-through display.
(Kiyokawa, 2007).*

In most optical see-through HMDs, partial transmissive and reflective optical combiners, typically half-silvered mirrors, are placed in front of the user's eye; thus at the end of the optical path (R. Azuma, 1997). The transmissive character of the combiner allows the user to have a direct look into the real world, while the combiner's reflective character enables the user to see the virtual superimposed images/objects that are "bounced off the combiners from head mounted monitors" (R. Azuma, 1997). (See Figure 2.11). Thus, the user sees the reflection of the virtual image on the optical combiner in an optical see-through HMD. The imaging device of an optical see-through HMD is normally "located above the optical combiner or to the side of the user's head with relay optics" (Kiyokawa, 2007).

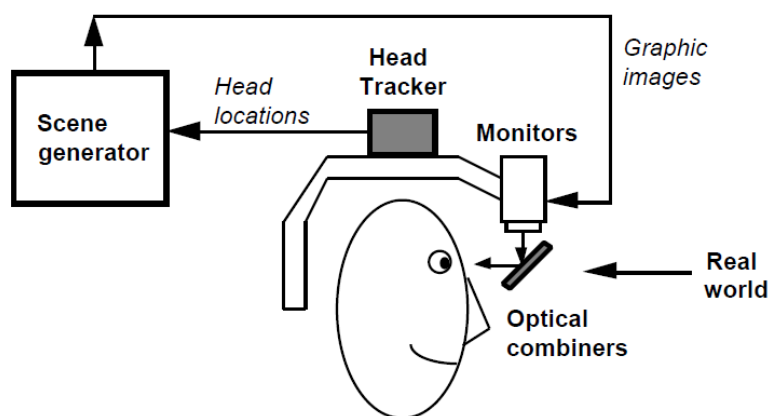


Figure 2.11 Optical see-through HMD conceptual diagram.
(R. Azuma, 1997)

This technology is relatively simple and cheap with best image resolution resulting from a direct view of the real world. One advantage of this system is that if the power is cut-off, the user can see the actual world. It also has instantaneous and natural views of the real world. At the same time, optical see-through technology has some disadvantages.

Some of these issues are related to the user's perception. For instance, the overlaid virtual images cannot be seen clearly. This is because the see-through displays are not able to ~~block~~ off incoming light [from the real world] to an extent that would allow for a non-transparent virtual object" (Nilsson, 2008). Thus, ~~virtual~~ projection cannot completely obscure the real world image" (Nilsson, 2008).

Furthermore, the quality of the virtual display is not as good as the surrounding image of the environment. According to Nilsson (2008), a computer science professor from Linköping University in Sweden, this is caused by the ~~semi-transparent~~" character of the presented virtual objects in optic see-through displays, which gives no depth clues to the user. Some other issues of optical see-through are technology related to ~~the~~ need for accurate and precise, low latency⁶ body and head tracking, accurate and precise calibration and viewpoint matching, adequate field of view..."(Milgram et al., 1994).

Latency creates a major issue in optical see-through displays. According to Kiyokawa (2007), a researcher from Osaka University in Japan, the resulted inconsistency that occurs between visual and vestibular sensations from latency causes severe registration error. This occurs when the virtual image swings around the real scene with the head motion in optical see-through HMD. As a result, the user experiences motion sickness,

⁶ Latency in AR system ~~is~~ a temporal lag from the measurement of the head position to the moment the rendered imagery is presented to the user" (Kiyokawa, 2007).

confusion, and distortion. Finally, the depth of field⁷ with HMDs makes it impossible to focus on the real world and the overlaid virtual image at the same time, “unless the focused object is at or near the HMD’s viewing distance.” (Kiyokawa, 2007).



Figure 2.12 Optical see-through HMD.
(S. K. Feiner & Höllerer, 2004)

2.3.1.1.2 Video see-through technology in HMD

With this fusion technology, the user doesn’t have direct view of the real world, unlike optical see-through systems. Instead, the user’s visual connection with the real world is controlled by one or two head-mounted live video cameras. The video cameras provide the user’s view of the real world, and are combined with a “closed- view HMD” (R. Azuma, 1997).

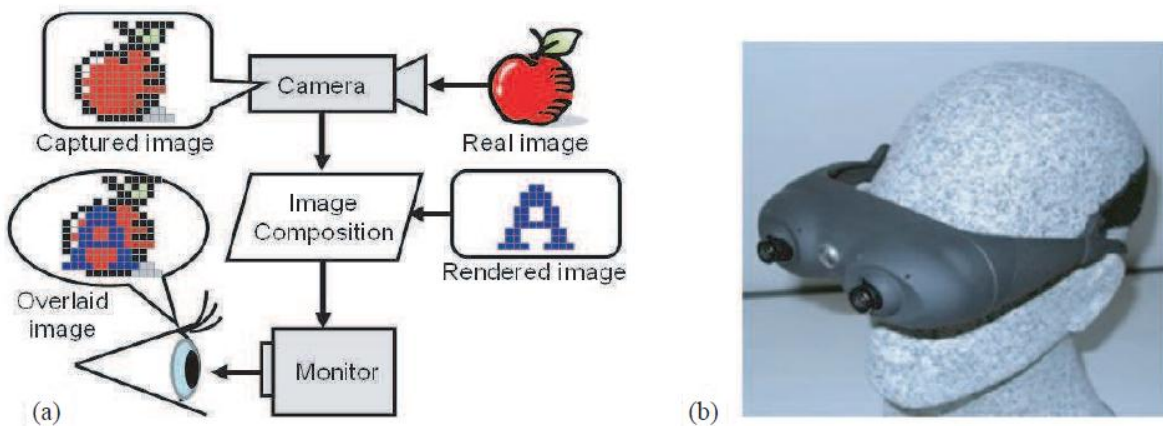
⁷ Depth of field “refers to the range of distances from the eye (or a camera) in which an object appears in focus” (Kiyokawa, 2007).

Blending the real world and virtual images take the following steps in video see-through displays:

- The real world scenes are captured (using the video cameras),
- The captured scenes and the virtual images are combined electronically
- The combined images (real and virtual) are displayed in a non-transparent ~~monitors~~ in front of the user's eyes in the closed- view HMD" (R. Azuma, 1997) (See Figure 2.13).

According to Kiyokawa (2007), there are very few commercial video see-through HMDs.

As a result, most of these types of HMD are built manually.



(a) Configuration, and (b) example HMD (used with permission from Trivisio Prototyping GmbH).

Figure 2.13 Video see-through display.
(Kiyokawa, 2007)

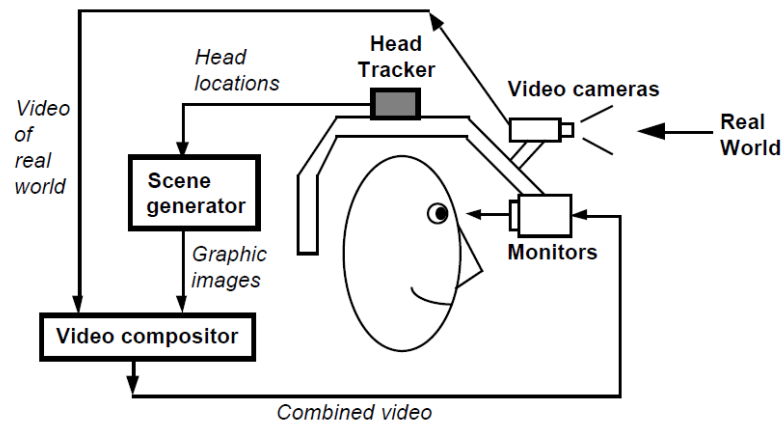


Figure 2.14 Video see-through HMD conceptual diagram
(R. Azuma, 1997)

In general, there are two different methods for the electronic merging of the real and virtual worlds (creating the video composition):

- 1- **Chroma-keying⁸**: In this method the virtual contents' background is set to a color that is not used by any of the virtual contents (for instance green or blue). The background is then replaced by the "corresponding parts from the video of the real world", which superimposes the virtual objects over the real world (R. Azuma, 1997). This technique is simple and widely used in video special effects in the broadcast and entertainment industry. Standard examples of this composition technique appear in movie productions and weather forecast

⁸ Chroma keying is a technique for mixing two images or frames together in which a color (or a small color range) from one image is removed (or made transparent), revealing another image behind it" (*The chroma key effect*.2010).

broadcasts, while a more advanced example of chroma-keying techniques appear in virtual sets⁹ used in children programs, interview, and news.



Figure 2.15 Replacing a blue screen with a virtual set using chroma-keying technique.
(*BlueScreenVirtualSet.jpg*.2010)

- 2- Using depth information:** This is a more sophisticated composition technique than the use of virtual set technology. As Azuma (1997) indicates the combination of real and virtual are done by a pixel-by-pixel depth comparison, which results in covering the real objects by the virtual content.

Similar to optical see-through, video see-through fusion technology has some advantages and disadvantages. Some of the perceptual and technological issues that exist in optical see-through have been overcome in video see-through technology. For instance, the displayed virtual images do not appear transparent in relation to the surrounding real

⁹ Virtual sets are artificially generated backgrounds that are chromakeyed behind people to make them appear to be in a particular location. They differ from standard chromakeys because the background changes each time the foreground camera view changes” (*Virtual sets*.2009).

environment, as is the case in optical see-through. With video see-through technology the virtual images appear as a high quality non-transparent projection. Also, the latency issue has been minimized in video see-through technology by ~~delaying~~ the real image to synchronize it with the synthetic imagery [virtual image]. This approach eliminates apparent latency between the real and the synthetic scenes, at the expense of artificial delay introduced in the real scene” (Kiyokawa, 2007). Video see-through technology is more flexible when it comes to composition and registration strategies. Finally, it is easier to match the real world and virtual images’ brightness in video see-through than optical see-through technology (R. Azuma, 1997).

However, video see-through fusion technology does have some specific drawbacks. In video see-through displays the user has visual access to the real world only through the two live video cameras attached to the HMD. This may result in some safety issues if the power cuts off from the cameras. In fact, it is better for the users to rely on his/her sense of vision when navigating an environment instead of relying on the video camera to see the world in an AR system (S. K. Feiner & Höllerer, 2004).

Furthermore, video see-through technology provides the user with digitized real images. As a result, the resolution of the real world’s scene is limited by the resolution of both the camera and display devices of this technology or as Feiner & Höllerer (2004) suggest ~~seeing~~ the real world at video resolution”. In video see-through, according to Kiyokawa (2007) , ~~Captured~~ images by a standard NTSC video camera typically have a resolution of $640 \text{ (or } 720) \times 480$, but recent IEEE 1394 digital video cameras have higher resolution

up to 1600×1200 at 15 fps, or 1024×768 at 30 fps.” These resolutions still do not compete with the resolution from the human vision system which has as high as 12000×7200 pixels (Kiyokawa, 2007).

Finally, eye offset from the distance between the user’s eyes and the cameras’ viewpoint constitutes another issue in video see-through technology. Eye offset makes the angle or height of view from the video see-through different from the user’s actual angle or height of view. This will create vertical and horizontal offsets. The vertical offset, occurs from mounting a camera above HMD in video see-through, which causes a false sense of height for a user, while horizontal offset introduces errors in depth perception (Kiyokawa, 2007).

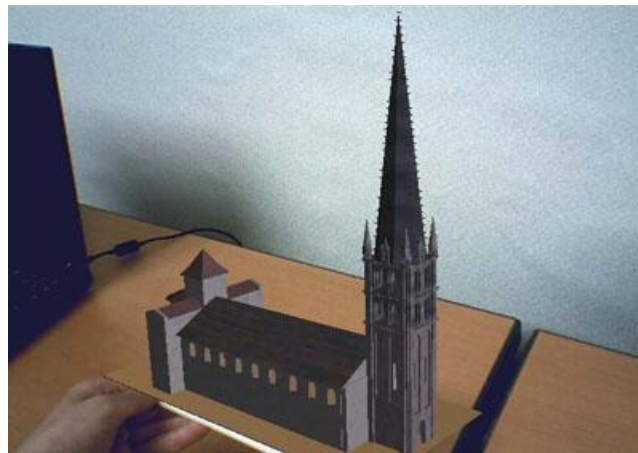


Figure 2.16 A view from video see-through HMD.
(Kondo et al., 2007)

2.3.1.1.3 Monitor-based technology

Monitor-based technology is an alternative to the see-through (video and optical) technology. In fusing virtual and real objects it is similar to video see-through. With monitor-based technology a single video camera or multiple video cameras capture the real world scenes. Images from the real world are then combined with the virtual content and they are displayed on a monitor. The user is able to see the augmented real world by looking at the monitor (See Figure 2.17).

The major difference between this technology and video see-through, however, is in detaching the AR system devices from the user. In detaching the video camera from the user, it must be fixed to a mobile robot (See Figure 2.18). In contrast to video see-through, for monitor-based fusion technology the user does not wear any devices.

Augmentation of the real world is displayed on a monitor rather than on a HMD. The only case in which the user needs to wear a pair of stereo glasses is when a stereo monitor is used for displaying the augmented environment (R. Azuma, 1997).

According to Bimber (2006) this technology is “most efficient and easy to realize with off-the-shelf components”. However, this technology doesn’t support direct interaction with the real and virtual objects and also doesn’t support mobile applications.



Figure 2.17 Monitor-based technology.
(Bimber, 2006)

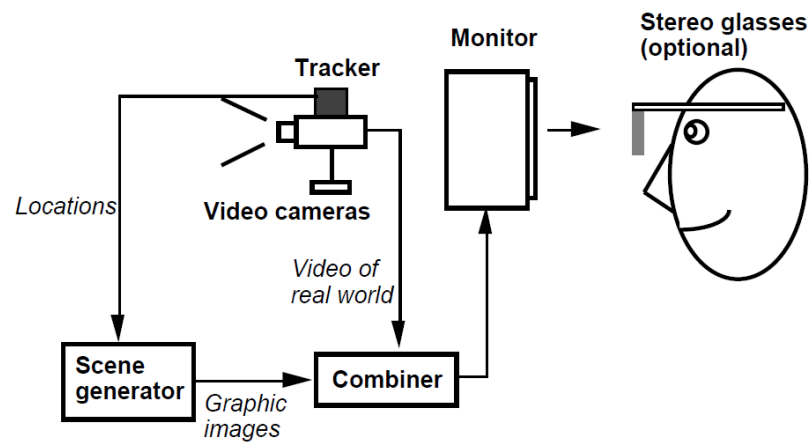


Figure 2.18 Monitor-based conceptual diagram.
(R. Azuma, 1997)

2.3.2 Tracking

AR applications require accurate knowledge of the position and orientation of real world objects for an accurate augmentation of virtual objects. This is achieved through tracking. Tracking is —the operation of measuring the position and orientation, known as six degrees-of-freedom (DOF) tracking, of real 3D objects (or humans) that exist in indoor or outdoor environments”(Liarokapis & Newman, 2007). As Fua & Lepetit (2007), researchers and computer science professors from Ecole Polytechnique Fédérale de Laussane (EPFL) in Switzerland, states —3D tracking aims at continuously recovering all six degrees of freedom that define the camera position and orientation relative to the scene, or equivalently, the 3D displacement of an object relative to the camera” (See Figure 2.20 a).

Tracking is one of the fundamental and most challenging components in an AR system, especially in the mobile AR applications, as it provides information about where to place virtual contents/objects in an augmented physical environment. Tracking establishes the spatial relationship between real and virtual object, a critical component of an AR system.

According to Liarokapis & Newman (2007), two computer science professors from the UK, —measurement of camera’s position and orientation (pose) can be performed when objects are static (fixed in space) or dynamic (changeable in space).” However, in the mobile AR applications a continuous, precise, fast, and robust tracking system for the user’s movement and viewpoint become critical. Without an accurate position and

orientation tracking system it is not possible to register and align virtual objects with an augmented real environment in an AR system. According to Höllerer & Feiner (2004),
 –Determining position and orientation of an object is often referred to as six-degree-of-freedom (6DOF) tracking, for the six parameters sensed: position in x, y, and z, and orientation in yaw, pitch, and roll angles.”

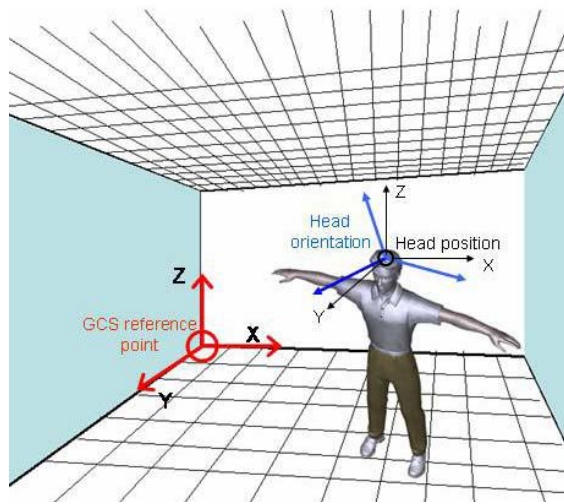


Figure 2.19 Tracking a user in a given space.
 (Wang & Dunston, 2007)

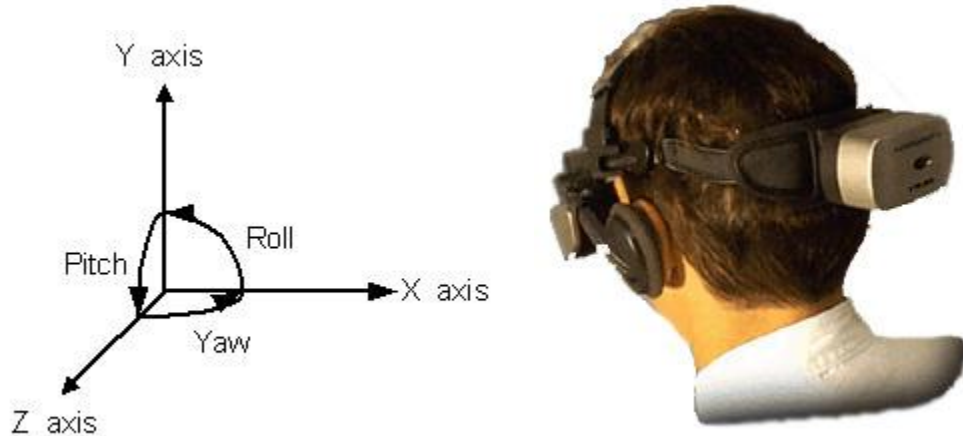


Figure 2.20 (a) The six-degree-of-freedom (6DOF). (b) A head tracker.
 (Kensek, Noble, Schiler, & Tripathi, 2000)

Tracking uses sensors for registration. The sensors used for receiving positional and orientation information about a physical environment are typical examples of tracking. These sensors can also be employed in conjunction with other input devices such as microphones, cameras, global positioning systems (GPS) and wireless communications” (Liarokapis & Newman, 2007). In video see-through displays, the cameras work as visual sensors that provide “vision based tracking” (Nilsson, 2008).

Building an effective AR system requires more than just locating the user in the augmented space or environment (from the sensors), but also requires information about the position of all the used objects for augmentation in a real scene. For instance, the depth map of the real scene is needed for supporting occlusion when rendering (R. Azuma et al., 2001).

There are several technologies available for tracking, depending on the AR application: Mechanical, magnetic head, optical, acoustic (ultrasonic), and inertial head trackers. Each of these trackers has its limitations and advantages. For example, despite the accuracy found in mechanical trackers, they tend to tether the user to a limited working volume (Fua & Lepetit, 2007). Furthermore, magnetic trackers are vulnerable to distortions by any metal object which exist in the environment, and ultrasonic trackers suffer from noise and tend to be inaccurate at long ranges because of variations in the ambient temperature. Inertial trackers drift with time.”(Fua & Lepetit, 2007). Some of these trackers have been combined together in order to create a more effective tracking system.

Also, some of these trackers can be mounted on a glove or body suit devices to provide tracking of a user's hand or some other body part" (Kensek et al., 2000).

In addition to the abovementioned tracking technologies, computer vision is the most promising tracking technology used for 3D tracking. This technology has the potential to yield "noninvasive, accurate, and low cost solutions" (Gutiérrez A., Vexo, & Thalmann, 2008b). According to Fua & Lepetit (2007), vision-based 3D tracking can be decomposed into two main steps; the first step is image processing used to extract some information from the images, and second, is the pose estimation itself.

There are two major methods for tracking in computer vision technology:

- 1- Marker-based tracking:** In this method fiducial markers that called *landmarks* or *markers*, such as LEDs or special markers are added to the augmented real scene or target objects (Gutiérrez A., Vexo, & Thalmann, 2008b). The markers significantly help both of the two main steps, image processing and pose estimation, of vision-based 3D tracking, as "they constitute image features easy to extract, and they provide reliable, easy to exploit measurements for pose estimation" (Fua & Lepetit, 2007). As a result, the registration task becomes easier in marker-based tracking techniques than marker-less tracking.

This method is widely used in indoor environments. However, it is not desirable by the end users in some applications due to the confusion the users might

experience from the markers in the scene. ARToolkit, which is an open software library for building AR applications, is relying on this method for tracking.



Figure 2.21 Marker-based tracking.
(Bimber & Raskar, 2005)

2- Marker-less tracking: In this method no markers are added in to the scenes or target objects. The tracking is achieved by tracking the existing object features such as edges, corners, or texture from the objects that exist in the environment. This is a more reliable method for outdoor environments, where it is difficult to add markers. It is also a more desirable method for tracking for the end-users of some AR applications, as the real scenes will not be covered with markers.

The task of tracking becomes more challenging in this method. As Gutiérrez A. and his colleagues (2008), a group of researchers from Virtual Reality Laboratory of EPFL, argue “Finding and following feature points or edges can be difficult because they are hard to detect, and in many cases there are not enough of them on typical objects.” Also the “Total or even partial occlusion of the tracked objects typically results in tracking failure” (Fua & Lepetit, 2007). Finally, fast

movement of the camera, results in image motion being blurred, and possible changes in lighting during a shot can confuse the tracking process (Fua & Lepetit, 2007).

As a result, 3D knowledge is often employed for easing tracking algorithms in the marker-less method. According to Gutiérrez A. and his colleagues (2008), “the 3D knowledge can come in the form of a CAD model, a set of planar parts, or even a rough 3D model such as an ellipsoid.” Edge-based methods and methods that rely on information provided by pixels inside the object’s projection (optical flow, template matching, or interest-point correspondences) are the recognized approaches for tracking in the marker-less tracking method (Gutiérrez A., Vexo, & Thalmann, 2008b).



Figure 2.22 Tracking in an outdoor environment using Marker-less tracking. (Comport, Marchand, & Chaumette, 2003)

Tracking error is one of the error sources for registration errors. It can occur “when the measurement returned by the tracker does not agree with the real pose of the tracker” (Baillot, Julier, Brown, & Livingston, 2003).

Furthermore, today's limitations of tracking technologies have affected the advancement of mobile AR applications in some aspects. These limitations become more challenging in uncontrolled and outdoor environments where there is less control over the environment in terms of tracking preparation. Keeping that in mind, it is suggested that an ideal position and location tracking technology for outdoor environments is GPS¹⁰ due to the following.

- 1- Its functionality on a global scale (considering there are signals from a minimum four satellites). According to Höllerer & Feiner (2004), GPS navigation is limited to the areas that have direct visibility to the satellites, have been sidestepped by assisted GPS (A-GPS), which ~~ma~~ makes use of a worldwide reference network of servers and base stations for terrestrial signal broadcast". The new generation of i-phone, iPhone 3GS, employs A-GPS and digital compass despite lacking GPS hardware (*Apple - iPhone 3GS - size, weight, battery life, and other specs*.2010).
- 2- The size and weight of GPS supports easier movement of the user in the environment.
- 3- The increasing commercial use of GPS makes it a more reliable method for tracking location.

¹⁰ Global Positioning System (GPS) is ~~a~~ U.S. space-based radio navigation system that provides reliable positioning, navigation, and timing services to civilian users on a continuous worldwide basis -- freely available to all. For anyone with a GPS receiver, the system will provide location and time"(*Global positioning system*.n.d.). GPS uses triangulation to identify an object position by using the location of known objects (Douangboupha, 2009) .

Typically, a minimum of three satellites are needed to obtain an accurate position tracking in GPS. GPS uses a triangulation method to calculate and determine a particular location. The use of more satellite would enhance the accuracy of the system in the order of nanoseconds (Douangboupha, 2009). –A GPS-enabled device provides geo-code location accuracy about 1 to 5 meters” (Douangboupha, 2009). This method is used for tracking by Google in the AR applications that use smartphones like iPhone.

2.3.3 Registration

In AR, registration means an accurate alignment of virtual and real objects with respect to each other in the user’s display. According to Azuma (1997) improper and inaccurate registration results in compromising the “illusion that the two worlds [virtual and real] coexist together”. The lack of accurate registration is a critical issue that raises serious concerns in many AR applications. When virtual objects are not correctly and/or do not remain correctly aligned with the augmented real environment it is a sign for registration error. When registration error occurs –the virtual objects appear to "swim around" the real objects, instead of staying registered with them” (R. Azuma, 2005). It is critical for the users of AR systems to understand the relationship between the virtual and the real worlds. Any registration errors become unacceptable due to the variation in the relationship between the virtual and real worlds every time the viewpoint changes (Holloway, 1995).

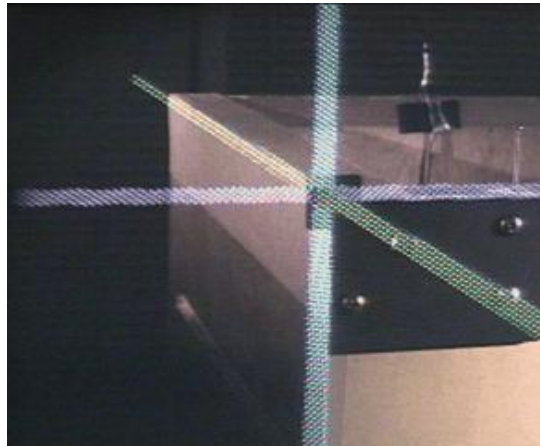


Figure 2.23 A correct registration example.
(R. Azuma, 2005)

Despite the recent advancement in AR technologies, registration is still a key issue that hinders advancement of AR systems. According to Azuma (2005) the following factors contribute in making registration a serious concern in most of AR applications.

- 1- The human visual system is very sensitive and can easily detect even small mis-registrations, because of ~~the~~ the resolution of the fovea and the sensitivity of the human visual system to differences. Errors of just a few pixels are noticeable.”
- 2- The system delay resulted from "the time interval between measuring the head location to superimposing the corresponding graphic images on the real world.”
The system delay makes ~~the~~ virtual objects appear to lag behind their real counterparts as the user moves around” (R. Azuma, 2005).

The tolerated registration errors in Virtual Environments (VE) are not acceptable in AR applications. In AR more accurate registration is needed because any inaccuracy in aligning virtual objects with the physical environment becomes more easily detectable when compared with a virtual world environment. In VE, the user is immersed in a virtual environment and sees virtual objects. Any registration errors cause visual-kinesthetic or visual-proprioceptive conflicts (R. Azuma, 1997). These conflicts in senses could result in motion sickness (Pausch, Crea, & Conway, 1992). With AR, users are exposed to a conflict of the senses that is known as visual-visual conflict. As Azuma (1997) states “kinesthetic and proprioceptive systems are much less sensitive than the visual system”, and as a result visual-kinesthetic and visual-proprioceptive conflicts are less detectable than visual-visual conflicts.

Registration errors are caused by many sources of errors, such as optical distortion, error in tracking system, calibration error, incorrect viewing parameters, and system delays. These sources can be categorized as static, when the user's viewpoint and the objects in the environment remain still, and dynamic errors, when the viewpoint or the objects are moving. The dynamic errors are by far the largest contributors to registration errors than the static errors (R. Azuma, 1997).

The lower limit for registration inaccuracy in AR, as Azuma (1997) indicates —is bounded by the resolving power of the human eye itself.” The human eye can “differentiate between a dark and light bar grating when each bar subtends about one minute of arc, and under special circumstances they can detect even smaller differences” (Doenges, 1985).

As such, the maximum of one minute of arc error in registration is an ideal tolerated level for registration error in an AR system. The limitation of existing technology and difficulties in controlling the source of errors results in less accuracy and larger errors in registration than that ultimate lower bound in AR applications (R. Azuma, 1997). As such, finding more advanced techniques for controlling the source of errors in registration would lead to achieving and maintaining better registration in AR applications.

Furthermore, the level of registration error tolerance may vary from an AR application to another. For instance, “If we are annotating the rough outlines of buildings, we can afford some registration error. When trying to pinpoint down the exact location of a particular window, we have to be more accurate” (S. K. Feiner & Höllerer, 2004).

Finally, the type of fusion technology used, video-see through or optical-see through displays, can contribute to minimizing registration error by providing time for correcting any mis-registration in the system. In video-based AR systems, “the real video image stream can be delayed to match the virtual image path latency which is the time it takes to measure mis-registration and generate a corrected virtual image” (Bajura & Neumann, 1995). The video delay in video-based AR makes it possible to “obtain exact temporal and spatial image registration at every recognized point in every image the AR user sees” (Bajura & Neumann, 1995). As a result; the user will not see any registration error. In optical-see through displays, this is not possible since the users have a direct visual access to their surroundings. Without a time delay no correction could be made for mis-registration.

2.3.4 Calibration

In an AR system, the virtual objects have to be positioned and displayed so they align with their corresponding real objects in the real environment (Whitaker, Crampton, Breen, Tuceryan, & Rose, 1995). As Whitaker and his colleagues (1995), a group of computer science professors from the USA, further indicate, “For practical reasons this alignment cannot be known a priori, and cannot be hard-wired into a system. Instead a simple, reliable alignment or calibration process is performed so that computer models can be accurately registered with their real-life counterparts.”

The registration of the camera’s motion, user’s environment and embedded virtual objects in the same frame of reference in an AR system typically is achieved by relying on 3D position tracking devices and precise camera calibration (Kutulakos & Vallino, 1998). Producing an accurate registration requires continuous calibration. Calibration is a process of measuring and determining variables required for accurate registration. Calibration measurements —my include camera parameters, field of view, sensor offsets, object locations, distortions, and so forth” (R. Azuma et al., 2001).

Different calibration methods exist ~~that~~ allow the parameters to be computed with more or less accuracy” (Gomez, Simon, & Berger, 2005). In a controlled environment ~~—accurate~~ parameters can be obtained from several images of a calibration target shot from various positions within the working space” (Gomez et al., 2005). In an outdoor and uncontrolled environment, however, this calibration method is not applicable. The size of the environment can cause inaccuracies in the calibration. An alternative method

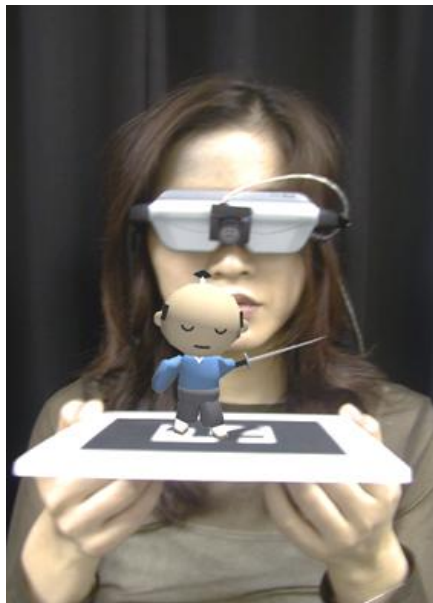
for calibration is the use of constraints in the scene, such as ~~the~~ use of a squared marker placed in the scene or the use of vanishing lines in the environment for calibration” (Gomez et al., 2005).

Calibration-free AR is an approach for video-based AR that has been developed by Kutulakos and Vallino in 1998, two computer science researchers from the University of Rochester, NY. The calibration-free AR, as Kutulakos and Vallino (1998) explain, ~~does~~ not use any metric information about the calibration parameters of the camera or the 3D locations and dimensions of the environment’s objects.” The only requirement, instead, is ~~the~~ ability to track across frames at least four fiducial points that are specified by the user during system initialization and whose world coordinates is unknown” (Kutulakos & Vallino, 1998). Calibration-free AR avoids the typical camera calibration errors, the additional calibration stages required for initialization of virtual objects, and the camera recalibration required whenever the camera position or its intrinsic parameters, such as focal length, change (Kutulakos & Vallino, 1998).

In addition to calibration-free AR, another method called auto-calibration has been developed for reducing calibration requirements. The algorithms of auto-calibration use ~~redundant~~ sensor information to automatically measure and compensate for changing calibration parameters” (R. Azuma et al., 2001).

2.4 AR and ARToolkit

The rapid AR applications growth has encouraged developers to create software libraries that can be used to build effective AR applications. ARToolkit is one of the most popular and reliable software library that supports building AR applications. ARToolkit is a software library that uses C and C++ language. ARToolkit can be used to overlay virtual imagery on top of the real world (*ARToolKit.n.d.*). ARToolkit is an open source product that is available freely for non-commercial use under the GNU general public license. ARToolkitPlus is a variant of ARToolkit for mobile devices (Gutiérrez A., Vexo, & Thalmann, 2008b).



*Figure 2.24 ARToolKit and AR.
(ARToolKit.n.d.)*

ARToolkit has an easy to use camera calibration routine, and it supports real time AR applications (*ARToolKit.n.d.*). It has solved the problem of tracking by using computer vision algorithms, and it uses the marker-based tracking method (Gutiérrez A., Vexo, &

Thalmann, 2008b). ARToolkit markers have a black border on a white background. The ARToolKit Professional version 4 supports both video and optical see-through augmented reality. The video tracking libraries in ARToolKit supports easy development of a wide range of AR applications as they “calculate the real camera position and orientation relative to physical markers in real time” (ARToolKit.n.d.).

ARToolkit was originally developed by Dr. Hirokazu Kato in 1999. The current ongoing development of ARToolkit is being supported by the Human Interface Technology Laboratory (HIT Lab) at the University of Washington; the HIT Lab NZ at the University of Canterbury, New Zealand, and ARToolworks, Inc. in Seattle (ARToolKit.n.d.).

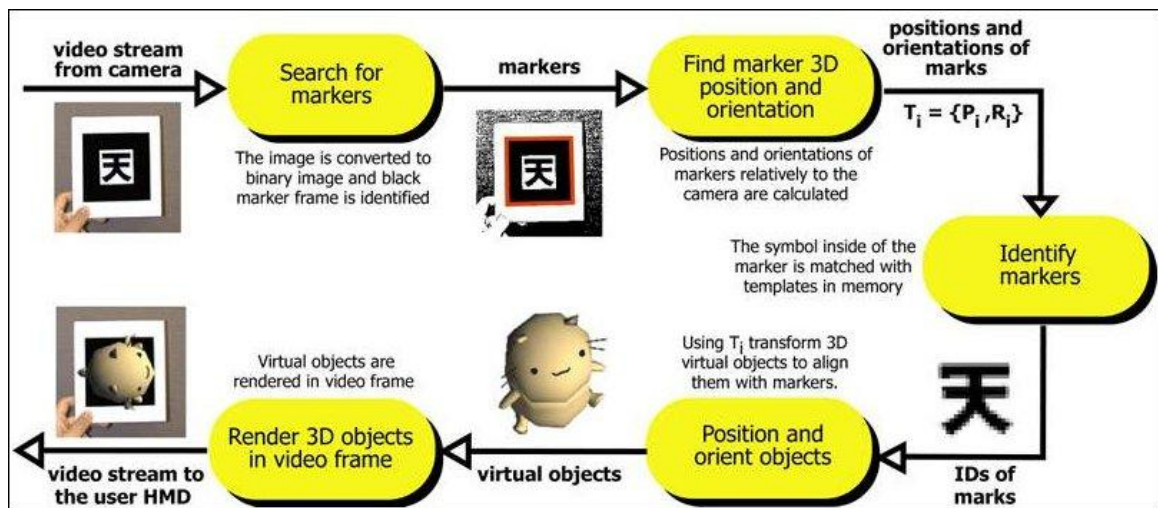


Figure 2.25 ARToolkit tracking steps.
(How does ARToolKit work?n.d.)

2.5 AR interface design

An effective interface is a crucial component in an AR system. Consequently, in recent years, the research in the AR community has expanded to include the study of

information visualization and presentation, user interaction, and interface design principles that are unique to AR. The character of blending real and virtual objects in AR provides an unprecedented opportunity to design and interface that combines the virtual and real objects together. In creating an interface for AR, it is important to understand AR's supporting technology demands such as, display devices. Also, it is critical to take into account the other factors such as, human-computer interaction and end-users' considerations.

In general, designing an AR interface adapts principles familiar with other types of interface design. One of the basic goals in AR interface designs is mapping user input onto computer output ~~using~~ "using an appropriate interaction metaphor" (Billinghurst, Grasset, & Looser, 2005). There are the three elements to be considered in any interface design; ~~the~~ "the physical components of the interface, the virtual visual and auditory display, and the interaction metaphors used to connect these together" (Billinghurst et al., 2005). The Figure 2.26 illustrates the relationship between these three key elements.



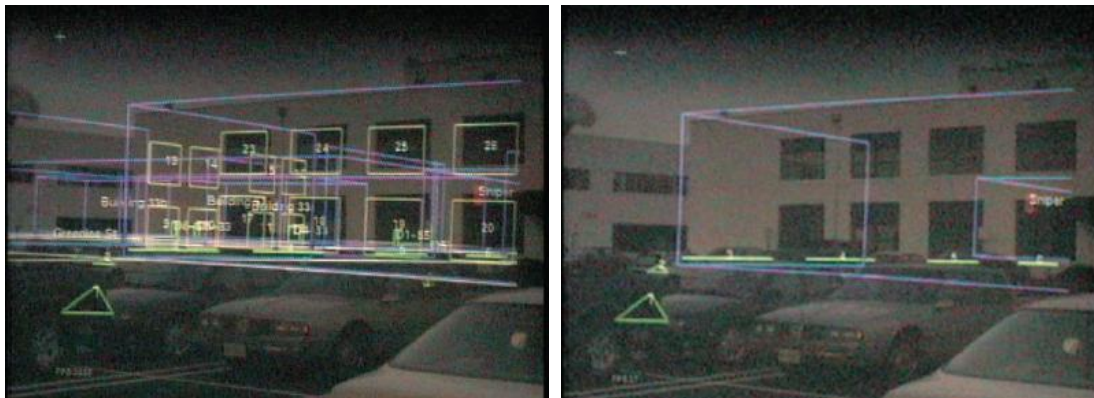
Figure 2.26 The key interface elements.
(Billinghurst et al., 2005)

In addition to these general principles, AR interface design principles must address issues similar to those facing designers of virtual reality systems. Some of these interface design principles are concerned with representing and displaying information, while the others are concerned with visualization and interaction.

The followings are some fundamental factors that should be considered during designing an AR interface:

- 1- AR interface design needs to have a level of harmonization and balance between the virtual and real worlds. If a real environment is augmented with vast amounts of information or virtual objects, the AR display may become cluttered and unreadable. As a result, users may experience confusion. In order to minimize information overload different strategies can be adapted. As a situated user interface takes into account the user's location, the augmented information in an AR interface can be organized and displayed according to various factors. In an AR interface, Julier and his co-researchers (2000), three computer science and AR researchers from the USA and Australia, suggest "information [that is augmented to a real scene] can be classified based on the user's physical context, as well as on their current tastes and objectives". For this purpose, Julier's team developed a region-based information filtering¹¹ algorithm. This algorithm, according to Julier and his co-researchers (2000), takes into account the state of the user (location and intent) and the state of individual objects. The algorithm can dynamically respond to changes in the

environment and the user's state. The purpose of the algorithm is to control the amount of information displayed according to the user's position and need (See Figure 2.27). Furthermore, Bell and his co-researchers (2001), three computer science researchers from Columbia University, expanded on Julier and his group's concept and developed algorithms for view-management in an interactive 3D user interface. In this approach the environment is modeled and real entities are tracked. This knowledge is then used to ensure that "virtual information isn't placed on top of important parts of the environment or other information" (R. Azuma et al., 2001) (See Figure 2.28).



(a) Original unfiltered view

(b) Filtered version

The left image shows an unfiltered, cluttered view of the environment. The right image shows the same view when the filter is activated

Figure 2.27 The effect of the information filter.
(Julier et al., 2000)

¹¹ Information filtering means "allowing the information that can potentially be displayed by identifying and prioritizing the information that is relevant to a user at a given point in time" (Julier et al., 2000).



(a)

(b)

(a) Naïve label placement at projected centroid of each building causes overlaps, and mislabeling because of buildings hidden partially or entirely

(b) Suppression of labels for buildings whose projected centroid is not visible



(c)

(c) Label placement using approach described by Bell and his co-researchers

*Figure 2.28 Area feature labeling comparison in virtual reality.
(Bell, Feiner, & Höllerer, 2001)*

- 2- AR interface should be designed with attention to technological limitations, such as tracking system limitations and registration errors, in mind (Billinghurst et al., 2005). For instance, “the measured location of an object in the environment may not be known accurately enough to avoid a visible registration error”, and this will

significantly affect the AR interface (R. Azuma et al., 2001). Different approaches need to be adapted in order to reduce the registration error and technological limitation effects on AR interfaces. A suggested approach for rendering an object in an AR interface when a large amount of registration errors exist ~~is~~ to visually display the area in screen space where the object could reside, based on expected tracking and measurement errors” (MacIntyre & Coelho, 2000) . Thus, estimating and adapting to the registration errors in the AR system can be resolved by designing an adaptive interface. In doing so, according to MacIntyre and Coelho (2000), two researchers from Graphics, Visualization and Usability Center at Georgia Institute of Technology, the virtual representation always contains the real counterpart in the AR interface.



In this image, the system highlights a building and two of its windows by outlining the area of the screen the objects could occupy.

Figure 2.29 Area An example of the use of registration error estimation.
(MacIntyre & Julier, 2002)

- 3- In designing AR interfaces, the display type and size must also be considered.

These factors should be matched to the nature of the task and purpose of the AR application (Billinghurst et al., 2005). For example, head-mounted displays (HMDs) provide more flexibility for moving inside an augmented space and interacting with the AR interface by keeping both users' hands free. It also provides the most engaging view of the AR content due to the size and location of the display (Billinghurst et al., 2005). At the same time, the use of HMDs reduces the user's peripheral awareness that doesn't support collaborative type AR applications. Hand-held displays are constrained by their size and location relative to the user's body. In particular the amount of information that can be displayed is restricted by the size of the device in an AR interface. At the same time hand-held displays are easy to carry.

- 4- Since AR is designed for users, the principles of Human-Computer Interactions (HCI) must play a key role during the design of an AR interface. HCI is the area of study devoted to the interaction between human users and computers (Liarokapis & Newman, 2007). HCI can also be used for assessing human performance in an AR system. In addition to HCI, AR interface needs to address human factors studies and perceptual problems. As Azuma and his co-researchers (2001) explain –Experimental results from human factors, perceptual studies, and cognitive science can help guide the design of effective AR systems.” For example addressing the occurred issues in depth perception (that ranges between

2-100ft.) in an AR system should be considered in the AR interface in order to minimize negative impacts on the user,

- 5- The design of an AR interface depends on the task and purpose of the application. Some AR applications require high-quality renderings and compositions in which virtual objects should be indistinguishable from the real objects in an augmented space. Examples of these applications include those applications that impose 3D virtual objects on to a real object or place, for example adding virtual furniture to a room. In some other applications, virtual graphics which appear not to be realistic might not be of a much concern; this includes the AR applications used for providing instructions.
- 6- Interface design decisions are affected by the type of the virtual augmented content, including video, image, text, and 3D objects. For example, graphic design considerations such as, font size and style need to be considered when text is attached to aspects of a physical environment in an AR interface. In using an image in an AR interface image resolution is always an issue.

2.5.1 AR interface design trends

Until recently, most AR interfaces were based on the desktop metaphor or used designs from virtual reality (VR) interface design. As Azuma and his co-researchers (2001) explain, ~~most~~ most AR prototypes concentrated on displaying information that was registered with the world and didn't significantly concern themselves with how potential users

would interact with these systems.” At the same time the AR prototypes that supported interaction often used desktop metaphors in their interfaces such as, using on-screen menus or typing on keyboards, or adapted designs from virtual environments research such as, using gesture recognition or tracking 6D pointers (R. Azuma et al., 2001).

More recently, new trends in AR interface design and interaction have appeared that help developing interface design guidelines, which enable developers to build interesting AR applications. *Heterogeneous* designs is one of the main trends in interaction research specific to AR systems that aims for blending and taking parts from both the virtual and real worlds. This is achieved by “using heterogeneous devices to leverage the advantages of different displays” (R. Azuma et al., 2001).

Tangible interface is another trend in AR interface design that focuses on the use of physical tools and objects for interacting with virtual objects. In tangible AR interfaces each virtual object is registered to a physical object, and the user can interact with the virtual objects by manipulating the corresponding physical objects (Billinghurst et al., 2005). These two characteristics make tangible AR a promising approach for AR interface design. Tangible AR facilitates a high degree of interaction desired by users of AR applications such as, the ability to create, add, delete, copy, annotate, or modify the virtual content in an AR system. It also enables users to use the skills they have developed throughout their lives to manipulate real objects by interacting with and manipulating 3D virtual objects. In other words, “taking advantage of the immediacy and familiarity of everyday physical objects for effective manipulation of virtual objects” (Billinghurst et al., 2005).

Tangible interfaces support direct interaction with the physical world by focusing on the use of real objects and tools. As an illustration, Azuma and his co-researchers (2001) provide an example of an AR tangible interface in which the user wields a real paddle to manipulate furniture models in a prototype interior design application. The user can select pieces of furniture, drop them into a room, push them to the desired locations, and remove them from the room by pushing, tilting, swatting, and other motions using the paddle (R. Azuma et al., 2001) (See Figure 2.30).

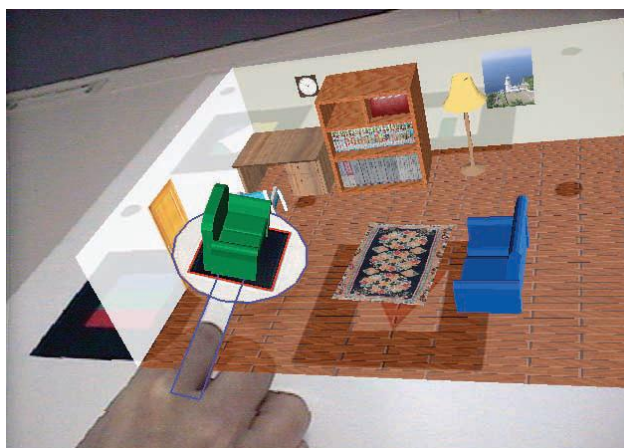


Figure 2.30 User wields a real paddle to pick up, move, drop, and destroy models. (R. Azuma et al., 2001).

AR MagicLens that has been developed by Billinghurst and his co-researchers (2005), three researchers from Human Interface Technology Laboratory New Zealand (HIT Lab NZ), is a good example of a tangible AR interface. The AR MagicLens prototype is built on the MagicLenses interface, a type of see-through interface, technique (Bier, Stone, Pier, Buxton, & DeRose, 1993). In the MagicLenses interface “semi-transparent user interface elements can apply transformations to whatever content lies beneath them”

(Billinghurst et al., 2005). Thus, the MagicLenses can “modify the presentation of application objects to reveal hidden information, to enhance data of interest, or to suppress distracting information” (Bier et al., 1993).

AR MagicLens interface prototype uses the design principles of MagicLenses interface to develop an AR Magic Lens implementation that enable users to effectively view inside virtual Datasets. Building the prototype requires a real handle (a ring mouse), that works as the physical elements of the interface and a paper-tracking mat, which serves as the coordinate space for the virtual information. In the AR application “the ring mouse appeared to be a virtual magnifying glass and a virtual dataset [a virtual globe in this example] appears over the tracking mat” (Billinghurst et al., 2005) (See Figure 2.31).

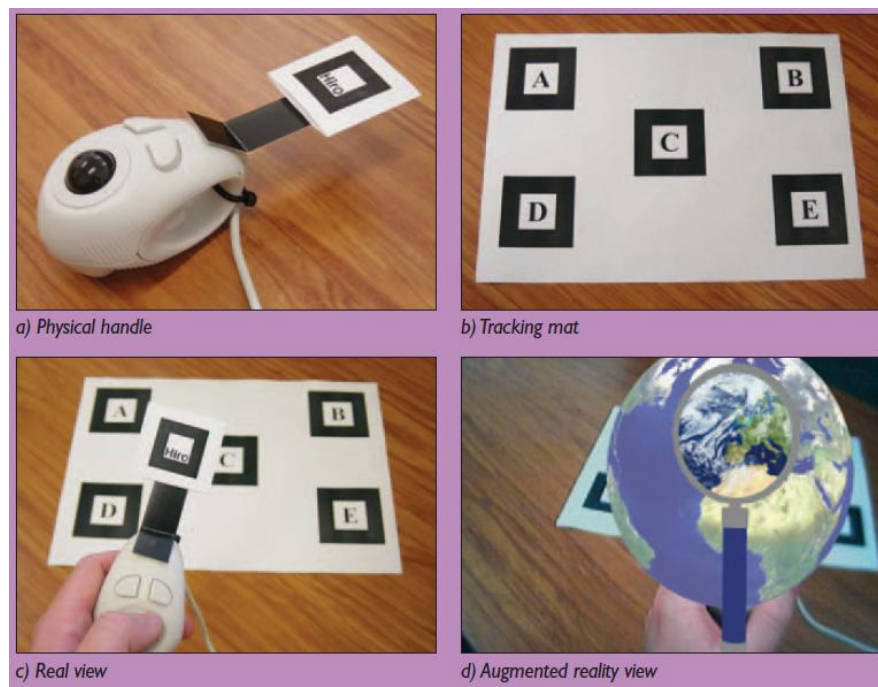


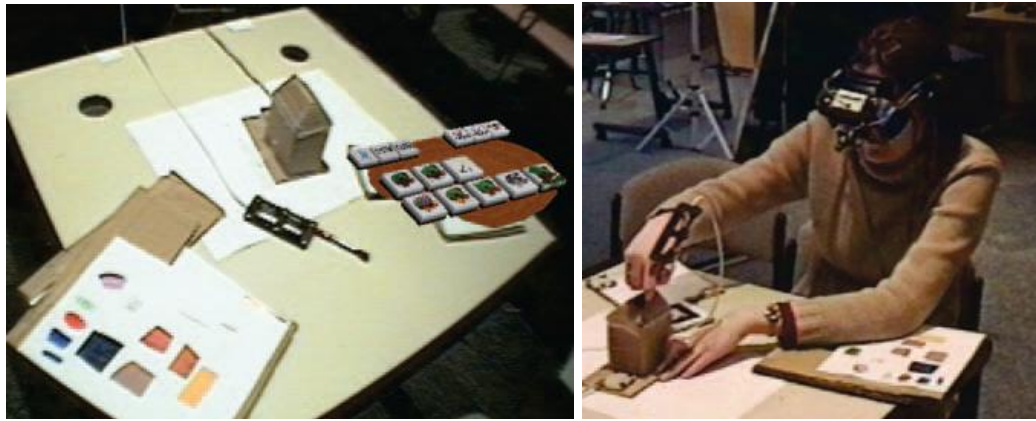
Figure 2.31 The AR MagicLens Interface Components.
(Billinghurst et al., 2005)

This interactive interface allows the user to see inside the dataset, and the interaction metaphor is that the user is holding a magnifying glass. As a result, “when the user moves the virtual magnifying glass over the globe, the area viewed through the magnifying glass appears different” (Billinghurst et al., 2005). This application represents an appealing way for information visualization, which enables users to reveal more information as they interact with the interface (See Figure 2.32).



Figure 2.32 Using the AR MagicLens to see different views of the earth.
(Billinghurst et al., 2005)

Another example of tangible AR interface that support a higher degree of interactivity developed by Billinghurst and his team (2005) allow users to add virtual objects and information to real objects in order to enhance the real objects. This application uses techniques and setups preferred by artists, painters, sculptors, and designers in creating a prototype or artefact. This system requires: a real working surface, tracked tools, a tool palette, a scratch area for sketching and experimentation, and an object (a building prototype, a sculpture, or a similar object). Also needed to make this system work is —a simple virtual design application and a one to one mapping between the functions and behaviours of the real objects and their virtual counterparts” (Billinghurst et al., 2005) (See Figure 2.33).



The concept of the virtual studio with tangible tools (left image) and a user experimenting with the first prototype on a house mock-up (right image).

Figure 2.33 The virtual studio setup.
(Billinghurst et al., 2005)

When combining the virtual and real components of the AR application in the user's view, "the user can pick up a real paintbrush, touch a virtual color on the virtual paint palette and start painting on a real object" (Billinghurst et al., 2005). The augmented view is achieved when the user wears an augmented reality headset that enables viewing the virtual and real components simultaneously. With this application an architect or designer can modify a real building model with virtual color, texture, and objects (See Figure 2.34). In building this application, Billinghurst and his co-researchers have been inspired by Steve Mann's notion of Mediated Reality "in which the computer can be used to filter our vision of the real world by adding virtual information" (Billinghurst et al., 2005).

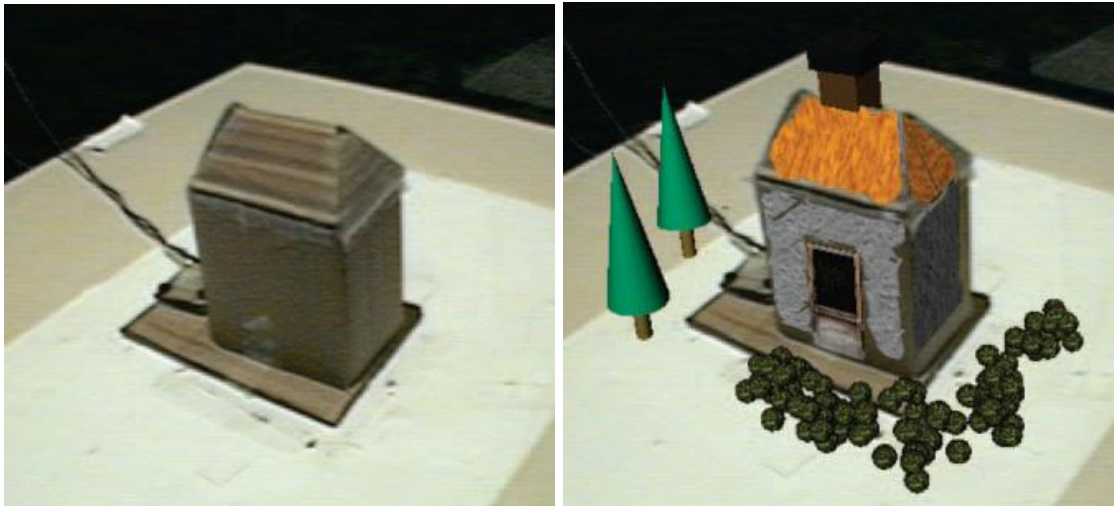


Figure 2.34 A “mediated” house mock-up. A real model with virtual enhancements. (Billinghurst et al., 2005)

2.6 AR challenges

As a new communication technology that blends virtual and real world together, AR uncaps a wide range of opportunities that support building appealing applications. The ability of adding meaning and augmenting the real world doesn't only strengthen people's perception and interaction with their surrounding environments, but also deepens their experiences with the physical environment and its contents.

Although AR technology has significantly expanded since the 1990s, the full potential of AR still faces many technical challenges. The task of combining the real with the virtual exposes the AR system to more critical issues than the VR system. The enabling technologies issues associated with aligning the virtual and real, tracking and registration, needs to be tackled before reaching AR's full potential. Also, in an AR system real-time

rendering of virtual objects, which requires fast and realistic rendering in order to decrease differences between the virtual and real objects, is crucial.

Furthermore, the augmented virtual objects and graphics need continuous updating and alignment. Changes in the user's perspective, while moving around in an augmented space, is also a critical issue in AR. This is a challenging problem for mobile AR applications, in which users' movements cause changes in their view's direction, distance, and position. These changes force the augmented virtual contents to be re-aligned.

2.7 AR Recent developments

AR is a promising communication technology. In the last decade AR has been applied to many fields including: medicine, engineering, and architecture. The recent advancements have contributed in increasing the quantity of AR applications in those fields. Among the developments, mobility proves to be the most breakthrough advancement in AR technology. The mobility in AR has provided opportunities for building vast numbers of location-based applications. It has also facilitated in targeting the mass market and bringing AR technology into the mainstream. In the recent years, mobile phones, with over 5 billion users, have become ideal platforms for building mobile AR applications due to their ubiquity (Henrysson, Ollila, & Billinghamurst, 2007).

2.7.1 The development of mobility in AR technology

Touring Machine was the first mobile AR system (MARS). Developed by Steven Feiner and his co-researchers (1997), a group of researchers from Columbia University, the goal of this project was to build a wearable computer system that supported a mobile AR application where the user could interact with the physical environment. In this system, a see-through head-worn display was integrated with an integral orientation tracker; a backpack holding a computer, differential GPS, and a digital radio for wireless web access; a hand-held computer with stylus and touchpad interface (S. Feiner, MacIntyre, Hollerer, & Webster, 1997).



*Figure 2.35 Touring Machine supporting technologies.
(History of mobile augmented reality.2009)*

Mobile AR systems continued to flourish, but it was not until significant computing and graphics power became available on handheld platform, that researchers started exploring the use of PDAs for building AR applications. One of the early examples using a PDA for building an AR application was the AR-PDA project, developed by Geiger and his co-researchers, a group of researchers from C-LAB in Germany. According to Geiger and his team (2001), by “adapting existing technologies for PDAs (personal digital assistants), high speed wireless computing, computer graphics and computer vision, AR services will be provided at low costs”. This was a major advance from the wearable computers using a backpack systems and HMD. In AR-PDA an intuitive metaphor, a magic pocket lens was used by the end users who were able to easily interact with mobile AR applications in many different scenarios (Geiger, Kleinnjohann, Reimann, & Stichling, 2001).

The goal of AR-PDA was to build AR applications that support consumers’ daily activities like shopping, sightseeing tours, playing games, or using household appliances and other technical devices (Geiger et al., 2001). Later on Wagner and Schmalstieg (2003), two researchers in virtual reality from Vienna University of Technology, “ported the ARToolKit tracking library to the PocketPC and developed the first self-contained PDA AR application”(Henrysson et al., 2007).



*Figure 2.36 The AR-PDA project.
(History of mobile augmented reality.2009)*

Mobile phone-based AR has followed a similar development path to that of PDAs. The early mobile phones were constrained by limited processing power. To solve this problem, researchers explored the use of a thin client¹² approach (Henrysson et al., 2007). In the AR-Phone project, Cutting and his co-researchers (2003), researchers from the School of Information Technologies at the University of Sydney, used Bluetooth to send phone camera images to a remote sever for processing and graphics overlay. Meanwhile, Henrysson and Ollila ported ARToolKit to smartphones such as, SonyEricsson P800 and Nokia 3650. These phones are handheld terminals that combine a camera with communication capabilities by both GSM/GPRS and Bluetooth, a processor and a color display. They are powerful enough to decode and display video and they are also capable

of limited, interactive 3D rendering”(Henrysson & Ollila, 2003). A year later, Moehring and his colleagues (2004), three researchers from the faculty of Media at the Bauhaus University, introduced the first running video see-through augmented reality system on a cell-phone. This system supports —the detection and differentiation of different markers, and correct integration of rendered 3D graphics into the live video stream via a weak perspective projection camera model and an OpenGL¹³ rendering pipeline” (Möhring, Lessig, & Bimber, 2004).

With the recent advancements in the mobile phone industry, the —current generation of phones have full color displays, integrated cameras, fast processors, and even dedicated 3D graphics chips” (Henrysson et al., 2007). At the same time, with the widespread adoption of built-in cameras in mobile phones, it is possible to include optical tracking in building AR applications for mobile phones.

¹² Thin client refers to —A client machine that relies on the server to perform the data processing”(Thin client.2008).

¹³ OpenGL (Open Graphics Library) is a software interface to graphics hardware that allows a programmer to —specify the objects and operations involved in producing high-quality graphical images, specifically color images of three-dimensional objects” (Segal, Akeley, Frazier, & Leech, 1998).



Figure 2.37 A video see-through example on a consumer cell-phone.
(Möhring et al., 2004)

Without the advancements in PDAs and mobile phones technology it would have been more challenging to use handheld devices as a platform for AR technology. The changes from HMD to handheld displays have also necessitated changes in interface and interaction techniques with AR's virtual content. For example, handheld displays, in which the user looks through the screen, require at least one of the user's hands to hold the device. This is in contrast to HMD in which both users hands are free. The interaction with the virtual content in handheld displays would be accomplished by using the other hand directly, on the touch screens, or indirectly by using a stylus. For this purpose, different interaction techniques need to be employed in the PDA and mobile phone-based AR (Henrysson et al., 2007). The ergonomic factor of handheld devices also makes them more appealing for building AR applications over the use of HMDs. This is mainly because of the lightweight character of these devices in comparison with wearable computers (backpack) systems used with the HMDs.

Mobile phones will soon become the main platform for all AR executions once the hardware limitations such as, having semi-accurate GPS, compass, and accelerometer

have been overcome (Wakefield, 2009). Currently, the choice among different hardware technologies for building AR applications still remains open and is subject to perceptual, technological, and economical considerations. The following table identifies some of the pros and cons of different types of devices used for building AR applications.



	PROS	CONS
PORTABLE & ULTRAPORTABLE PC 	<ul style="list-style-type: none"> • PROCESSING POWER • GRAPHIC CAPABILITIES • WINDOWS BASED • SCREEN RESOLUTION 	<ul style="list-style-type: none"> • WEIGHT & SIZE • HIGH PRICE • POWER CONSUMPTION
PDA/SMARTPHONE 	<ul style="list-style-type: none"> • BIG MARKET • COMPUTATIONAL VS SIZE • CONNECTIVITY 	<ul style="list-style-type: none"> • NO GRAPHIC ORIENTED • VIDEO OUTPUT RESOLUTION
HANHELD GAME CONSOLE 	<ul style="list-style-type: none"> • GRAPHIC CAPABILITIES • WEIGHT & SIZE 	<ul style="list-style-type: none"> • PROPRIETARY DEVELOPMENTS • CLOSED PLATFORMS
MULTIMEDIA PLAYER 	<ul style="list-style-type: none"> • WEIGHT & SIZE • CONNECTIVITY • MULTIMEDIA CAPABILITIES 	<ul style="list-style-type: none"> • NO GRAPHIC ORIENTED • PROPRIETARY DEVELOPMENTS
PAD & TABLET 	<ul style="list-style-type: none"> • COMPUTATION ABILITY • GRAPHIC CAPABILITIES • CONNECTIVITY 	<ul style="list-style-type: none"> • BIG MARKET • SIZE • LACK OF CAMERA (I-PAD)

Figure 2.38 Processing devices comparison.
Adapted from (Izkara, Pérez, Basogain, & Borro, 2007)

2.7.2 AR and Smartphones

The recent connectivity and computing ability, gained by some mobile phones, have accelerated building effective and reliable AR applications in mobile phones. These phones, such as Android, BlackBerry, and iPhone are called “Smartphones” because of their ability to run advanced applications. They have more powerful processors, more memory, built-in cameras, and connectivity via WiFi¹⁴ or 3G¹⁵. The connectivity feature allows data from the internet to be overlaid on a view of the physical world. Some of these smartphones have a digital compass and built-in GPS that enables outdoor positioning. In addition to the technological support that these smartphones have, the fact that they are widely used by end-users makes them one of the best candidates for building mobile AR applications.

In 2007, Apple Inc. introduced an advanced smartphone called the “iPhone”. The iPhone is a device that combines three devices together: a mobile phone with camera, a multimedia-enabled device, and an Internet device (*Apple- iPhone.2010*). The combination of these three features creates an interesting platform for building AR applications. The iPhone has a LCD touch screen and different generations of the iPhone provide internet connectivity via either WiFi or 3G. The later generation of the iPhone,

¹⁴ WiFi is the popular name for the wireless Ethernet 802.11b standard for WLANs. “Wireline local area networks (LANs) emerged in the early 1980s as a way to allow collections of PCs, terminals, and other distributed computing devices to share resources and peripherals such as printers, access servers, or shared storage devices” (Lehra & McKnight, 2003).

¹⁵ 3G is “a technology for mobile service providers. Mobile services are provided by service providers that own and operate their own wireless networks and sell mobile services to end-users, usually on a monthly subscription basis” (Lehra & McKnight, 2003).

iPhone 3GS, has improved performance, a higher resolution camera, built-in video camera with editing, and a digital compass (*Compare iPhones 3GS and iPhone 3G.2010*). The digital compass is used for instant navigation providing direction on an iPhone 3GS (*Apple announces the new iPhone 3GS.2010*).

Furthermore, both the iPhones 3GS and iPhone employ A-GPS. Despite the lack of GPS hardware, on January 2008 a software update enabled the first generation iPhone to triangulate user's position using nearby Wi-Fi base stations or cellular towers (*Apple enhances revolutionary iPhone with software update.2010*). This feature can be used for finding local points of interest. The Maps application in the iPhone 3GS provides access to Google Maps in map, satellite, or hybrid form.

In addition to the advancement in the smartphone industry, Google and its competitors have created some new online mobile products such as Google Maps, Goggles, Wikitude, and Layers. These products have provided new opportunities for AR researchers and application builders. The smartphones' connectivity with the internet provides access to use these online products for AR uses.

1- Google Maps:

Google Maps is an online mapping service application that has been supported and marketed by Google. Google Maps displays high-resolution imagery aerial photography taken from airplanes. Originally, it had been developed by brothers Lars and Jens Rasmussen with Google's support. As Lars Rasmussen indicates, Google Maps is "a way of organizing the world's information geographically" (Lars

rasmussen on inventing google maps - science and technology - browse - big ideas - ABC TV.2010). Google Maps is available free for non-commercial use and it is becoming a ubiquitous online navigation system. Currently, “Google Maps has a wide array of APIs [such as the Google Earth API] that let you embed the robust functionality and everyday usefulness of Google Maps into your own website and applications, and overlay your own data on top of them” (*Google maps API family*.2010). Google Street View, Google Transit, and Google Sky are some of Google Maps’ products.

In 2006, Google Maps was introduced to mobile phones through a Java application called Google Maps for Mobile, and this was considered a major breakthrough in smartphone technology (*Google maps for mobile*.2010). Google Maps for mobile employs a GPS-like location service that does not require a GPS receiver as in the case of the iPhone. The maps application in the iPhone 3GS or its equivalent in the other smartphones provides access to Google Maps for mobiles’ various features including navigation, search by voice, my location, business listings, street view, and satellite view. However, not all smartphones support all the available features in Google Maps for mobile. For example, Android phones support all the features, while iPhones do not support some of the features such as, navigation and search by voice (*Google maps for mobile*.2010). This is because of the lack of GPS hardware in the iPhone and also some of the company’s policies.

The "My location" a beta feature in Google Maps for mobile is an effective tool for determining a user's current location by pressing the "My location" button. When the "My location" button is pressed in the GPS enabled phones, Google Maps indicates an accurate location of the user (*Google maps for mobile with my location (beta)*. 2007). With non-GPS enabled phones, Google Maps provides an approximate location of the user. When "My location" in Google Maps is accessed the available connected cell towers gives the users the reception they need to access map information. Google Maps then finds and displays the user's location (*Google maps for mobile with my location (beta)*. 2007). This happened because Google Maps calculates an estimated location of the user's handset or phone-based on the unique footprint of nearby towers.

Recently, Google Maps has played a key role in creating a wide range of interesting location-based AR applications for the iPhone and other smartPhones. For example, Acrossair¹⁶ has developed a number of iPhone-based AR applications including "New York Nearest Subway", "Nearest Places", and "London Nearest Tube", which are highly dependent on Google Maps. The "London Nearest Tube" application allows users to find their nearest underground station in central London. The application enables iPhone users to point their handset's camera and see underground stops float over the picture. "New York Nearest Subway" is another AR application from

¹⁶ Acrossair is a new kind of company that is "working with companies to take advantage of the Apple iPhone platform for everything from fun games to enterprise applications" (*Acrossair/about*.2010).

Acrossair that provides iPhone users with the necessary information for finding the nearest subway station with their iPhones video function (See Figure 2.39).

By adapting GPS and digital compasses it becomes easy to imagine that AR will become “the means of choice for delivering information that's specific to wherever we are, whenever we're there” (King, 2009).



Figure 2.39 A view from New York Nearest Subway iPhone application developed by Acrossair.
(King, 2009)

2- Goggle :

Goggle is a visual search application for mobile phones developed by Google. It allows users to search for information about a famous landmark or work of art by taking a photo of that object with their mobile phone (Wakefield, 2009). Google is an ideal method for acquiring information while interacting with and navigating in the

physical world. With Google ~~there's~~ no need to type or speak your query - all you have to do is open the app, snap a picture, and wait for your search results” (*Google goggles (labs): Overview*.2010).

When taking a picture for visual search purpose using Goggle, the user needs to hold the phone in "left landscape" mode and press the on-screen shutter button with the right thumb in order to get the best result (*Google goggles (labs): Overview*.2010).

The following is the procedure of Goggle’s visual search for finding related web information about a targeted object or place according to Google (Arghire, 2010):

- a) Google sends the users taken image (using a mobile phone camera) to Google’s datacenter.
- b) Google then creates signatures of objects in the image using computer vision algorithms.
- c) The next step is comparing signatures against all other known items in Google’s image recognition databases.
- d) Google then finds the matches for the image in the database, and finally Google returns one or more search results, based on the available metadata and ranking signals.

It is worth mentioning that the entire time for Goggle to follow the above procedure doesn’t exceed a few seconds.

Currently, Goggle supports certain types of queries such as, pictures of books, DVDs, landmarks, logos, contact info, artwork, businesses, products, barcodes, or text. Other type of queries related with things like animals, plants, cars, furniture, or apparel have yet to be developed (*Google goggles (labs): Overview*.2010). Also, Goggle is currently available only for Android phones (Arghire, 2010).



Figure 2.40 Using Goggle for finding information about a landmark online.
(*Google goggles for android*.2010)

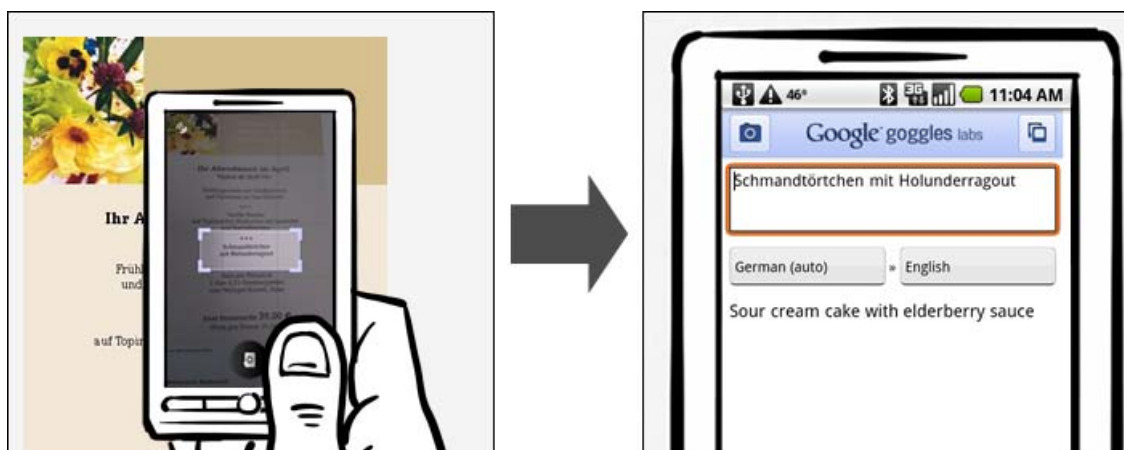


Figure 2.41 Using Goggle for finding information about a text online.
(*Google goggles for android*.2010)

The integration of this search service, Google, with a wide range of other services and features, including maps and search by location, has paved the way for emerging appealing AR applications. Google enables calling up information and virtual graphics in a very effective and simple ways (Arghire, 2010).

3- Wikitude:

Wikitude is a mobile Augmented Reality application that imposes virtual entities and objects and their information on the real world to enrich users' visual perception. This application has been developed by Mobilizy. The current applications for Wikitude include Wikitude World Browser and Wikitude Drive. At this stage, these applications can only be used for the iPhone, Android, and Symbian software platforms.

Wikitude World Browser application –aims to show people encyclopaedic information about nearby landmarks” (Sutter, 2010). This application combines GPS (or GPS like) data and compass data with Wikipedia entries (*History of mobile augmented reality*.2009). Wikitude World Browser equips users with knowledge about their surrounding physical world by overlaying information from Wikipedia on the real-time camera view of their smartphones (*History of mobile augmented reality*.2009). In addition to extracting information, Wikitude also allow users to add information to the service similar to Wikipedia.



Figure 2.42 iPhone Screenshots for two different scenarios using Wikitude World Browser.

(WIKITUDE for iPhone 3G, iPhone 3GS, and iPhone 4 on the iTunes app store.2010)

Currently, Wikitude World Browser is used as a travel guide for providing location-based information (Karpischek, Magagna, Michahelles, Sutanto, & Fleisch, 2009). By using this application users can get web-based information about their surrounding environments such as the architectural style of a building or finding a restaurant. It is worth mentioning that the architectural data provided in this application is provided by archINFORM¹⁷.

The dimensions of this online AR application are yet to be discovered and realized. There are lots of potential uses of this application in the horizon including shopping, marketing, and any location-based services in general.

¹⁷ ArchINFORM is an online database for international architecture. It originally emerged from records of interesting building projects from architecture students. It has become “the largest online-database about worldwide architects and buildings from past to present”. It contains plans and images of buildings and records the architecture of the 20th century (*International architecture database*.2010).

4- Layar:

The Layar Reality Browser is an AR application that —show what is around you by displaying real time digital information on top of the real world as seen through the camera of your mobile phone”(What is layar?2010) . Layar’s AR works by assembling data from the mobile phone’s camera, compass and GPS (or GPS like data in the case of the iPhone 3GS). The information is then used to identify the user’s location and field of view. Layar then retrieves the data and information based on the geographical coordinates and overlays the data over the user’s camera view (What is layar?2010). A Layar user —sets his or her phone to video mode, aims it around and sees all kinds of information pop up on the screen: blinking dots on apartments that are for sale, the value of the units, and pull-down reviews of the bar up on the corner...” (Sutter, 2010).

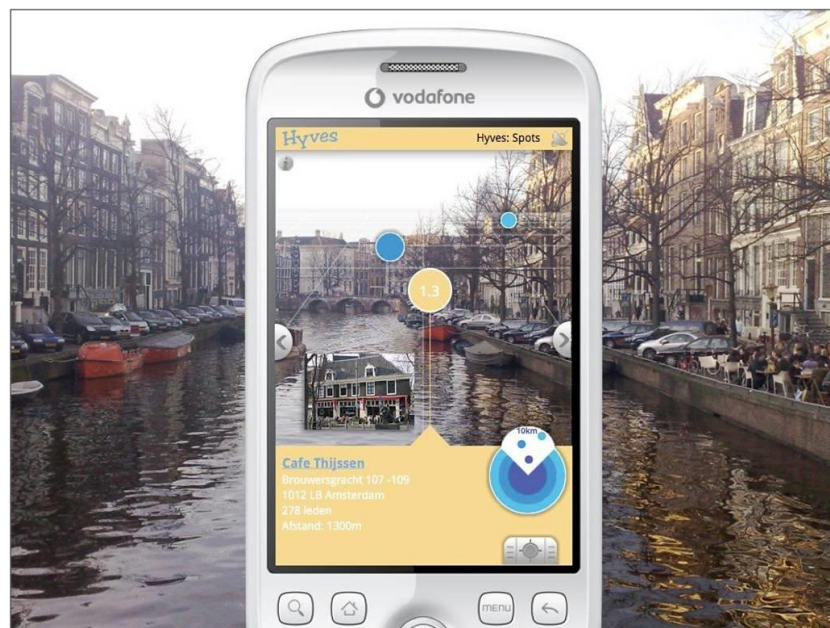


Figure 2.43 Using Layar for finding information about a restaurant.
(Fuld, 2010)

Layar is an advanced variant of Wikitude, and was developed by a Netherlands based company called SPRXmobile (*History of mobile augmented reality*.2009). There are different types of layers in the Layar application. “Content layers are the equivalent of web pages in normal browsers” (*History of mobile augmented reality*.2009). The current existing layers in Layar include Wikipedia, Twitter and Brightkite as well as local services like Yelp, Trulia, store locators, nearby bus stops, mobile coupons, Mazda dealers and tourist, nature and cultural guides (*History of mobile augmented reality*.2009). Most of the contents of Layar’s layers are created by users (Simmons, 2009) with the number of layers applications increasing.

In May 2010, Walt Disney launched the augmented reality outdoor campaign for the new ‘Prince of Persia’ movie. The campaign is built upon Layar, through a special Prince of Persia layer connected to outdoor posters, in which you can play, win and share”(Maurice, 2010). The new layer is created by TAB Worldmedia, “the first company that combines outdoor advertising with the possibilities of the Layar platform” (Maurice, 2010).

With this layer, users of Android and iPhones who are standing near one of the outdoor film posters “can play the movie trailer and play an augmented reality game - by using their Layar browser. They can collect 50 Movie Minute value points as a reward for playing the game” (*Connecting augmented reality to outdoor advertising*.2010). According to TAB Worldmedia, “as soon as a person who is near one of the ‘Prince of Persia’ posters starts up the Layar browser on his smartphone a

GPS connection is made to locate his position and the augmented reality game for ‘Prince of Persia’ automatically appears in his screen” (*Connecting augmented reality to outdoor advertising.2010*).



Figure 2.44 Augmented reality outdoor campaign for the new ‘Prince of Persia’ movie. (*Connecting augmented reality to outdoor advertising.2010*)

As Layar has significantly expanded since its launch, it has been dubbed the world's first augmented reality browser (Simmons, 2009). Most recently, May 2010, Layar announced Layar Stream. Layar Stream is another application of Layar which reveals what AR content is available around the user (*Layar announces layar stream.2010*). Layar Stream —holds information about the type of available content and whether it contains 3D objects, images, video or audio. Users can optimize their stream by filtering keywords, categories and distance” (*Layar announces layar stream.2010*).

2.8 Summary

In this chapter the fundamental components of AR technology were presented. By analyzing different types of AR, their supporting hardware and software technologies, and their applications, this chapter uncovered the opportunities of AR technology and challenges. By providing examples about requirements and different types of AR interface, this chapter outlined the fundamental interface design guidelines which need to be considered when developing AR applications. The recent advancements in AR technology discussed in this chapter identified the state-of-the art of AR technology and the advanced reliable platforms used by current developers of AR applications. This will provide future AR application developers with insights into selecting an appropriate platform that fits the needs and technology of the new era.

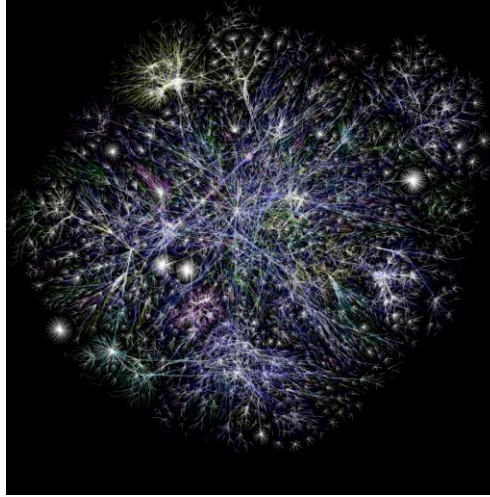
Chapter Three: AR in architecture, urban planning, and cultural heritage

This chapter discusses the uses of AR applications in enriching historic sites, buildings, and monuments with content from the virtual world during an on-site visiting. For that purpose, this chapter will first present the uses of AR in architecture and urban planning and design fields that are concerned with designing and enhancing the surrounding real environment and spaces. In doing so, this chapter uncovers the many uses of AR including, information visualization, way finding, guiding, navigation in an environment, adding context, and enriching the architectural and urban spaces with virtual content by examining a wide range of AR applications. Later this chapter presents a number of AR applications in the cultural heritage field in order to; first identify the current uses of AR technology for cultural heritage and historic resource management uses, and secondly to determine potential content that can be incorporated when developing an AR application for navigating around historic sites and buildings.

3.1 AR, Architecture and Built Environment

Traditionally, the material nature of architecture as a spatial art has gained it a static nature. Concepts like foundations, durability, inertia, and tradition have dominated architecture for many centuries and have become a standard nomenclature in architecture (Bouman, 2005). More recently research groups have emerged and questioned the static nature of architecture in the presence of new technology. The aim is to push the

architectural design boundaries to achieve a more dynamic and interactive architecture that reflect the *zeitgeist*¹⁸.



*Figure 3.1 Internet map represents information flow.
(Internet map.2010)*

These research groups can be categorized into two main groups. The first group works on achieving dynamic architecture by creating dynamic and flexible structure and geometry in architecture. Examples of this architecture are responsive architecture, adaptive architecture, and performative architecture that works on incorporating building components that are moveable and dynamic in responding to surroundings.

Inspired by the current need for information and communication, the second group aims to achieve dynamic architecture by incorporating Information and Communication Technologies (ICT) with architectural structures and spaces. The goal is to enrich

¹⁸ *Zeitgeist* refers to “The spirit of the time; the taste and outlook characteristic of a period or generation” (*Zeitgeist* .2010).

architecture with ICT's traits, which enables access to information in a world that is rapidly changing. "Heterarchitecture of the future" is a trend in this group, which calls for replacing analog architecture with an architecture that fulfills the information age's¹⁹ requirement; an interactive architecture that is connected with its surrounding built environment. In Heterarchitecture, virtual and real objects and environments are blended together to create mixed-reality (hybrid) spaces. Heterarchitecture, according to Flachbart (2005), the co-editor of "Disappearing Architecture: From Real to Virtual to Quantum" book, is "a genuine interface between the real and the virtual - a dynamic open space, an enabling platform."

Currently, information flow, which is supported by advancements in ICT technologies and new media,²⁰ has significantly reshaped people's lives. People's daily activities in today's world consist of "constant access-to and processing-of a large quantity and variety of information" (Sparacino, 2002). As a result, the demands for frequent and quick access to information have significantly increased. Consequently, most spaces in built environments, cities, public spaces, and private spaces, are equipped with sensors and display devices that display and assist with accessing digital information. Also, various personal small devices, such as mobile phones and handhelds have been developed to provide wireless access to information.

¹⁹ Information age is a term used in referring to the current age, which is characterized with the ability to have instant access to information and information flow.



Figure 3.2 An aerial view of the Shibuya district in Tokyo, with a large variety of LCD displays and animated screens in the cityscape.
(*Shibuya.jpg*.2010)

In responding to these significant transformations in people's lifestyle, architecture and built environments urge to "supports these new modalities of communication and living" by augmenting physical spaces with digital information (Sparacino, 2002). Architecture and built environment need to redefine their boundaries and scope to include information. As William Mitchell, professor of Architecture and Media Arts and Sciences at MIT and former dean of the School of Architecture and Planning at MIT, explains "Architecture is no longer simply the play of masses in light. It now embraces the play of digital information in space". Failure to incorporate new technology and media in contemporary architecture causes breakage between architecture and its alliance industries such as engineering and construction. Bouman (2005), an architect and director of the

²⁰ New media refers to digital, computerized, or networked information and communication technologies such as, Internet, and computer multimedia.

Netherlands Architecture Institute which owns one of the world's largest architectural collections and publishes its own books, indicates:

Would architecture survive if the entire tectonic tradition of construction and making connections were to vanish as a source of design inspiration in favor of the visual story for architecture when any of its buildings can be animated and transformed by projections and electronic displays?

For this purpose, new dynamic spaces that support information exchange and are equipped with sensors and computing technologies which will replace the traditional 3D spaces. This new type of space –offers unprecedented opportunities to merge the virtual and the real, the information landscape of the Internet with the urban landscape of the city, to transform digital animated media in storytellers, in public installations and through personal wearable technology” (Sparacino, 2002).

AR is a communication technology tool that permits tagging virtual objects into a physical space in an appealing way. AR stretches the boundaries of physical world to include virtual world. AR can provide unique spatial experiences when navigating in the hybrid spaces (from real and virtual worlds) that have not been experienced before. As a result, –architects become less concerned with differentiating between physicality and virtuality, and increasingly explore beyond the conventional boundaries of spatial, formal and aesthetic concerns to redefine what actually constitutes space, architecture and event” (Rashid, 2005). AR, also provides access to information and the virtual world's

visualization in real-time. Furthermore, by using AR architects and urban designers and planners are able to add events and interaction to a conventional static three-dimensional space; thus, incorporating time with space in their designs and creating four-dimensional (4D) spaces.

The key influences of AR on architecture and built environment include revolutionizing human interaction within architectural spaces, spatial design and configuration, walking through time and space, and connecting to information and the virtual world (Lehman, 2010).

3.1.1 Augmented Reality Applications in Architecture and Urban Design and Planning

Contemporary trends in architecture and urban planning and design acknowledge the cultural significance of ICT and the new media on today's societies. As a result, ICT technologies are embraced and integrated with buildings, streets, and cities. As Lehman (2010), an architectural author and a former instructor and returning critic at the Harvard University Graduate School of Design, argues, —a we enter the world of tomorrow today, we as architects need to think of buildings as more than just static entities around which occupants are in motion. Instead, architecture should also flex with its inhabitants — helping them to make connections everywhere.” This is dynamicity could be easily achieved by incorporating ICT into the spatial design related fields such as architecture and urban planning.

AR is used in many different fields ranging from medicine and science to entertainment. It has even found its way into architecture and other design disciplines including, urban

design and planning. In architecture and urban planning and design, AR applications have been used to add layers of information to the surrounding architectural space and built environment which have several advantages. Also, they have been used for enhancing the physical spaces by augmenting objects from the virtual world. Providing information or instruction in the right time and place is another outcome from using AR for urban planning and design.

The followings are some of the AR uses in architecture and urban planning and design fields.

3.1.1.1 AR as a tool in architectural design and information visualization:

Architects and Designers have always depended on representation techniques such as, drawings and models to communicate their ideas and designs to their clients, engineers, construction professionals, and the public. Representation of all design information is needed for describing buildings throughout different phases of design, construction, and management process. Conventionally, two-dimensional (2D) drawings such as, floor plan drawings have been employed for representing design and construction information (Howard & Bo-Christer, 2008). In the last decades, various computer software and drawing packages have replaced the traditional way of representing building information, hand drafting. Computers have enabled architects and designers to construct three-dimensional (3D) computer modeling of every aspect of their designs for extracting design related information; thus, constructing desired scales of a building in the virtual world.

AR as an effective communication technology has many potential uses for location - based information visualization during the design and construction phases of a building. AR can be incorporated with information visualization and management methods, such as BIM (Building Information Modeling), in order to increase communication among architects, engineers, and contractors. BIM is an integrated process for generating and managing building design information in an interoperable and reusable way (Lee, Sacks, & Eastman, 2006). Autodesk, which is one of the world's leaders in 2D and 3D design software for manufacturing, building, construction, engineering, and media and entertainment, offers one of several BIM solutions in the marketplace today. BIM provides a platform for integrating all of a building's information across different design and construction phases into a single database (Howard & Bo-Christer, 2008). BIM aims to improve information flow and communication among extended design and construction teams in order to increase productivity and accuracy and reduce waste (*Autodesk - building information modeling - about BIM*.2010). Integrating BIM with AR technology makes it possible to augment 3D modeling of a building or its components in a full scale into its assigned real site.

SecondSite is a demo for an augmented reality system for BIM visualization that extends the efficiency, accuracy, and speed of the BIM approach to the active construction site. SecondSite uses building information (2D or 3D) of a building from BIM, and project them in the specified coordination in a construction site. The SecondSite visualization device allows the user to see the designated layers within the digital model overlaid onto a real time video of the specific area in the construction site. The real-time video is

captured by a small camera affixed to the back of the Second Site device (*SecondSite – BIM visualization.n.d.*).

BIM allows all parties involved with a project to work from a single digital model of a building in real-time. SecondSite will then ~~utilize~~ a custom built software platform to bring the usefulness of this approach to the active job site to mitigate on site construction errors, wasted resources, and construction delays inherent to the current building process” (*SecondSite – BIM visualization.n.d.*). This system provides continuous 3D model updates from BIM, and it also allows construction administrators to see ~~real~~ time 3D visual representations of coordinated plumbing, electrical, mechanical and architectural construction systems” (*SecondSite – BIM visualization.n.d.*).



*Figure 3.3 Using SecondSite to visualize a part of a project on-site before it is built.
(SecondSite – BIM visualization.n.d.)*

This system also enables architects to see the latest photos and videos associated with the physical construction in order to make necessary adjustments; thus, providing an architect with a continuous visual access to his/her the project without on-site visiting. Since SecondSite utilizes BIM model, that has a single central model, the system has a tendency to auto correct itself according to the update from BIM (*SecondSite – BIM visualization.n.d.*).



*Figure 3.4 SecondSite visualization device.
(SecondSite – BIM visualization.n.d.)*

The SecondSite device has a Wi-Fi connectivity that actively links selected construction elements to manufacturer's websites to identify pricing or specification information, and it continually self calibrates to the user's current location” (*SecondSite – BIM visualization.n.d.*). The built in functions in the device allow the user to visualize and interact with various construction elements on screen.

In addition to SecondSite, AR4BC (Augmented Reality for Building and Construction) is another similar AR system for on-site building information visualization that is developed by VTT Technical Research Centre of Finland²¹. AR4BC aims to provide mobile users in a construction site with “direct two-way access to 3D CAD and 4D²² BIM information” (Woodward, Hakkarainen, & Rainio, 2010) . This AR system allows building AR applications that “enable real time visualization and comparison of scheduled plans with the actual situation at construction site, as well as multimedia feedback to the BIM system using the mobile terminal” (*Augmented reality /Projects.2010*).



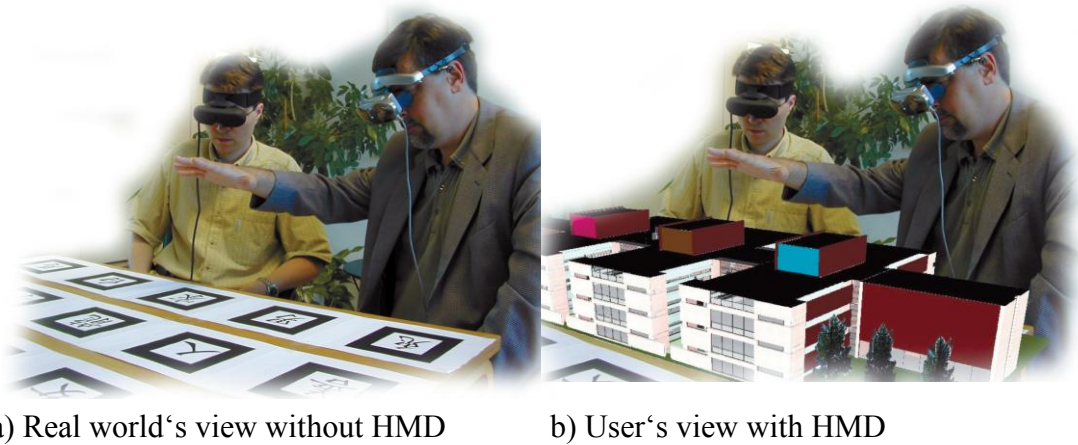
Figure 3.5 Using AR4BC for on-site information visualization.
(Woodward et al., 2010)

²¹ VTT Technical Research Centre of Finland is “the biggest multi-technological applied research organisation in Northern Europe. VTT provides high-end technology solutions and innovation services” (*VTT technical research centre of finland - business from technology.2009*).

²² 4D model is the combination of 3D model with the appropriate scheduling data (*Modelling and simulation of construction processes using VR technology - 4D.2003*).

Finally, AR technology can be used for off-site building information visualization such as 3D scaled model of a project. The ARARAT project is an augmented reality project that develops AR applications for architecture and interior designs. This project was launched and funded by VTT, TEKES, and ten Finnish architecture and construction companies in 2004 (*Augmented reality /Projects.2010*). This project aims to provide instant visualization and improve communication in architectural design projects. In its current stage, ARARAT uses ARToolKit software from HITLab NZ²³ and Osaka University in Japan for tracking and marker detection. AR-Scale Model and AR-Interior are two applications of this project. With AR-Scale Model, the traditional scale models can be replaced with virtual scale models that are viewed through a HMD worn by user (*Augmented reality /Projects.2010*). Virtual scale models are very flexible and provide many opportunities that would be impossible to have with traditional scale models. For instance, it is possible to enlarge different parts of a 3D model, look inside the model, and explore materials and lights while looking at the virtual scale model. In some cases, the used ARToolkit markers are placed on a printed floor plan sheets during 3D Model augmentation.

²³ HITLab NZ (Human Interface Technology Laboratory New Zealand) is a human-computer interface research centre hosted at the University of Canterbury in Christchurch, New Zealand.



*Figure 3.6 AR- Scale Model application in the ARARAT project.
(Augmented reality /Projects.2010)*

Furthermore, AR- Interior application is similar to AR- Scale Model except that instead of augmenting scale models, virtual furniture can be augmented to a physical interior space using ARToolKit trackers.



*Figure 3.7 AR- Interior application in the ARARAT project.
(Augmented reality /Projects.2010)*

3.1.1.2 AR for way finding, guiding, and geotagging:

As built environments and cities grow, they also become more complex and crowded. As a result, navigation and finding ways in these places become more challenging. For this purpose, different representation and communication techniques such as, signage and maps have been employed for providing spatial related information about a city, street, or neighbourhood. The information eases navigating and finding places.

AR as a location-based technology provides an excellent opportunity for accessing a wide range of location related information that cannot be obtained by using other sources of location related information. AR has the ability to geotag in real time; thus, adding ~~geographic~~ information to places, pictures, or things based on a user's location” (Simmons, 2009). The mobile phone-based AR applications help people find their way around and also find places and services easily by providing location related information. In addition to guiding users to a service or store in an environment, AR makes it possible for users to find out what a store is selling ~~without~~ having to actually set foot inside the store” (Wakefield, 2009). These features from AR system provide lots of opportunities for building interesting AR applications in urban planning and design fields. Monocle is an augmented reality application from Yelp²⁴. It allows iPhone 3GS users to find local information service and locate nearby coffee shops by holding up their phones

²⁴ Yelp is ~~an~~ online urban city guide that helps people find cool places to eat, shop, drink, relax and play, based on the informed opinions of a vibrant and active community of locals in the know” (Yelp, inc.2010). Yelp was founded in 2004.

(Wakefield, 2009). Monocle uses the iPhone's A-GPS and compass to display markers for nearby businesses on top of the camera's view.

Furthermore, in some major and crowded cities like London and Paris, AR applications have proved their efficiency by facilitating effective moving around and place finding. Metro Paris Subway iPhone AR application is “a comprehensive guide to travelling through Paris” (*Metro paris subway (subway) iPhone and iPod touch application.2010*). When users look at the city through their iPhone's camera, this application provides them with location related information. It also provides users with updated transit information about Paris's buses and subways (Metro) by using subway maps.



Figure 3.8 Using Metro Paris Subway application for finding nearby Metro stations in Paris.

(*Metro paris subway (subway) iPhone and iPod touch application.2010*)



Figure 3.9 Automatically receiving notification when a disrupted line is detected in Paris Metro (A feature in Metro Paris Subway iPhone application).

(Metro paris subway (subway) iPhone and iPod touch application.2010)

The latest version of this application displays information about Paris's businesses, supported by the advancement in iPhone's operating system (OS) (Kirkpatrick, 2010). In this version, it is also possible to add new Point of Interest (POI) databases to Metro Paris Subway application via in-app purchase" (Metro paris subway (subway) iPhone and iPod touch application.2010). These databases allow users to activate different POI such as, restaurants, coffee shops, and accommodations in all over France, and locate nearby POI on Google Map as well (Metro paris subway (subway) iPhone and iPod touch application.2010). This application is fully compatible with Google Maps.



Figure 3.10 Using Metro Paris Subway application for finding businesses and POI in Paris.

(Metro paris subway (subway) iPhone and iPod touch application.2010)

3.1.1.3 AR for adding context into Built Environments:

In addition to the role of AR in finding ways and places when moving around a space, AR is also a great tool for adding cultural and historical context to a place, building, or object. AR enables access to various types of information (historical and cultural) in various formats (image, video, and text) beside location related and geographical information. Calling up historical background information of a place while walking in that place, for instance, doesn't only make that place memorable but also enriches the experience with the place. This feature of AR encourages people's integration with architectural spaces and with the surrounding world. It also supports a great level of interaction and unprecedented opportunities for exploring and learning about a built environment; thus, building unique informed experiences with a place or environment.

Currently, a wide range of AR applications have accommodated and emphasized this feature for interactive tour guiding and sightseeing purposes such as, Augmented

GeoTravel, Mouse Reality for Disney World and Disneyland, and EyeTour. In Augmented GeoTravel, users can get Wikipedia -based information about their surroundings from a mobile camera view. Similar to the other mobile phone- based AR applications, GeoTravel uses GPS, a compass, and an accelerometer to calculate users' current positions. Once user's position is identified, the application provides access to Wikipedia data set (*Augmented GeoTravel - features.2010*). One feature that is unique for GeoTravel, however, is the "full OFFLINE functionality" (*Augmented GeoTravel - features.2010*). The offline mode in Geo Travel allows users to access information from Wikipedia for the points of interest within a chosen destination, even if no Internet connection is found on-site.



Figure 3.11 GeoTravel application as a tour guiding.
(*Augmented GeoTravel - features.2010*)

In addition to working as an on-site touring guide, GeoTravel also allows trip planning off-site. It lets users know in advance about the places of interest within a destination (for example, a restaurant in a city) and also save information about them for offline uses.

Finally, GeoTravel also keeps the record of a user's tour by saving all the settings of the

tour, the places that have been already visited, and those yet to be visited (*Augmented GeoTravel - features*.2010). Currently, GeoTravel is running on iPhone 3GS only.

Mouse Reality for Disney World and Disneyland and EyeTour are two new layers in Layar AR application for guiding and sightseeing developed by Layar. Mouse Reality helps finding and navigating through all of the attractions, shows, shops, dining, transportation, and more in Disneyland and Disney World (*Layar launches world's first augmented reality content store – augmented reality browser: Layar*.2010) . Thus, it serves as a pocket and parent-friendly park guide (Van Grove, 2010) .



Figure 3.12 Mouse Reality layer for guiding in Disneyland.
(Van Grove, 2010)

EyeTour, on the other hand, helps exploring Puerto Rico's natural beauty and rich cultural heritage through exclusive video content of historical sites, museums, restaurants, parks and more" (*Layar launches world's first augmented reality content*

store – augmented reality browser: Layar.2010). The applications of AR continue to increase to assist with guiding and touring. Someday it would be possible to develop AR applications that make air travels more bearable and provide users with views from airplanes with more than just a series of visual cues, but rather interesting interactive tour on a large scale (Brandon, 2010).



Figure 3.13 EyeTour layer for exploring Puerto Rico.
(EyeTour puerto rico.2009)

3.1.1.4 AR for advertising and projection:

The continuous and quick advancement in Internet and computer technology have attracted the advertising industry toward exploring the World Wide Web (www) as a new platform, due to the convenience it provides consumers (Lu & Smith, 2008). The Internet is an ideal place to aggregate, disseminate, and collect statistics” used as primary tools by people in the advertising field (Carver, 2003). Amazon.com, Dell.com, and eBay.com are some online shopping companies that use cyber space for advertising and shopping.

At the same time, the progress in communication technology, wireless services, and handset technology has opened new doors for instant access to the Internet and its associated resources without necessarily sitting at a desk but instead while walking. AR technology, which allows overlaying data and information from Internet on a view of the physical world, has expanded location-based use of the Internet. This has been achieved by the increasing number of AR applications that allow users to access and use Internet resources (data and information) for various purposes, including advertising and shopping.

Fashionista Virtual Dressing Room and Magic Mirror, for example, are two interesting AR applications for interactive advertising and online cloth shopping which were developed by some online retailers. These applications aim to enhance the online shopping experience by setting up a virtual dressing room. Both of the applications provide ~~an~~ augmented reality (AR) dressing room experience in which shoppers can virtually try on items using their webcams and share snapshots with friends on Facebook for feedback”(Augmented reality is a fit for retailers.2010).

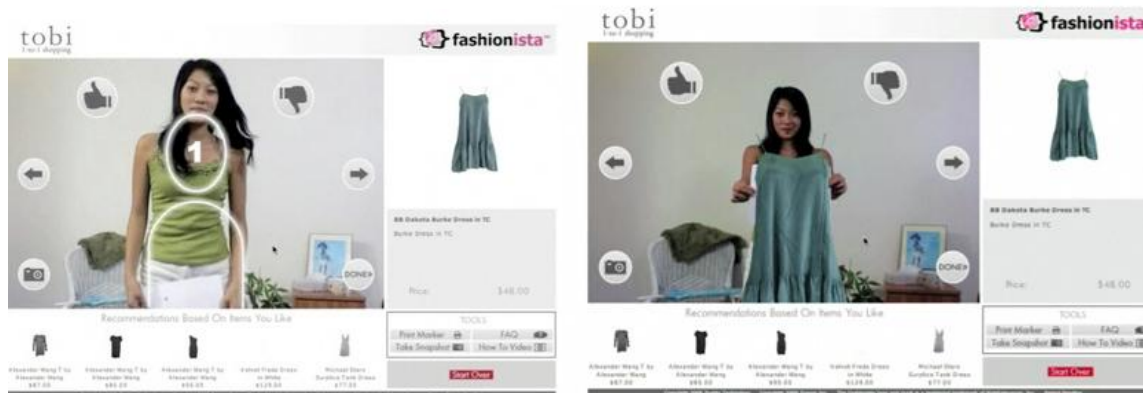


Figure 3.14 Using Fashionista Virtual Dressing Room for trying on clothes and navigating among selections from Tobi online retailer. (Augmented reality is a fit for retailers.2010)



Figure 3.15 Using Magic Mirror for try on clothes in online shopping. (Kuang, 2010)

In calculating a user's position, the applications make use of the motion-capture technology found in the webcam. And the size of the products, clothes, in relation to user's body and location are calculated and adjusted by holding an ARToolkit marker prepared by the online retailers for that purpose (Kuang, 2010). In a formal usability

experiment, Lu (a mathematician researcher from Wolfram Research Inc.) and Smith (a mechanical engineering professor from National Taiwan University) (2008), concluded that an AR system for online shopping could be used ~~to~~ provide more direct product information to online shoppers and thereby help them make better purchasing decisions.”As a result, users prefer AR e-commerce system more than traditional e-commerce and VR e-commerce systems.

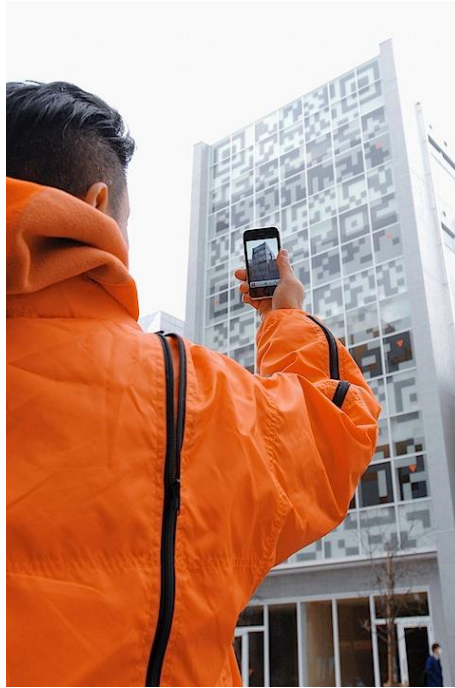
In addition to online advertising and shopping, AR technology also improves location-based advertising and shopping. By imposing nearby businesses and products related information in various forms (image and text) onto a user’s camera phone view, the user can easily find out about products and services without having to visit every single store or retailer. Therefore, AR makes the shopping experience easier and timely by directing users to what they are looking for without wasting too much time. AR also helps retailers in advertising and attracting shoppers by making their products and services accessible and visible when navigating near a close place. As previously indicated, Walt Disney has already used AR technology for advertising by using the Layar application in an outdoor campaign.

With the continually increasing number of AR uses for advertising and shopping, many interesting opportunities have come to the surface for integrating advertising representation techniques with architectural and urban spaces. The visual nature of advertisement and AR features are main contributors for this. For example, with AR it is possible to build façade systems that display virtual information and graphics, which

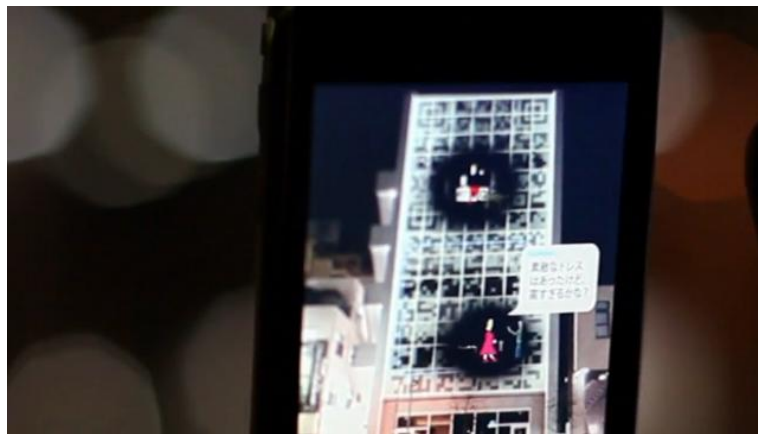
results in a change to the static state of a building to a more dynamic and interactive state; thus creating a communicative architecture that has interactive or responsive surfaces.

An example of a building that has incorporated AR technology with its façade is a commercial building called “N Building”. N Building is located in a Tokyo shopping district in Japan. In this building, the façade has been covered with QR code²⁵ instead of covering the facade with typical billboards and neon lights. This allows passers-by to view the QR Code with their mobile devices for a very unique augmented reality experience that will display up to date shop information, interactive advertisements and even display the tweets that are coming out of the building” (*N building featuring augmented reality*.2010). Users can also browse shop information, make reservations, and even download coupons.

²⁵ **QR Code (Quick Response)** is “a kind of 2-D (two-dimensional) symbology developed by Denso Wave (a division of Denso Corporation at the time) and released in 1994” (*About 2D code*.2010). In contrast to bar code, QR Code contains information in both the vertical and horizontal directions and not only one direction. QR Code “holds a considerably greater volume of information than a bar code” (*About 2D code*.2010). Most current Japanese mobile phones can read this code with their camera.



*Figure 3.16 N Building in Tokyo, Japan.
(N building.app – iPhone meets architecture.2010)*



*Figure 3.17 An augmented view of N Building from a mobile phone camera.
(N building.app [iPhone].2010)*

Furthermore, Augmented Space and 555 KUBIK are two façade projections in which virtual graphics are augmented on top of two existing building façades. –Augmented Space” is an urban installation (façade projection) by Pablo Valbuena in which interesting lights and animation are overlaid on Hague’s city hall façade in the Netherlands. This projection has entirely changed the appearance of existing building façades to a more dynamic façade using AR technology.



*Figure 3.18 Hague’s city hall urban installation.
(Pablo valbuena: Augmented space.2010)*

A year later a similar façade projection, 555 KUBIK, was developed and applied to Hague's city hall building. The idea behind the 555 KUBIK facade projection was —how it would be, if a house was a dreaming” (*Digitalexperience.2010*). This art piece —was a projection on the Kunsthalle in Hamburg, Germany that transformed the sterile facade into a dynamic sculpture based on the physical structure of the building” (*Digitalexperience.2010*). The existing façade of the building isn't that exciting itself, —but the projection takes it to a new level” (*555 KUBIK facade projection - today and tomorrow.2010*) . In addition to graphic projection, this project includes sound projection as well.

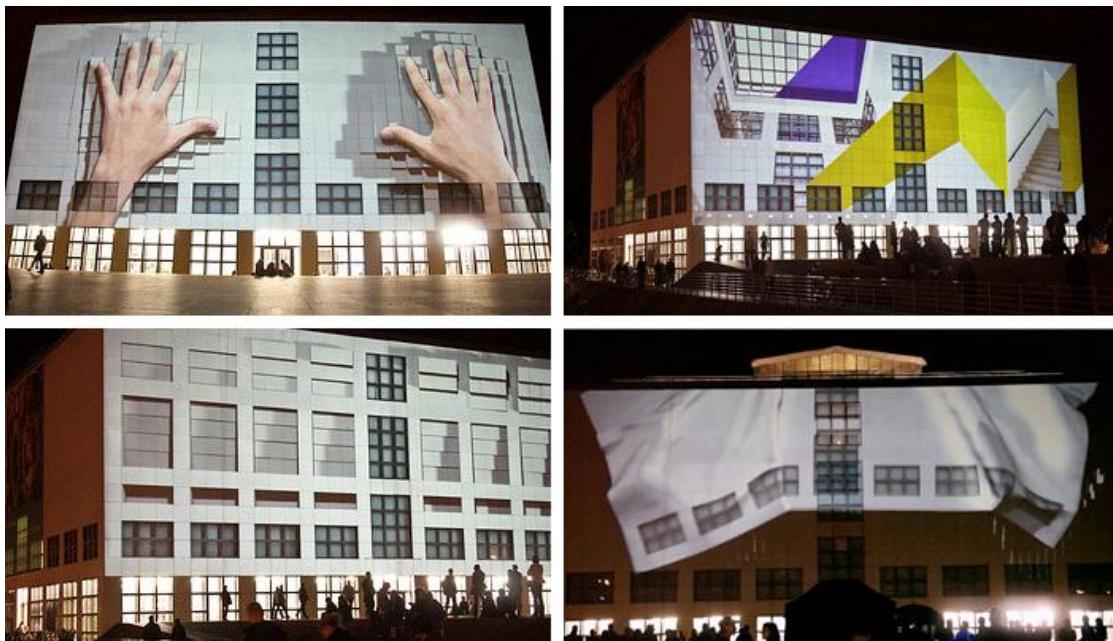


Figure 3.19 The 555 KUBIK façade projection on Kunsthalle in Hamburg, Germany. (Dreaming architecture.2010)

3.1.1.5 AR for Art Installations in architectural and urban spaces

In the last decades, the attention of the artist community has shifted from traditional art representation techniques to digital ones. Various digital technologies have been utilized for generating artistic works and art installations. AR as a platform for emerging the virtual and real has inspired artists and architects to build creative and interactive art installations and art works in architectural and urban spaces. These works have attracted many observers and uncovered new dimensions for urban space usage.

Energy_Passages is an art installation in a public space that generates a linguistic space of the city in the form of a data flow. In this art installation hundreds of catchwords are taken from current newspapers and displayed via RSS-Feeds in a projected "information flow". The catch words are then spoken by artificial computer voices. –As soon as passers-by select individual words, thematically related networks of terms start to perform in this flow. Thus, text is detached from its linear context and is staged as a media reading in urban space” (Strauss & Fleischmann, 2005).



*Figure 3.20 The Energy Passages art installation.
(Energy_Passages - media art installation.2004)*

Augmented Sculpture is another media art work by Pablo Valbuena in which AR technology has been used effectively. According to Valbuena, “this project is focused on the temporary quality of space, investigating space-time not only as a three dimensional environment, but as space in transformation” (*Pablo valbuena.2010*). The project consist of two layers that are viewed by users in real time; the physical layer, “which controls the real space and shapes the volumetric base that serves as support for the next level”, and the virtual projected layer on the physical layer “that allows controlling the transformation and sequentiality of space-time”(Pablo valbuena.2010). The resulting blend of these two layers “gives the impression of physical geometry suitable of being transformed” (*Pablo valbuena.2010*).

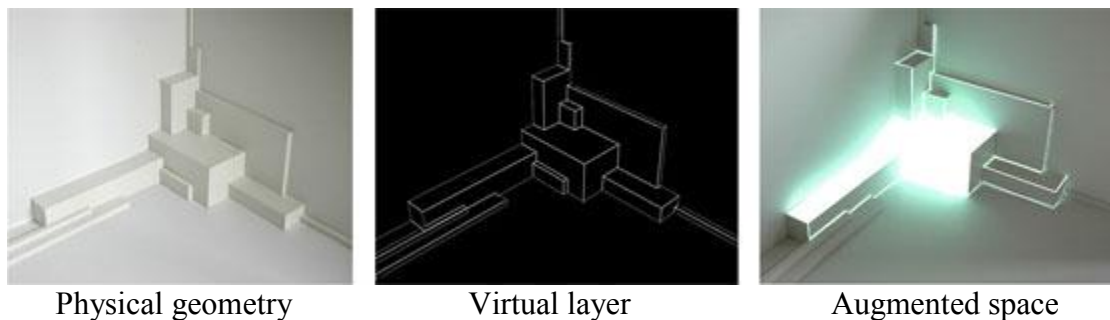


Figure 3.21 The Augmented Sculpture project’s layers.
(Pablo valbuena.2010)

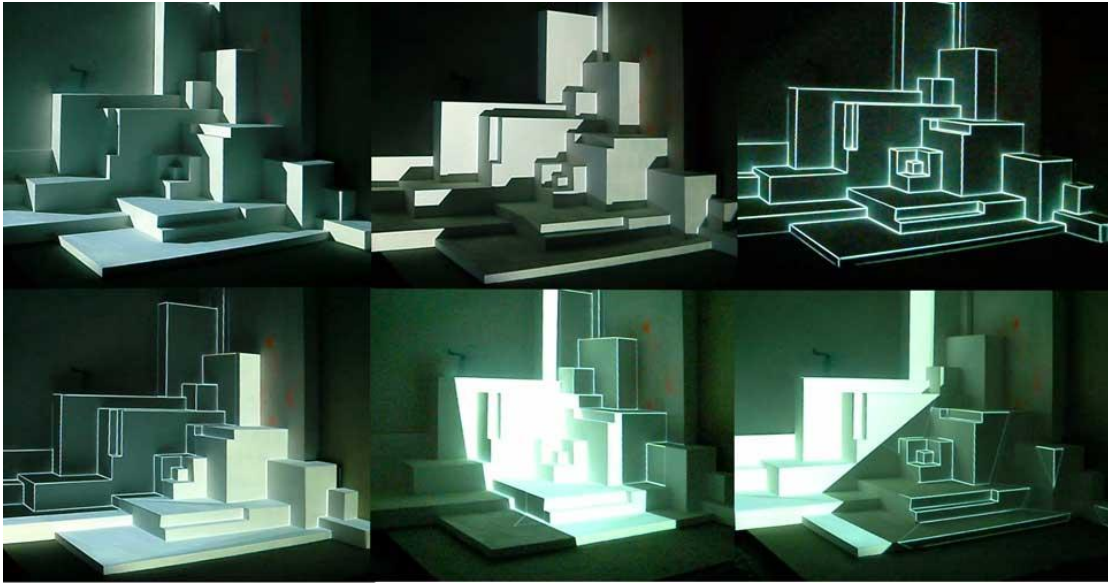


Figure 3.22 Different views from the Augmented Sculpture layers by Pablo Valbuena.
(*Artintelligence: Pablo valbuena, augmented sculpture.2010*)

3.2 AR, Cultural Heritage, and Historic Resource Management

The use of AR in cultural heritage²⁶ and historic resource management has steadily increased. AR provides many appealing features that can be exploited for representing, documenting, and managing cultural heritage resources. AR combines the benefits of the virtual world's objects, which are flexible and enable a high level of interactivity with the physical world's objects and environments, which are locational and characterized with materiality.

²⁶ Cultural heritage “is not limited to material manifestations, such as monuments and objects that have been preserved over time”, but also “encompasses living expressions and the traditions that countless groups and communities worldwide have inherited from their ancestors and transmit to their descendants, in most cases orally” (*Intangible heritage : UNESCO-CULTURE.2010*).

AR technology enables users to see and interact with virtual and physical entities all at once in the same time and location, in contrary to VR technology, which only enables access to virtual objects and environments.

The value of tangible (physical) cultural heritages, such as historic sites, buildings, and artefacts is represented in the layers of time each holds; thus, their age. The age of a historic artefact would not be visible and estimated only from visual cues of the artefact, especially for non-specialized people. Without revealing historical information and evidence it won't be possible, for example, to differentiate between the original stele of Hammurabi's Code from ancient Babylonian time with a fake from a few centuries ago.

In fact, lack of information may result in some misunderstanding of the significance of a historic building or site (Gutiérrez A., Vexo, & Thalmann, 2008a). For that purpose, AR technology offers unprecedented alternatives for managing and representing cultural heritage and historic building resources. It also provides an effective approach for accessing historic or other related information while navigating on-site; thus facilitates location-based learning.

3.2.1 AR applications in Cultural Heritage and Historic building representation

AR enhances people's perception about a place or object in real time by revealing unseen layers of information that enrich their experience. Exploring this feature of AR helps stretching the boundaries of this ever growing technology for cultural heritage representation uses. This can be achieved by learning about the current AR applications

such as way finding, location-based learning, and information visualization. In exploring these uses, in the first section of this chapter, a wide range of AR applications in architecture and urban planning and design has been introduced. These applications help to reveal the opportunities that AR technology can offer for managing, representing, and reconstructing significant cultural artefacts including historic building. It is also important to cast light on the available AR applications and projects in cultural heritage and historic resource management and examine their uses. The following are some of the AR uses in historic resource management:

3.2.1.1 AR for information representation

The ability to insert virtual content and information into real world's scenes has enabled AR application developers to develop interesting applications for historic resource management in cultural heritage. AR can be used for representing the history of tangible cultural heritages including historic sites and artefacts in effective ways. Some historic artefacts are still located in their original sites. Visitors can access them by visiting on-site. Some others are located in museums or exhibition halls. In both cases visitors need to explore these historic artefacts beyond visually decoding them. Obtaining information about an object or place plays an important role in broadening the viewer or visitor's knowledge about that object. For that purpose, cultural facilities like heritage sites and museums use various representation techniques such as, pictures, audio, and text in order to communicate various types of information and stories.

In museums it is possible to use multimedia technology to present more detailed information on artefacts housed in the collection. Audio guide is an example of exploiting a multimedia technology for fostering long-lasting relationship between the artefacts and visitors when navigating a historic site or museum (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008). Mobile phone tours in the form of audio guiding used for indoor and outdoor touring in museums, streets, and cities allows visitors and tourists to access cultural information in multiple languages by dialling a phone number about a specific site or object they are interested in (Filippini-Fantoni & Proctor, 2007).



Figure 3.23 Mobile phone tour at Tate Modern's David Smith: Sculptures exhibition. (Proctor, 2007)

AR as a cutting edge technology has become an effective alternative platform for representing information in museums and historic sites. AR makes it possible to link sources of information such as, text, drawing, painting, picture, audio, and video with the related historic objects by augmenting them to the scenes in the user's view. This

augmentation allows a high degree of flexibility, manipulation, and interaction because the augmented entities remain in the virtual world. For example, it is not possible to zoom-in and zoom-out of a printed text without a magnifier while an augmented text in an AR system can be manipulated according to the user's preference. This is because of the virtual property of the augmented text in an AR system. By using these abilities of AR, people with different disabilities can fully personalize and enjoy their touring experience. With AR it is also possible to read and listen to information in different languages by incorporating these abilities into its system or facilitating access to online resources such as Google translator. In fact, the mobile phone-based AR applications enable access to the World Wide Web (www), providing continuous connectivity with the internet and its resources.

The location aware characteristic of AR also provides substantial opportunities for information representation in the right time and place for visitors when navigating around in a museum or historic site. Interactivity is another aspect of AR that poses a range of possibilities for representing cultural heritage. AR enables interaction with objects (2D and 3D) and information it augments. All of these characteristics make AR superior over the other self-guiding touring techniques used by museums and other cultural facilities for communicating and representing information.

Several AR applications for cultural heritage uses have been developed. These applications work as a self-guiding tour tool for both for indoor and outdoor uses when visiting museums and historic sites and buildings. Japan is one of the leading countries

for excessive use of AR technology. Currently, iPhone-based AR application are being developed and used ~~to~~ help visitors navigate their way through a museum and to find data on the exhibitions” (Simmons, 2009).

In Spain, a similar approach exists for guiding tourists and for sightseeing purposes. Vadinia is a mobile AR system that is used for locating, guiding, and giving information to people with visual disabilities. Vadinia has been developed by the Human Communication and Interaction Research Group in Spain. Vadinia uses handheld devices such as mobile phones to provide users with real time information about the physical world around them.

This system also provides foreigner visitors, who do not understand Spanish, as well as people with limited sight with context location-based information that helps them learn about interesting places. Of course, the system can be used for all types of visitors too. Vadinida ~~works~~ in any PocketPC device running Compact Framework 2.0 and is powered by a Wifi and Bluetooth connection” (*HCI-RG: Technologies - vadinia.2010*). User’s location is obtained using GPS antennas in open sky environments (such as cities and historic sites) and Bluetooth antennas inside buildings (*HCI-RG: Technologies - vadinia.2010*). Information about the surrounding environment in Vadinia system ~~is~~ easily edited in a Context Markup Language (CML) which renders its contents in real time using visual and auditory interfaces, providing an accessible interface for users with different kinds of disabilities” (*HCI-RG: Technologies - vadinia.2010*).

The first application of Vadinia system was an interactive tourist guide of the city of Oviedo, which is the capital city of the province of Asturias in Spain. The guide ~~includes~~ context aware information about the main monuments and buildings of the town describing their history using text, images and sounds” (*HCI-RG: Technologies - vadinia*.2010). Once a user arrives at the specified areas where the buildings and monuments are located the user gets audio instruction. This application also allows inputs from users, enabling them to attach their own images and text to the objects discovered during their visit.

In addition to being an effective method of communicating information to tourists and visitors, AR also supports flexible and independent tourist guiding and sightseeing. ~~History unwired (HU)~~” is a multi-year investigation of the narrative uses of mobile technology in historic cities (M. Epstein & Vergani, 2006). As an experiment, a mobile AR walking tour was developed for one of Venice’s more hidden neighbourhoods. This project was delivered over location-aware multimedia phones and PDAs (*History unwired*.n.d.). This walking tour was sponsored and developed in 2004-2005 by a team of researchers from MIT and University of Venice (faculty of Architecture, IUAV) who worked with local artists, citizens, and academics (M. Epstein & Vergani, 2006). This project was a first mix of mobile video, animation, audio, and Bluetooth locative technologies in the tourism sector (*History unwired*.n.d.). The tour takes visitors around one of the neighborhoods of Venice, Castello, and users are ~~guided~~ by the voices of Venetian citizens who depict a particularly local experience of art and craft, history and folklore, public and private spaces” (*History unwired*.n.d.).



*Figure 3.24 HU walking tour application start-up interface.
(History unwired.n.d.)*

The goal of the HU project was to —develop a media form that would take tourists to lesser-traveled, yet culturally-rich areas of Venice and give them an intimate experience of Venetian life” (M. Epstein & Vergani, 2006). According to Epstein and Vergani, two researchers from MIT and Venice International University, this could be achieved by building a mobile AR system for self-guiding tour that supports navigating in and exploring these interesting historic areas that have less tourist guiding facilities. In doing so, the organizers of the project also hoped that its success would also lead to reducing the number of tourists to popular sites, such as St Mark’s Square. By using this application, tourists may no longer need to be in a group in order to learn and explore the surrounding historic buildings, but could personalize their experience and navigate freely throughout the city.

The project has been developed in a time when Venetian citizens have started to complain, reported in a New York Times article, from the growing number of visitors to

some particular area of the city where Venetian houses are located in close proximity (M. Epstein, Garcia, & dal Fiore, 2003). The HU walking tour was tested on over 200 users, and was followed by an extensive survey. The project achieved a remarkable success rate and –several academic and commercial entities around Venice have expressed interest in expanding the tour to other areas of Venice” (M. Epstein & Vergani, 2006) .



Figure 3.25 A shot of Spanio, the baker and singer, appears on the screen before the HU guide and invites the user to go inside the bakery. (M. Epstein & Vergani, 2006)

Today, the many uses of mobile phone-based AR technology are continuously expanding for guiding users through historic sites and cities. In 2010, the London Museum found that AR provided an unprecedented opportunity for users to explore the museum's impressive archive of London images to the streets of London (Eccleston-Brown, 2010). StreetMuseum is an iPhone 3GS-based AR application that has been supported by the London Museum to mark a new set of £20m galleries that celebrate 350 years of London

history (*Museum of london: Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store*.2010). This application enables users to view Old London with new eyes. –The app, which is compatible with over 200 sites across the capital, lets you view landmarks such as the Thames through your phone while simultaneously seeing a photograph or painting of it as it was in days gone by” (Eccleston-Brown, 2010).

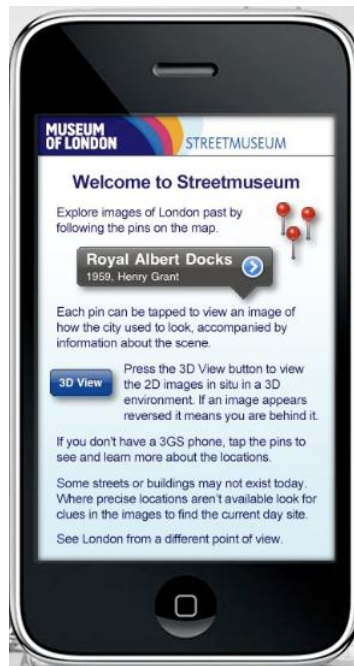


Figure 3.26 Launching StreetMuseum application on iPhone 3GS. (Museum of london: Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store.2010)

StreetMusuem lets Londoners discover London's hidden secrets by viewing its history and learning about it while navigating through London's streets. The following section describes the steps to use the StreetMueum application:

- 1- Once the application has launched, a number of pins appear on London's map on the iPhone. The pins indicate the archival images augmented to their original locations in London city (See Figure 3.27).
- 2- The user can then follow a pin and see the historic image assigned to it and learn more about the image's location by tapping the pin. By pressing the information button on the top of the right side of the screen more information and historical facts about the image become available (*Museum of london: Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store*.2010) (See Figure 3.28).
- 3- Once the user has located and has come closer to the image, he/she can hold up the phone's camera and press the 3D view button to view of the 2D image in situ in the actual 3D view appear on the screen from the camera (See Figure 3.29).
- 4- In order to read the historic facts while in 3D view mode and also enlarge the image, the user can tap the text below the image (See Figure 3.30).



Figure 3.27 A view from an iPhone showing the pins on London's map in StreetMuseum app.
 (Museum of London: Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store.2010)

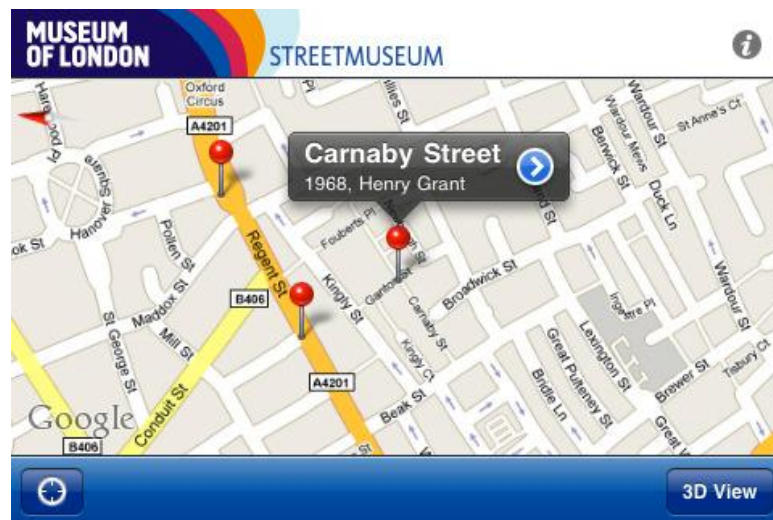


Figure 3.28 A view from the iPhone after tapping the pin on Carnaby Street on the map.
 (Museum of London: Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store.2010)



Figure 3.29 A view from the iPhone showing the 2D image of Carnaby Street in 1968 and appears to be aligned with the real view of the street today.
(Museum of London: *Streetmuseum* for iPhone, iPod touch, and iPad on the iTunes app store.2010)



Figure 3.30 A view from the iPhone showing the Carnaby Street image in 1958 enlarged with historical facts about the street.
(Museum of London: *Streetmuseum* for iPhone, iPod touch, and iPad on the iTunes app store.2010)

—The Salvation Army International headquarters at 23 Queen Victoria Street was bombed during the severest raids of the Blitz on 10 May 1941” and by using the AR application today a visitor —can see a photograph taken as its facade crumbled to the ground emerge as a ghostly alignment with the current building” (Eccleston-Brown, 2010) (See Figure 3.31).



Figure 3.31 The aligned 2D image of the bombed headquarters building appears on top of the view of the renovated building today using the StreetMuseum application. (Museum of London: *Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store*.2010)

3.2.1.2 AR for restoration, reconstruction, and visualization

In addition to information representation and augmentation of 2D representation techniques (such as, pictures and texts), AR also allows augmenting 3D representation of objects. Not all archaeological and historic sites are well preserved. In fact, most historic sites around the world are in a state of decay or have been demolished, which make it impossible for on-site visitors to see them in their glory days (Gutiérrez A., Vexo, &

Thalmann, 2008a). AR as an effective communication technology enables visitors of a historic site or building to travel back through time and walk through the site or building while they were in their best shape. This can be achieved by augmenting the 3D reconstructed model of the building, or parts of it, in the virtual world into its corresponding location in the real world in the visitors' view.

AR's ability to virtually restore historic buildings and display them in their original locations has attracted people in the cultural heritage resource management sector. AR makes it possible to restore historic sites which at present are only ruins (Papageorgiou, Ioannidis, Christou, Papathomas, & Diorinos, 2000). The ARCHEOGUIDE (Augmented Reality-based Cultural HERitage On-site GUIDE), for example is an AR project that aims at providing visitors of cultural-heritage sites with archaeological information in an innovative new way (ARCHEOGUIDE.2002). In this project, —instead of rebuilding historical remains and thus interfering with archaeological research, Augmented Reality (AR) techniques are used to present virtual reconstructions of the artefacts in the real environment” (Gleue & Dahne, 2001). The project provides real-time on-site access to archaeological multimedia data, enables the 3D reconstruction of ancient monuments, and revives the scenes from ancient life. —The project fills the gap left by conventional paper guidebooks, info kiosks and audio guides and provides truly mobile devices with navigation, personalization, and interactivity features” (Vlahakis, Karigiannis, & Ioannidis, 2003). The project's main objectives include virtual reconstruction of monuments, personalized navigation according to users' profiles, and attracting more people to cultural heritage sites by the lure of the newest and best technology

(Papageorgiou et al., 2000). In doing this, ARCHEOGUIDE –will provide a new approach to visits in cultural heritage sites by overcoming the disadvantages that physical or virtual tours have” (Papageorgiou et al., 2000).



Figure 3.32 An augmented view with historic buildings from ancient Olympia site using the ARCHEOGUIDE system.
(Papageorgiou et al., 2000)

In this system, visitors are equipped with a small mobile computer and a HMD, and the mobile device tracks the visitor's position on the site. As the visitor navigates through the real site, he/she sees the 3D virtual reconstructions of the historic buildings integrated seamlessly into the user's natural field of view (Gleue & Dahne, 2001).



Figure 3.33 The ARCHEOGUIDE system's devices worn by the visitor.
(Gleue & Dahne, 2001)

By additionally determining the viewing direction of the user the ARCHEOGUIDE system computes the current view of the reconstructed objects. The rendered images are then shown in the display unit, yielding an augmented view of the real world adapting to the user's movements in real-time" (Gleue & Dahne, 2001). In order to provide a large number of structured new-media information to the visitor, a rigorous database model will be developed that can serve both site visitors (for guided tours) and scientists, by providing complete and thorough site documentation" (Papageorgiou et al., 2000).

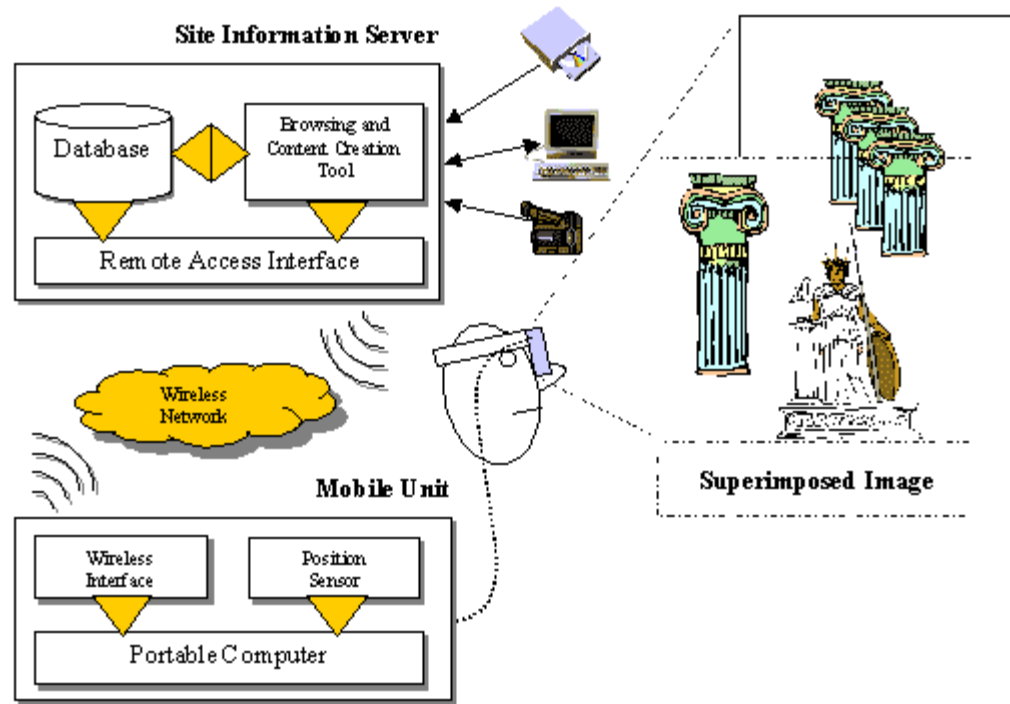


Figure 3.34 The ARCHEOGUIDE overall system Architecture.
(Papageorgiou et al., 2000)

This project was first installed as a 3D interactive and on-site Visualization tool of the ancient Olympia site, “the birthplace of the Olympic games and from where the Olympic light begins its journey to the host city of the games every four years” (Papageorgiou et al., 2000), in Greece. This was mainly to attract the visitors of the Olympic Games in 2004 in Athens, Greece. ARCHEOGUIDE is pursued by a consortium of European organizations that are funded by the European Union IST framework (ARCHEOGUIDE.2002).



a) The real view

b) The view from HMD

Figure 3.35 An AR reconstruction example: The Philippion Temple at Ancient Olympia. (Vlahakis et al., 2003)

Reconstructing and visualizing historic buildings can be extended to the urban scale using AR technology. With AR technology it becomes possible to walk around a historic city that has changed dramatically and have a view of its past. In 2004, in Switzerland the first AR sightseeing tour, called LifeClipper, was developed. LifeClipper is an open air art project developed by new media organization Plug. The system offers an audiovisual walking experience by using AR technology (*Augmented reality GPS tour beyond tomorrow*. 2007) .The project allows visitors to see some of Basel city's landmarks and streets in St. Alban Quarter from medieval times while walking in the modern city of Basel (*lifeClipper*.2005). By using a traditional mobile AR technology (a HMD and wearable computing units that include GPS and tracking devices) it is possible to immerse users in historical scenarios around St. Alban Quarter which have a rich historical heritage (*Augmented reality GPS tour beyond tomorrow*. 2007).



Figure 3.36 A user wearing LifeClipper AR technology to navigate in St. Alban Quarter. (lifeClipper.2005)

In this project, sounds are also augmented into the user's surroundings and changes according to the user's location (Reid, 2005). In addition to the 3D reconstruction of medieval city streets, virtual people wearing medieval clothes are visible from the HMD; this further enriches the touring experience (*lifeClipper.2005*). The audiovisual augmentation makes it possible for the user, for example, to hear inner workings and hear the sounds of the mechanics thumping while seeing them as well (*lifeClipper.2005*). This project has some challenges that are mainly associated with the technology such as a narrow eye-view of the world and system delay from the HMD and a low resolution of the images (*Augmented reality GPS tour beyond tomorrow. 2007*).



a) A real view from St. Alban Quarter's tour **b)** The augmented view from the HMD

*Figure 3.37 Two view of the same spot from LifeClipper project.
(lifeClipper.2005)*

In summary, the applications of AR technology in cultural heritage are continuously growing, and this is due to the uniqueness of projects that this technology has been applied to. AR's ability to uncover buried layers of history, visual reconstruction, contribution in learning in the right time and place, creating informed experience for users who are touring historic sites, personalizing touring experience in historic sites, and provides the users with the ability to merge the real and virtual which provides tremendous ground for further integrating AR technology with cultural heritage uses. AR promises to transfer historic sites and buildings from static spaces to narrative spaces that dynamically reveal the hidden stories of these significant cultural areas.

3.3 Summary

In this chapter a number of AR applications in architecture, urban planning and design, and cultural heritage fields have been examined. This has led to understanding and

highlighting the AR uses for many purposes including, way finding, visualization, and restoration. The examination of the AR applications included the application uses, system components, interfaces, technologies, and features. In doing so, this chapter casted light on the features, technology, and interface that could be adapted and incorporated when building future AR applications and prototypes.

Chapter Four: Design Guidelines

In this chapter, design guidelines for building smartphone-based AR applications will be developed. The extensive literature review from the previous two chapters made it possible to develop these guidelines, which help building AR applications for many purposes, including exploring historic sites.

4.1 Design guidelines for developing AR applications and prototypes

In developing an AR application or prototype, a developer needs to make a series of decisions related to various aspects of the application or prototype. In general these decisions are categorized into two main categories:

- 1- Technological decisions: such as, hardware technology, display types, and tracking methods.
- 2- User interface decisions: such as, virtual contents and user interface design.

In AR there are no formal design guidelines that developers can adapt when developing AR applications. The extensive literature review which was conducted in the previous chapters on AR technology, its components and advancements, and applications in architecture, urban planning and design, and cultural heritage, has casted light on many technological and interface design considerations. In this research, these considerations have been used toward developing design guidelines that could be adapted by developers when developing AR prototypes or applications for many purposes including, representing historic sites and artefacts to visitors and researchers.

The followings are the recommended design guidelines:

4.1.1 AR technology:

As discussed in Chapter two, selecting the appropriate hardware as an AR application platform is greatly affected by the purpose of the application and the hardware's ability to adapt the AR system. In mobile AR applications (in general) and cultural heritage applications (more specifically) the followings technological components are recommended:

- Light weight devices: With the increasing demands for mobile AR applications (such as for navigating in a historic site), the need for light weight devices is continuously expanding. Ergonomic factors, high degree of mobility, and flexibility are three main reasons for this need. The developments and examples of AR supporting technologies, discussed in Chapter two and three, presented smartphone as a reliable and ideal platform for building mobile and location aware AR applications (especially the ones that require a high degree of independency and mobility). Smartphones are GPS or A-GPS enabled, contain digital compass and high resolution camera, and can be connected with the internet. Smartphones are also ubiquitous and used by billions of people (Henrysson et al., 2007).
- Reliable Operating System (OS): As connectivity with internet has become an important feature for AR applications, it is crucial to use reliable OS that support accessing most of the AR's supporting online products like Google Maps, Goggles, Wikitude, and Layers. These online products allow building effective AR

applications. Based on the studies from the previous chapters, it is recommended to use both the iOS (iPhone's OS) and Android (Google's OS for mobile devices) due to their wide range of uses, features, access to many online products, and reliability.

4.1.2 AR user interface:

An effective AR user interface should consider the technological abilities and limitations of the used platform (Billinghurst et al., 2005). An AR interface should integrate the type and amount of the augmented contents such as, video, audio, text, and image with the applications' requirements.

The followings are some user interface design guidelines suggested in this research for facilitating building smartphone-based AR prototypes and applications for many purposes, including historic sites exploration:

4.1.2.1 The augmented virtual contents:

- Variety: In order to create an effective AR interface it is better to use a variety of virtual contents such as images, text, audio, video, and 3D models in an AR application.
- Visual cues: It is better to use images, diagrams, maps, and visual cues in an AR interface instead of text for recalling or explaining a procedure, and using textual explanations as supplementary (Liarokapis & Newman, 2007). When images are used, it is crucial to use supported formats by the selected device. In general common image formats such as, JPG, GIF, TIFF, and PNG are supported in smartphones like

the iPhone. The standard bit depth for images is 24 bits (*iPhone human interface guidelines: Creating custom icons and images*.2010). Also, size and resolution of images should match the device's requirements and interface ability, and it is better to keep image sizes under 1024x1024 pixels (*iPhone human interface guidelines: Creating custom icons and images*.2010).

- Video usages: For communicating sequence of events it would be better to use video instead of still images (Liarokapis & Newman, 2007). The video formats used in an AR application have to be supported by the selected AR platform (such as smartphone devices). For example, iPhone 3GS supports H.264, MPEG-4 in .mp4, .m4v, .mov video formats (*Apple - iPhone 3GS - size, weight, battery life, and other specs*.2010). Each of these formats has different specifications. For example, the specifications for MPEG-4 video format in iPhone 3GS are "up to 2.5 Mbps, 640 by 480 pixels, and 30 frames per second" (*Apple - iPhone 3GS - size, weight, battery life, and other specs*.2010).
- Audiovisual usages: This research encourages using audiovisual augmentation for guiding users in the AR applications that work as tour guiding. This will enrich the users' experience. The audiovisual usage will also be helpful for people with hearing or vision disabilities and enable them to enjoy their tour around a historic site or building, for example, without any communication barriers (*HCI-RG: Technologies - vadinia*.2010).

- Show what cannot otherwise be seen (3D model augmentation): The AR technology's ability to show 3D objects that don't exist in the real world should be incorporated in AR applications. For example, it is possible to construct 3D models of missing or damaged artefacts or buildings and augment them into their once original locations in a historic site. This feature enables users to see the historic sites in their glory times and provide them with more information in an effective way (Gleue & Dahne, 2001). When re-constructing and augmenting 3D model of a historic building or artefact the following two factors have to be considered :
 - 1- Scale of the 3D model according to its surrounding, city or street scale. When placing a 3D model of a building or artefact in city scale, Google Earth can be used. A mass model of the building or artefact with some texture mapping is sufficient for city scale.
 - 2- Level of details in the 3D model. This is greatly affected by the available sources of information when reconstructing the 3D model of missing parts or the entire buildings or artefacts. For this purpose various source of information, such as footprints from air photos and photographs, can be used. Also, different modeling techniques like photogrammetric techniques and software (Google SketchUp and 3D Studio Max) can be used. The level of detail should switch according to user's location in relation to the 3D model of a building or artefact. As the user gets closer to the 3D model more information and details should be revealed.

4.1.2.2 User Interface (UI) design:

- Layering information: Layering augmented information, texts or images, is a fundamental interface design requirement for an effective AR application. This will avoid overwhelming users with information, and thus distracting them from enjoying their experience (Julier et al., 2000) and (*What is layar?*2010).
- Appropriate size: It is crucial for the size of the UI contents in an AR application to be in relation to the size of the display of a selected device and also the device's technical features (Billinghurst et al., 2005). For example, in iPhones and other touch screen-based devices the UI elements must be big enough to hit with a finger. For this purpose, the size of the buttons and their effective areas should be at least 44by 44 pixels (Harrington, 2008). Even if the buttons look smaller still they have to have a 44 by 44 active area.
- Legibility: It is important for the information in an AR interface to be legible. If text is used, it should be clear and easy to read on a small screen. This could be achieved by having legible text sizes and font styles. For example, the iPhone-based AR applications can use iPhone's default system font style, Helvetica, due to consistency and its readability (*iPhone human interface guidelines: Table views, text views, and web views*.2010). The color of a text may vary according to the color of its text box in the background.

- Easy Navigation and accessibility: To facilitate clear and easy navigation in an AR interface it is preferable to use buttons that provide quick access to some important sections such as main menu. It is also important to access the most-frequently used features in no more than 1 tap-away (Harrington, 2008). Finally, different visual and audio cues should be used for indicating and communicating the available features in an AR interface. For example, where there is a video to watch and audio to listen to the user should be able to know about them through a cue or sign communicating the availability of these features.

4.1.2.3 Interactivity:

- Flexibility: An AR application should be flexible in enabling users to personalize the contents of its interface (M. Epstein & Vergani, 2006). For example, the application may allow users to plan their AR tour contents off-site (*Augmented GeoTravel - features.2010*).
- Interaction: Increasing users' interaction with their surrounding environments, objects, and buildings through AR applications enriches users' experience. This could be done by augmenting context related contents that support exploring and interacting with the surrounding environments (Liarokapis & Newman , 2007) and (*Connecting augmented reality to outdoor advertising.2010*). It is also possible to engage and involve users by allowing inputs from them that could be used for future development (Papageorgiou et al., 2000).

- Exploration: An AR interface should support exploring its contents and reveal more details when users interact with the interface. For example, it should be possible to zooming-in and zooming-out on an image to see more details, and in this case it is recommended to use images with high resolutions (Eccleston-Brown, 2010).
- Spatial AR: For creating interesting dynamic effects on static structures and objects, it should be possible to employ spatial AR. This allows projecting virtual contents onto objects, paths, and buildings found in a historic site (*555 KUBIK facade projection - today and tomorrow*.2010), (Strauss & Fleischmann, 2005), and (*Pablo valbuena*.2010).

4.1.2.4 Connectivity with real and virtual world:

- Ability to geotag: AR technology makes it possible to geotag photos automatically while navigating in an environment (Simmons, 2009). This is an effective feature to be employed in AR applications. With this ability, a user should also be able to find geotagged photos within an appropriate distance from an object or place.
- Getting updates: When developing AR applications, it is essential to incorporate AR supporting platforms' ability to connect with internet. This ability facilitate getting updated information from supporting databases such as, traffic information and street view information (*Metro paris subway (subway) iPhone and iPod touch application*.2010).

- Translation ability: AR technology offers opportunities for overcoming communication related barriers. For this purpose, it is important for an AR application to have translation ability (text and audio) in a wide range of languages. This feature becomes more crucial in the AR applications that are used for tour guiding in a historic site given the ethnic diversity found in visitors and tourists of cultural heritage sites throughout the world (*HCI-RG: Technologies - vadinia*.2010).
- Working off-line: The ability to work offline in places where internet connection is limited or unavailable is an important feature to be employed in AR applications (*Augmented GeoTravel - features*.2010).
- Visual search: It would be very effective to incorporate visual search feature from Google's Goggle in an AR application. This will facilitate getting web information about a particular point of interest (*Google goggles (labs): Overview*.2010).

4.2 Summary

In this chapter a number of design guidelines have been developed. These guidelines could be used when building smartphone-based AR applications for cultural heritage uses, especially enriching the experience of historic site visitors. These guidelines were developed by examining AR technology, its system components, and advancements discussed in Chapter two, and also by examining various AR uses and applications in architecture, urban planning and design, and cultural heritage in Chapter three.

Chapter Five: The Arbela Layers Uncovered (ALU) Proof of concept

The design guidelines from the previous chapter facilitate developing a smartphone-based AR proof of concept in this chapter. In order to develop the proof of concept, I selected a historic site called Erbil citadel as a case study. For this purpose, this chapter looks at Erbil citadel's history, context and the primary reasons for choosing it as a case study. In the later section of this chapter, the ALU's technology and interface components are discussed. In order to assess the ALU proof of concept, in the last section of this chapter, a checklist for the assessing the design guidelines satisfaction are developed.

5.1 A Smartphone-based AR proof of concept for Erbil Citadel

In order to expand AR uses in cultural heritage more applications and prototypes need to be built and examined. The more AR prototypes that are developed; the better developers understand and examine various aspects of AR technology and interface design requirement for cultural heritage uses. As a result, AR becomes a more reliable communication technology for the exploration of historic sites than the other traditional media used for representing tangible cultural heritages.

In this research an AR proof of concept is developed for a historic site in Kurdistan Region of Iraq called Erbil citadel. Erbil citadel has witnessed the first raise of human civilization and yet stands and breaths in modern times. The uniqueness of this historic site makes it an ideal candidate for examining the use of smartphone-based AR in cultural heritage. Developing an AR proof of concept for Erbil citadel provides a useful precedent for future uses of AR technology as a vehicle for virtual tours of historic sites. It also

casts light on using AR technology for reconstructing and representing layers of information and structures of a historic site without compromising the real site.

5.2 A brief history of Erbil Citadel

Erbil Citadel Town, also known as Hawler, Arbil, and Arbela is a historic settlement that is —situated dramatically on top of an artificial 32-meters high earthen mound, and visually dominating the expansive modern city of Erbil [the capital of Kurdistan Region of Iraq]]” (*Erbil citadel - UNESCO world heritage centre*.2010). The artificial mound is the result of successive periods of occupation. Erbil citadel is located close to the area to the famous historical cave, Shanidar cave, in which Neanderthal skeletons have been found (Solecki, 1954).



Figure 5.1 Erbil citadel which locates in the center of Hawler (Erbil) city. (Gordon, 2008)

Although, the period in which Erbil has emerged is not precisely known, but — it has been grown from a prehistoric settlement together with its contemporaneous Neolithic villages that appeared in the same region, such as Mu‘allafāt on the Khazir, Mattarah, Hassuna and others all in the 7th to the 6th millenniums BC” (Deblauwe, 2005). The urban life at Erbil, however, is believed to date back to 5000 BC, and thus is — regarded as the oldest continuously inhabited settlement in the world” (*Erbil citadel - UNESCO world heritage centre*.2010). According to Kanan Mufti, general director for antiquities in KRG, —the probes sunk deep into the hill have shown evidence of layers of successive civilizations”. Thus, the current citadel stands on a hill that is still waiting for exploration (Deblauwe, 2005).

Erbil’s name appears in many historic scripts and records under different names. In the Sumerian’s holy writings (about 2000 B.C.), For instance, Erbil is referred to as Arbilum, Orbelum or Urbilum(Gordon, 2008). Erbil or Arbela has witnessed the rise and fall of many great civilizations such as, Akkadians, Sumerians, Medes, Assyrians, Persians, Greeks, Parthians, and Abbasids. Its location, —on a fertile plain at the junction of two rivers and in the foothills of the Zagros Mountains” (Deblauwe, 2005), played a key role in making it an important city for successive ancient and historic civilizations in the area. For instance, since its occupation by Assyrian, Erbil became one of the significant Assyrian centers, particularly in relation to religion. Erbil was a centre for the worship of the Assyrian goddess Ishtar (Gordon, 2008).

Internationally, Erbil is well known for witnessing the decisive battle, Gaugamela or Arbela battle, between Alexander the Great and King Darius III (the Persian Empire

King) in 331 BC (Heckel & Yardley, 2004). The battle took place in Gaugamela, “a village beside the river Bumodus 75 miles west of Arbela” (Sheppard, 2008), and in this battle Alexander defeated King Darius III. This battle is considered one of the most famous battles in history as “it provided Alexander the opportunity to spread Greek civilization throughout vast territories while establishing more than twenty new cities that became regional trade and cultural centres” (Lanning, 2005). Erbil’s significance continued after Alexander’s battle and the city became an important centre for many successive civilizations and empires.



Figure 5.2 Alexander's route to Babylon through Arbela. (Sheppard, 2008)



Figure 5.3 A 17th century painting of the battle of Gaugamela by Jan Bruegel the Elder. (Sheppard, 2008)

Today, Erbil citadel stands on an elliptical-shaped mound that is built by successive layers of settlements with an area of about 10 hectares. The new city's growth around the citadel has turned this historic monument into an excellent landmark, as UNESCO indicates –“The Citadel is today one of the most dramatic and visually exciting cultural sites not only in the Middle East but also in the world” (*Erbil citadel - UNESCO world heritage centre*.2010). Throughout the past millenniums, the citadel has been continuously inhabited and expanded vertically. This has resulted in burying the long history of Erbil and its tangible heritage under the current existing fabric and structures that goes back to only several hundred years ago.

The existing dense fabric of Erbil citadel composed mainly of ~~tr~~traditional courtyard houses and built in ochre-colored bricks. In addition, there are several important public buildings such as 3 mosques, a public bath (Hammam), 7 historic graves, two gates, and several open urban spaces” (*Erbil citadel - UNESCO world heritage centre*.2010). Some houses (330 of a total of 500 houses), public buildings, and urban spaces, ~~h~~ave authentic cultural values and show remarkable ingenuity and resourcefulness in local architectural traditions” (*Erbil citadel - UNESCO world heritage centre*.2010).

In Summary, Erbil Citadel

~~r~~epresents a unique example of a town that has nested on top of a hill for several millennia and has, since then, not only accumulated numerous and important archaeological layers within but also possesses a very important traditional architectural and urban heritage. As such, it deserves to be included on the Tentative List of World Heritage Sites and hopefully, later on, on the World Heritage Sites List.”

(*Erbil citadel - UNESCO world heritage centre*.2010)

5.3 Why develop a smartphone-based AR proof of concept for Erbil Citadel?

The significance of tangible cultural heritages such as historic sites and buildings cannot be understood only by looking at them, but also from decoding their history. In that sense

AR, as a location-based communication technology, offers many opportunities for extracting digital media and information out from cyberspace and library archives and augment them into real scenes of the historic sites and buildings.

Developing an on-site smartphone-based AR proof of concept for Erbil citadel renders the potential uses of AR technology for on-site exploration of historic sites interactively. It will also uncover possible approaches for on-site virtual excavation and restoration of every single layer of similar vertically expanded historic sites without compromising the sites and their accumulated historic layers (something that is impossible to achieve in the physical world).

The following are some major reasons that make Erbil citadel a good candidate when applying the knowledge gained and the design guidelines developed in this research toward developing a smartphone-based AR proof of concept for Erbil citadel:

- 1- Erbil citadel is different from most of the other historic sites in its structure and growing history. Despite its long history, today it is impossible to see the physical remains from the older successive civilization that occupied this citadel. Also, UNESCO's consideration of most of the citadel's fabric and structures that locate in the last layer as a traditional heritage, make it unviable to perform a complete archaeological excavation of the site to uncover the lower hidden, yet more valuable, layers. Developing an AR proof of concept for Erbil citadel provides tremendous opportunities for thinking about an AR interface design when

augmenting layers of historic information and 3D objects that no longer have corresponding physical remains or any other form of visual cues on the historic sites.

- 2- Erbil citadel's current tangible structures don't indicate the long age of the citadel. This might lead to misunderstandings and missing the historic treasures that are lying beneath the current structures. As such, AR can enrich the visitor's experience by augmenting a 3D representation of historic objects, people, and buildings from ancient time that are no longer available on Erbil citadel's site.
- 3- In 2002 the World Monument Fund (WMF) in New York included Erbil citadel as one of the 100 most endangered cultural sites in the world (*Architectural heritage*.2010). Using an innovative technology like AR for on-site touring encourages preserving the citadel and also documenting some parts of the citadel in virtual world.
- 4- The recent attempt by the Kurdistan Regional Government (KRG) to preserve and revitalize this unique town, by preparing a "*Conservation Master Plan*" for the citadel under UNESCO's supervision, is aiming to attract more tourists around the world to explore and learn about this forgotten, but outstanding historic monument. Tourist groups have already started to visit this historic site. As such using such effective technology, AR, for communicating this lost history would contribute to making Erbil citadel's on-site exploration an unforgettable

experience. Also it could become an effective learning tool about one of the most continuously inhabited settlements in the world.

- 5- Erbil citadel's documents, resources, and archives are not well organized and collected. Also Political suppression placed by the Iraqi regime, prior to establishing KRG in 1991 forbade archaeological excavation and full documentation of the historic sites in Kurdistan Region. As a result, a visitor or researcher needs to spend a lot of time in searching for Erbil citadel's records, archives, and documents. Adapting AR paves the path for establishing a central online database for all Erbil citadels' historical and archival related records and information. The central database facilitates the process of finding Erbil citadel's documents and records it in a timely efficient way. The database can become the main source for supplementing Erbil citadel's AR application with a wide range of information during on-site visiting. It can also be updated according to the latest archaeological findings when the archaeological excavation of some parts of the citadel starts in the near future. Finally, the database can be used for recording visitors' experience which can later be analyzed for marketing purposes.
- 6- After an on-site visit it became visible that Erbil citadel lacks advanced technology used for guiding tourists, which enables visitors to fully enjoy their learning about the citadel's hidden history. AR technology enables visitors of the citadel to not only overcome communication barriers but also personalize their experience by selecting the information they would like to obtain in an effective way.

5.4 ALU Proof of concept

ALU, ARBELA Layers Uncovered, is an AR proof of concept developed for Erbil citadel in this research. ALU aims to uncover, retrieve, and represent Erbil citadel's memory and history for on-site visitors and researchers in an innovative way. The proposed proof of concept is an intervention for the design guidelines developed in this research with consideration given to the unique context of Erbil citadel and its long history. The proof of concept is a mobile phone-based AR to be run on smartphones' OS like iPhone and Android. This project could potentially be sponsored and adapted by the Ministry of Culture that supervises the archaeological, historic, and heritage sites in the Kurdistan Region.



*Figure 5.4 Running ALU application on an iPhone.
(Apple iPhone 3G.2010)*



*Figure 5.5 Using ALU for on-site visiting of Erbil citadel.
Background Photo (HansMast.com: Iraq – erbil.2010).*

ALU aims to provide visitors of Erbil citadel with historic and heritage information by augmenting various representation techniques, such as text, pictures, and 3D models, into Erbil citadel's real site; thus it works as an audiovisual independent tour guide for visitors. The information compiled and presented in the proof of concept is extracted from various records of Erbil citadel such as, books and archives in Kurdish, English, and Arabic languages. ALU's main sources of information are provided from HCECR's database.

5.4.1 ALU Technology

ALU uses smartphone technologies (such as iPhone and Android) hardware and OS that were suggested in the design guidelines. smartphone is also a suitable and handy technology for on-site navigation of Erbil citadel due to its wide availability in market in Kurdistan . As a result, users of smartphones like iPhone and Android can run ALU.

5.4.2 ALU Interface design

In addition to adapting most of the interface design suggestions found in the design guidelines, ALU's interface also reflects on the opportunities and challenges accompanying Erbil citadel's context. The information augmented in ALU's interface is categorized into three main modes; history, heritage, and database (See Figure 4.6). These categories are appropriate due to the type and amount of the current available information and also the main documentation categories of Erbil citadel in HCECR's database. In addition to the three mode buttons, there is also a status bar in the interface. The status bar includes a "Home" button, a compass, and an audio button. The user has the option to activate the audio guide by pressing the audio button any time it appears on the screen. This would help people with visual disabilities. In ALU, the interface components appear on top of the camera view from the smartphone; thus the camera becomes activated once the ALU is launched. In its current stage, ALU provides users with the option of taking the tour in Kurdish, English, Italian, French, Spain, and Arabic languages; thus the system has been setup and designed to present information (text and audio) in six languages. A preferred language can be selected in the main interface after launching the ALU from the smartphone.



*Figure 5.6 ALU's main interface and the three modes.
Background Photo (Panoramio - photo of citadel of erbil.2008).*



*Figure 5.7 A brief about the content of each mode appears after tapping the screen once.
Background Photo (Panoramio - photo of citadel of erbil.2008).*

5.4.2.1 History:

The History mode augments and provides historical information about Erbil citadel's 7000 years. Historic events under successive civilizations which could be included are, Akkadians, Sumerians, Medes, Assyrians, Persians, Greeks, Parthians, Abbasids, and many others that occupied the citadel throughout history. The information provided in this mode interface is organized according to a timeline. The information comes in various forms such as text, paintings, and audio. Despite the lack of detailed historic information in HCECR's database at this moment, this project assumes accessing most of the historic information using the HCECR's database. ALU should also facilitate accessing historic information using Google and some other search engines in database mode. At this stage, due to a lack of archaeological excavations, the historic information is not geographically tagged (non location-based) to Erbil citadel; thus, they can be reached anywhere on or off the site.

Once the history mode is activated, a group of buttons appear on the screen. Each button provides information about a historic period or event from Erbil citadel's long history. The user can find information in text and image about a historic period or event by pressing a corresponding button.



Figure 5.8 The main interface in history mode where the historic information is arranged according to a timeline.

Background Photo (*Erbil citadel-SkyscraperCity*.2010).



Figure 5.9 An illustration for the interface content after tapping Arbela Battle in the history mode.

Background Photo (*Erbil citadel-SkyscraperCity*.2010).



Figure 5.10 An illustration of the user's ability to select and zoom-in on an image. Background Photo (Erbil citadel-SkyscraperCity.2010).

5.4.2.2 Heritage:

This mode provides information about the traditional and local architecture of the buildings (houses and public buildings) or elements which today stand on the Erbil citadel. It also provides information about Erbil citadel's urban form evolution. Most of the buildings located in the citadel are from the last few centuries of Erbil citadel site's 7000 years and have historical value that is worth preserving, according to UNESCO World Heritage. The information provided in the architectural heritage mode is location-based; thus are geographically tagged to Erbil citadel's site. A user can access various sources of information while navigating through the citadel. The information in this mode facilitates location-based learning when the user gets information about the surrounding structures and objects. The user can also use re-construct function to see missing

buildings or components where there is a sign indicating this. The heritage mode information can be viewed and tagged on Erbil citadel's map as well as in the 3D camera view of Erbil citadel. Once activated the heritage mode buttons appear (2D view, 3D view, and re-construct buttons) on the screen (See Figure 4.11).

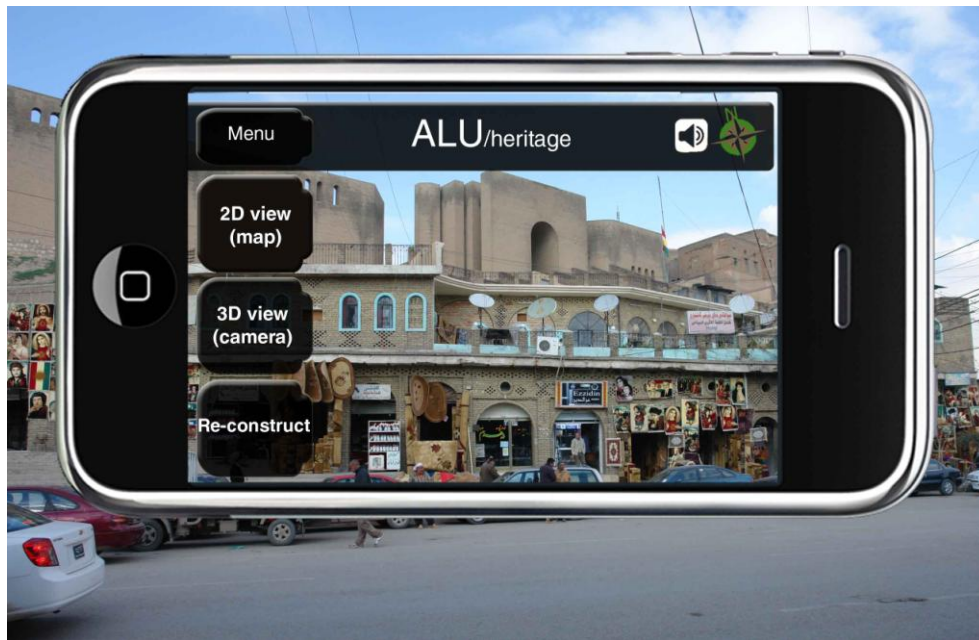


Figure 5.11 The main interface in heritage mode where the three functions appear. Background Photo by Karim Shekhany.

The 2D view function locates the user on the Google map using the “My location” feature from Google Maps for mobile. If the user is close to or in the citadel, then a number of pins appear on the Erbil citadel's map that appears from the smartphone's screen (See Figure 4.12). The pins indicate information augmented to different buildings and components in the citadel. A user can tap close by pins and get information assigned to the pins while in the map view (2D view). The map view can also be used to navigate to points of interest.



Figure 5.12 Close by pins appears on Erbil citadel's map when a user activates the 2D view function on-site. The blue circle indicates user's location.
Background Photo by Karim Shekhany.

The user can also get the information with a real view of the surroundings by selecting the 3D view button on the screen and holding the phone's camera toward the surrounding real scenes (See Figure 4.13). Circles then appear tagged to the surrounding buildings and structures. Similar to the 2D view, a user needs to tap the circles to get more detailed information about a particular augmented building or structure. The size of the circles differs in relationship to the user's location and increases as the user gets closer to the targets. Also, the color of the circles becomes lighter once they are tapped to denote activation (See Figure 4.14).



Figure 5.13 Obtaining information in camera view in heritage mode.
Background Photo by Karim Shekhany.



Figure 5.14 Information appears after a circle is tapped in heritage/3D view mode.
Background Photo by Karim Shekhany.

The Re-construct button in the heritage mode enables users to see archival pictures or 3D model reconstructions of buildings and structures or parts of them that are no longer available in their location or have changed over time and are aligned in their original location. Circles that indicate the availability of this feature appear on the screen only when a user gets closer to the areas where the 3D model or image reconstruction of a building or structure is available (See Figure 4.15).

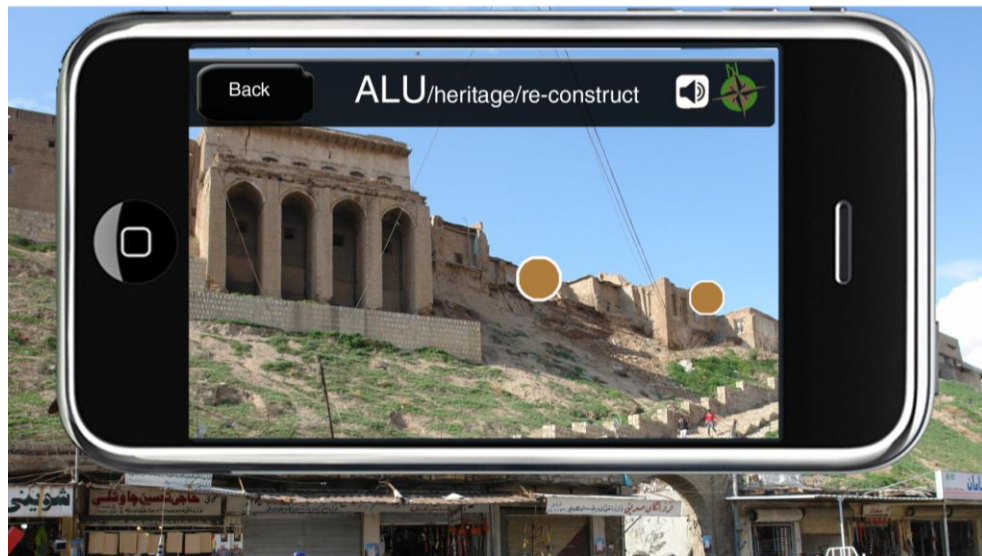


Figure 5.15 Circles indicating availability of re-construction in heritage mode.
Background Photo by author.

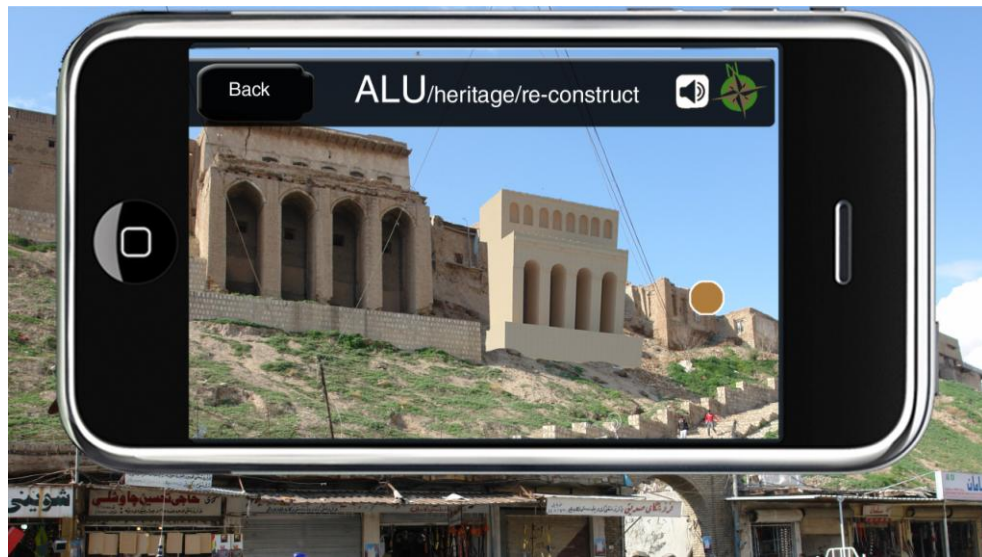


Figure 5.16 3D model of a reconstructed part appear in its original location as the user taps the indicating circle (illustration).
Background Photo by author.

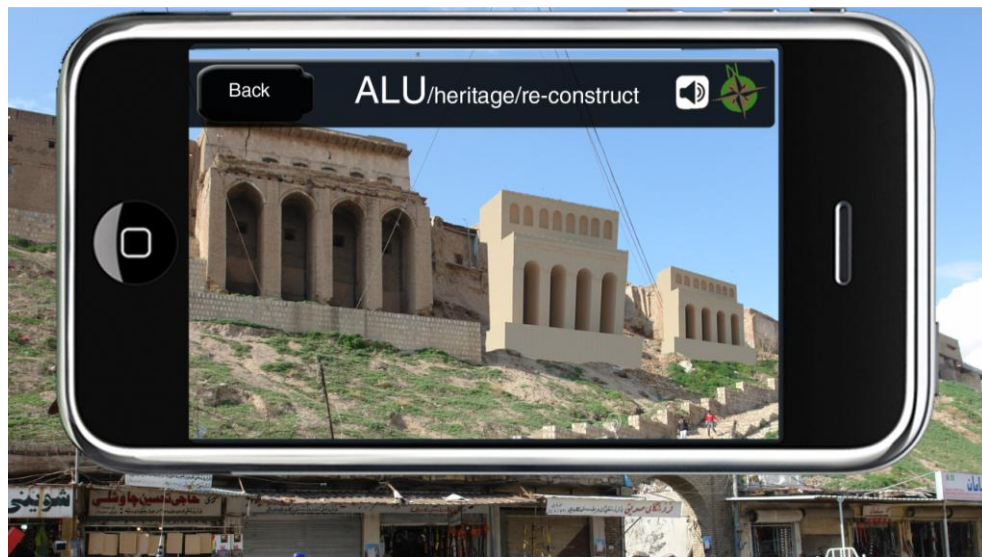


Figure 5.17 The user can tap more than a circle on the screen to see the re-construction.
Background Photo by author.

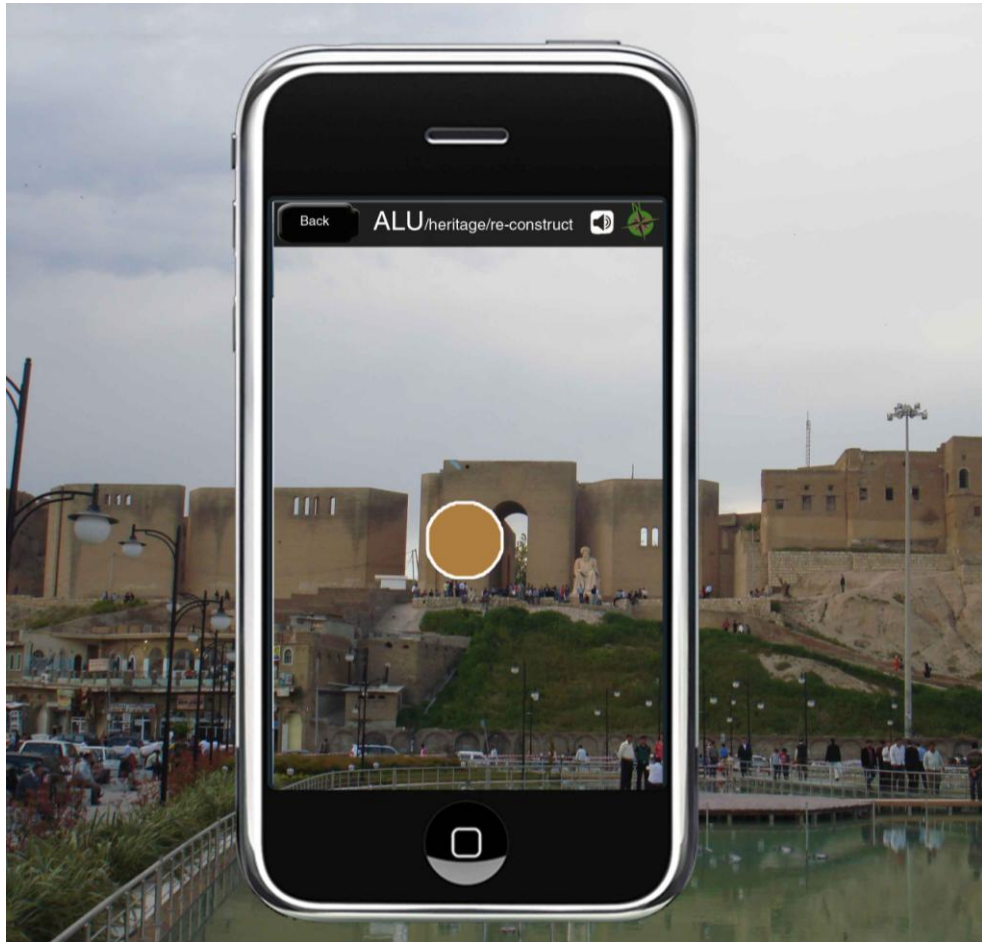


Figure 5.18 An indication of the ability to re-construct Erbil citadel's main gate in heritage/re-construct mode.
Background Photo (*Panoramio-kurdistan-hawler castle.2010*).



Figure 5.19 Re-constructing Erbil citadel's main gate in 1918 using the image alignment technique.

Background Photo (*Panoramio-kurdistan-hawler castle.2010*).

5.4.2.3 Database:

The Database mode allows the user to connect to various websites and databases that have Erbil citadel's images, archives, and information, including the HCECR webpage.

This mode works on and off the citadel's site. The HCECR is officially working on documenting the citadel, and has presented documentary and archival information of various aspects of Erbil citadel in HCECR webpage. This mode resembles a search

engine page in which a user can get more detailed information and resources that are not available in the other two modes.

In this mode, the user can access Google's Goggle for image recognition. Goggle facilitates instantaneous query of information about any point of interest in any of the two previous modes without necessarily navigating back and forth in the menu. Using image recognition as a search engine is an excellent opportunity for the users of ALU to get an informed touring experience. At this time, Goggle works only on Android smartphones. The database mode also facilitates access to Google translator that would help in translating the information obtained from the internet to a wide range of languages. Visitors of Erbil citadel can record their experience and impression and also can upload their inputs as image and text into the HCECR database. The inputs can then be used for researching or entertainment purposes.



Figure 5.20 Accessing HCECR webpage in database mode for finding more information.
Background Photo by Karim Shekhany.

In addition to working as an independent tour guide for communicating Erbil citadel's history, ALU has potential uses by researchers. As discussed previously, Erbil citadel doesn't have a central online database that includes all of its documents and the archives

are not well collected and organized. ALU encourages and proposes collecting Erbil citadel's archives and documents into a central database. This will help researchers to find information and documents about the citadel very quickly; thus, saving money and time. The online database also makes it possible to obtain Erbil citadel's information in different languages.

ALU aims to provide visitors with a vast resource without the need for any conventional tour guide. However, more location-based information needs to be included in the proof of concept before ALU reaches its full potential. Currently, the lack of full documentation of Erbil citadel has created a challenge for developing a comprehensive touring guide in this research. Some of the features of ALU such as the 3D view are only exploration of the possibilities and is a demonstration of what can be achieved. With more location-based information and documentation of the citadel it will be possible to create a tour guide function in ALU. The tour guide function helps visitors setup the tour in terms of start and end points, tour duration, and objective.

The uniqueness of Erbil citadel as a vertically expanded historic site and AR's capabilities in adding or removing objects from a scene provide a substantial opportunity for building interesting features in ALU. For example, it may be possible to build an on-site AR game for demonstrating the major historic events which took place at or close to Erbil citadel such as, Arbela or the Gaugamela battle. This could be used for educational purposes.

The cultural heritage applications of smartphone-based AR are boundless. On-site accessing information is one of the many opportunities that come with the use of AR technology. Interactively finding information in the right time and place reveal very promising potentials in AR uses in cultural heritage. With AR a visitor can easily and effectively find out archival and documentary information that otherwise would be buried in the basement of a museum or on a shelf in a library. In a case like Erbil citadel, AR applications will help exhibiting the memory and rich history of a monument which has stood the test of time in an appealing way to its visitors.

5.5 Evaluating the Proof of Concept Design

The ALU proof of concept has adapted and satisfied almost all of the suggestions proposed in the developed design guidelines. The reason for not adapting the remaining guidelines has to do with some limitations associated with a lack of technical resources and a lack of Erbil citadel's full documentation. It is aimed to adapt all the design guidelines when building ALU application in the future. The following table measures the adaptation of the design guidelines in the ALU proof of concept.

1. Technology	ALU Proof of concept
- Light Weight Devices	Yes
- Reliable OS	Yes
2. Interface	ALU Proof of concept
2.1 Interface content	
- Variety	Yes
- Visual cues	Yes
- Video usages	No
- Audio visual usages	Yes
- 3D model augmentation	Yes
2.2 UI Design	
- Layering information	Yes
- Appropriate size	Yes
- Legibility	Yes
- Easy Navigation and accessibility	Yes
2.3 Interactivity	
- Flexibility	No
- Interaction	Yes
- Exploration	Yes
- Spatial AR (Projection)	No
2.4 Connectivity	
- Ability to geotag	Yes
- Getting updates	No

- Translation ability	Yes
- Working off-line	No
- Visual search	Yes

Total Yes = 15

Total No = 5

5.6 Summary

In this chapter the ALU proof of concept was analyzed. By applying the design guidelines from Chapter four and also learning about Erbil citadel's context it was possible to build a proof of concept that facilitate independent on-site touring of Erbil citadel. The discussion included the history of Erbil citadel and its context which has established the reasons for choosing Erbil citadel as a case study in this research. Finally, the design guidelines checklist provided a tool for assessing ALU proof of concept's adaptation of the design guidelines.

Chapter Six: Conclusion

This chapter includes a summary of AR technology and its uses in cultural heritage. It also includes a summary of this research's accomplishments followed by a brief overview of possible future work in this area based on the findings from this research.

6.1 Summary

The rapid and continuous expansion of AR's supporting technologies, including the recent shifts to ubiquitous mobile phones, and applications, contribute in developing a wide adaptation of AR across many fields including cultural heritage, tourism management, urban planning, and architectural history. AR has already attracted cultural heritage institutions to include it with their tool kits. In fact, AR is becoming a novel technology in cultural heritage for on-site visiting due to the convenience and opportunities this technology provides. In this sense, it is predicted that AR will soon replace all of the traditional multimedia and other representation techniques that are used for exhibiting the invisible value of a historic site or building.

The ability to obtain information on-site, while visually decoding cues, about a historic site or building supports an excellent location-based learning experience. AR applications, prototypes, and proof of concepts like ALU enable experiencing cultural heritage sites in a revolutionary, interactive, and more personalized way.

6.2 Conclusions

The four objectives set for this research were accomplished in different ways. The extensive literature review for AR technology and its system components, challenges, and advancements discussed in Chapter two have uncovered AR's state-of-the-art technologies. Exploring AR and its features for cultural heritage uses including on-site visiting of historic sites has been achieved by examining AR uses and applications in architecture, urban planning and design, and cultural heritage in Chapter three. The knowledge gained from Chapter two and three was then employed to develop design guidelines, the third objective of this research, in Chapter four. These design guidelines help developing smartphone-based AR applications that serve as an independent tour guide during on-site visits of historic sites. The fourth objective is then accomplished when ALU was developed in Chapter five.

6.3 Future Research

As the demand for continuous access to information increases, so do AR applications across many fields including cultural heritage and historic resource management. At the same time, the increasing adaptation of AR technology in cultural heritage with its diverse resources and requirements introduces new challenges for AR researchers and application developers. Therefore, there is significant room for future research in AR's interface component and design and supporting technologies.

In future research, it is possible to conduct surveys or focus groups with real users in order to determine the validity of the guidelines developed in this research. It is also

possible to develop an interactive website that allows users to navigate and explore interface components of an AR proof of concept like ALU, and also collect inputs and feedback from users .

Also, collecting and presenting archaeological and historic information in an AR application are challenges that face AR researchers. Investigating methods and techniques for dealing with these challenges is crucial for AR developers. Also, studying AR's ability to remove objects from a real scene and reconstructing buildings and environments are two interesting areas to explore in the AR applications in cultural heritage. Further research is also required in AR's user interface design for on-site visits given the size of the screen in smartphones. Building supporting databases for historic sites would also support building effective AR applications for on-site tour guides.

Another area of research could be building a beta version of smartphone-based AR applications in cultural heritage, including ALU, and testing them with real users. This study may uncover interesting reactions to AR use as an independent tour guide during on-site visits; thus studying human computer interaction in AR applications for historic resource management.

The shift in AR's platform from HMD to smartphone uncaps many technological and interface challenges for AR application developers. The various OS in different smartphone devices contributes in creating a variation in accessing the available online resources such as, Layar and Goggle that support building interesting AR applications.

This would also be a potential area for further investigation. With the availability of different smartphone technologies, further research could be focused on advancing smartphone's capability for accommodating AR's ever growing features. Developing AR online products could also be another possibility for advancing AR technology. Furthermore, in the foreseeable future, it will be possible for AR to move off from smartphones screens onto futuristic sunglasses. Wrap 920AV pair of sunglasses is the first step toward this shift in AR's platform. With this tremendous technological, interface, and human computer interaction opportunities come to surface that need to be explored.

References

- Apple announces the new iPhone 3GS.* (2010). Retrieved 05/20, 2010, from <http://www.apple.com/pr/library/2009/06/08iphone.html>
- Apple enhances revolutionary iPhone with software update.* (2010). Retrieved 05/20, 2010, from <http://www.apple.com/pr/library/2008/01/15iphone.html>
- Compare iPhones 3GS and iPhone 3G.* (2010). Retrieved 05/20, 2010, from <http://www.apple.com/iphone/compare-iphones/#footnote-2>
- Zeitgeist .* (2010). Retrieved 03/20, 2010, from <http://dictionary.reference.com/browse/Zeitgeist>
- 555 KUBIK facade projection - today and tomorrow.* (2010). Retrieved 06/05, 2010, from <http://www.todayandtomorrow.net/2009/07/23/555-kubik-facade-projection/>
- About 2D code.* (2010). Retrieved 06/04, 2010, from <http://www.denso-wave.com/qrcode/aboutqr-e.html>
- Acrossair/ about.* (2010). Retrieved 05/7, 2010, from <http://www.acrossair.com/about.htm>
- Alternate_reality.jpg.* (2010). Retrieved 08/21, 2010, from http://cache.gizmodo.com/gadgets/images/alternate_reality.jpg
- Apple - iPhone 3GS - size, weight, battery life, and other specs.* (2010). Retrieved 02/28, 2010, from <http://www.apple.com/iphone/iphone-3gs/specs.html>

Apple- iPhone. (2010). Retrieved 05/20, 2010, from <http://www.apple.com/iphone/why-iphone/>

Apple iPhone 3G. (2010). Retrieved 08/24, 2010, from http://gsmdepot.ca/catalog/popup_image.php?PID=38

ARCHEOGUIDE. (2002). Retrieved 6/18, 2010, from <http://archeoguide.intranet.gr/project.htm>

Architectural heritage. (2010). Retrieved 08/03, 2010, from <http://www.erbilcitadel.org/ArchitecturalHeritage/index1.php>

Arghire, I. (2010). *Introducing google goggles, visual search on handsets using a phone's camera.* Retrieved 05/5, 2010, from <http://news.softpedia.com/news/Introducing-Google-Goggles-Visual-Search-on-Handsets-129103.shtml>

Artintelligence: Pablo valbuena, augmented sculpture. (2010). Retrieved 08/24, 2010, from <http://artintelligence.net/review/?p=343>

ARToolKit. (n.d.). Retrieved 12/27, 2009, from <http://www.hitl.washington.edu/artoolkit/>

Augmented GeoTravel - features. (2010). Retrieved 05/31, 2010, from <http://www.augmentedworks.com/en/augmented-geotravel/features>

Augmented reality /Projects. (2010). Retrieved 05/28, 2010, from <http://virtual.vtt.fi/virtual/proj2/multimedia/index.html>

Augmented reality GPS tour beyond tomorrow. . (2007).[Video/DVD] Retrieved from

<http://www.youtube.com/watch?v=5JZLWMHrenY>

Augmented reality is a fit for retailers. (2010). Retrieved 06/03, 2010, from

http://threeminds.organic.com/2009/12/augmented_reality_is_a_fit_for.html

Autodesk - building information modeling - about BIM. (2010). Retrieved 05/27, 2010,

from <http://usa.autodesk.com/company/building-information-modeling/experience-bim>

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001).

Recent advances in augmented reality. *Computer Graphics and Applications, IEEE*, 21(6), 34-47. doi:10.1109/38.963459

Azuma, R. (1997). A survey of augmented reality. *In Presence: Teleoperators and Virtual Environments*, 6(4), 355-385.

Azuma, R. (2005). *Registration errors in augmented reality*. Retrieved 12/21, 2009, from

http://www.cs.unc.edu/~azuma/azuma_AR.html

Baillot, Y., Julier, S. J., Brown, D., & Livingston, M. A. (2003). A tracker alignment framework for augmented reality. Paper presented at the *Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality*, 142-150.

Bajura, M., & Neumann, U. (1995). Dynamic registration correction in video-based augmented reality systems. *Computer Graphics and Applications, IEEE*, 15(5), 52-60. doi:10.1109/38.403828

- Baltsavias, E., Gruen, A., Van Gool, L., & Pateraki, M. (Eds.). (2006). *Recording, modeling and visualization of cultural heritage*. London, UK: Taylor & Francis Group.
- Bell, B., Feiner, S., & Höllerer, T. (2001). View management for virtual and augmented reality. Paper presented at the *Proceedings of the 14th Annual ACM Symposium on User Interface Software and Technology*, Orlando, Florida. 101-110.
doi:<http://doi.acm.org/10.1145/502348.502363>
- Bier, E. A., Stone, M. C., Pier, K., Buxton, W., & DeRose, T. D. (1993). Toolglass and magic lenses: The see-through interface. Paper presented at the *SIGGRAPH 93, Computer Graphics Annual Conference Series, ACM*, Anaheim, CA. 73-80.
doi:<http://doi.acm.org/10.1145/166117.166126>
- Billinghurst, M., Grasset, R., & Looser, J. (2005). Designing augmented reality interfaces. *ACM SIGGRAPH Computer Graphics*, 39(1), 17-22.
doi:<http://doi.acm.org/10.1145/1057792.1057803>
- Bimber, O. (2006). Modern approaches to augmented reality: Introduction to current approaches. Paper presented at the *ACM SIGGRAPH 2006 Courses*, Boston, Massachusetts. doi:<http://doi.acm.org/10.1145/1185657.1185797>
- Bimber, O., & Raskar, R. (2005). *Spatial augmented reality: Merging real and virtual worlds*. Wellesley, MA: A K Peters Ltd.
- BlueScreenVirtualSet.jpg*. (2010). Retrieved 08/22, 2010, from <http://www.csudh.edu/televisionarts/images/BlueScreenVirtualSet.jpg>

- Bouman, O. (2005). Building terminal _For an architecture without objectness. In G. Flachbart, & P. Weibel (Eds.), *Disappearing architecture: From real to virtual to quantum* (pp. 258-263). Basel, Boston, Berlin: Birkhauser - Publishers for Architecture.
- Brandon, J. (2010). *Augmented reality past, present and future: How it impacts our lives*. Retrieved 06/02, 2010, from <http://www.digitaltrends.com/features/ge-augmented-reality-iphone-app-past-present-and-future-how-it-impacts-our-lives/>
- Broll, W., Lindt, I., Ohlenburg, J., Wittkämper, M., Yuan, C., Novotny, T., Fatah gen. Schieck, A., Mottram, C., & Strothmann, A. (2004). ARTHUR: A collaborative augmented environment for architectural design and urban planning. *JVRB - Journal of Virtual Reality and Broadcasting*, 1(1), 1-10. Retrieved from <http://www.jvr.org>
- Carver, B. (2003). Marketing and advertising. *Journal of Business & Finance Librarianship*, 8(3), 245-252.
- CGV - computer graphics and knowledge visualization. (2010). Retrieved 08/21, 2010, from http://v3d2.tu-bs.de/CGV/VRLab/Dave#public_demo
- The chroma key effect. (2010). Retrieved 02/17, 2010, from http://www.borisfx.com/tutorials/chroma_key.php
- Comport, A. I., Marchand, E., & Chaumette, F. (2003). A real-time tracker for markerless augmented reality. Paper presented at the *Mixed and Augmented Reality, 2003. Proceedings. the Second IEEE and ACM International Symposium*, 36-45.

Connecting augmented reality to outdoor advertising. (2010). Retrieved 08/22, 2010,

from http://tabworldmedia.com/TAB_media_campaigns_Disney.html

Contactum. (n.d.). Retrieved 08/21, 2010, from [http://www.augmented-](http://www.augmented-reality.com/technology.php)

[reality.com/technology.php](http://www.augmented-reality.com/technology.php)

Cultural tourism : UNESCO-CULTURE. (2008). Retrieved 6/15, 2010, from

<http://portal.unesco.org/culture/en/ev.php->

[URL_ID=36700&URL_DO=DO_TOPIC&URL_SECTION=201.html](http://portal.unesco.org/culture/en/ev.php-URL_ID=36700&URL_DO=DO_TOPIC&URL_SECTION=201.html)

Damala, A., Cubaud, P., Bationo, A., Houlier, P., & Marchal, I. (2008). Bridging the gap

between the digital and the physical: Design and evaluation of a mobile augmented

reality guide for the museum visit. Paper presented at the *DIMEA '08: Proceedings*

of the 3rd International Conference on Digital Interactive Media in Entertainment

and Arts, Athens, Greece. , 349 120-127.

doi:<http://doi.acm.org/10.1145/1413634.1413660>

Deblauwe, F. (2005). *The iraq war & archaeology archive 65.* Retrieved 6/19, 2010,

from <http://iwa.univie.ac.at/iraqarchive65.html>

Digitalexperience. (2010). Retrieved 06/05, 2010, from

<http://digitalexperience.cavi.dk/?paged=3>

Doenges, P. K. (1985). Overview of computer image generation in visual simulation.

Paper presented at the *SIGGRAPH '85 Course Notes #14 on High Performance*

Image Generation Systems, San Francisco, CA. (14)

Douangboupha, P. (2009). *Location Tracking techniques*. Retrieved 01/20, 2010, from

<http://chw.rit.edu/blog/?p=195>

Dreaming architecture. (2010). Retrieved 08/24, 2010, from

<http://www.idsgn.org/posts/dreaming-architecture/>

Eccleston-Brown, O. (2010). *BBC - old london seen with new eyes thanks to mobile apps*.

Retrieved 6/18, 2010, from

http://news.bbc.co.uk/local/london/hi/things_to_do/newsid_8700000/8700410.stm

Energy Passages - media art installation. (2004). Retrieved 08/24, 2010, from

http://energie-passagen.de/presse_engl.html

Epstein, M., Garcia, C., & dal Fiore, F. (2003). History unwired: Venice frontiers

[Abstract].

Epstein, M., & Vergani, S. (2006). History unwired: Mobile narrative in historic cities.

Paper presented at the *AVI '06: Proceedings of the Working Conference on*

Advanced Visual Interfaces, Venezia, Italy. 302-305.

doi:<http://doi.acm.org/10.1145/1133265.1133327>

Erbil citadel - UNESCO world heritage centre. (2010). Retrieved 6/19, 2010, from

<http://whc.unesco.org/en/tentativelists/5479/>

Erbil citadel-SkyscraperCity. (2010). Retrieved 08/24, 2010, from

<http://www.skyscrapercity.com/showthread.php?p=53875493>

EyeTour puerto rico. (2009). Retrieved 08/22, 2010, from

<http://eyetour.com/blog/tag/iphone/>

Feiner, S., MacIntyre, B., Hollerer, T., & Webster, A. (1997). A touring machine:

Prototyping 3D mobile augmented reality systems for exploring the urban environment. Paper presented at the *Proceedings of 1st IEEE International Symposium on Wearable Computers (ISWC 97)*, Cambridge, MA. 74-81. doi:10.1109/ISWC.1997.629922

Feiner, S. K., & Höllerer, T. H. (2004). Mobile augmented reality. In A. Hammad, & H. A. Karimi (Eds.), *Telegeoinformatics: Location-based computing and services* (pp. 221-258). Boca Raton, Florida: CRC Press LLC.

Filippini-Fantoni, S., & Proctor, N. (2007). Evaluating the use of mobile phones for an exhibition tour at the tate modern: Dead end or the way forward? Paper presented at the *EVA London Conference*, London, UK. 8.1-8.12. Retrieved from <http://www.eva-conferences.com/sites/eva-conferences.com/files/public/active/0/08-Filippini-Fantoni.pdf>

Fua, P., & Lepetit, V. (2007). Vision based 3D tracking and pose estimation for mixed reality. In M. Haller, M. Billinghurst & B. Thomas (Eds.), *Emerging technologies of augmented reality: Interfaces and design* (pp. 1-22). Hershey, PA: Idea Group Inc.

- Fuld, H. (2010). *Layar for android leads the way in augmented reality apps*. Retrieved 08/22, 2010, from <http://blog.appboy.com/2009/12/layar-for-android-leads-the-way-in-augmented-reality-apps/>
- Geiger, C., Kleinnjohann, B., Reimann, C., & Stichling, D. (2001). Mobile AR4ALL. Paper presented at the *Proceedings of the 2nd IEEE and ACM International Symposium on Augmented Reality (ISAR 2001)*, New York. 181-182.
doi:10.1109/ISAR.2001.970532
- Gleue, T., & Dahne, P. (2001). Design and implementation of a mobile device for outdoor augmented reality in the archeoguide project. Paper presented at the *VAST '01: Proceedings of the 2001 Conference on Virtual Reality, Archeology, and Cultural Heritage*, Glyfada, Greece. 161-168.
doi:<http://doi.acm.org/10.1145/584993.585018>
- Global positioning system*. (n.d.). Retrieved 03/10, 2010, from <http://www.gps.gov/>
- Gomez, J. -. V., Simon, G., & Berger, M. -. (2005). Calibration errors in augmented reality: A practical study. Paper presented at the *Mixed and Augmented Reality, 2005. Proceedings. Fourth IEEE and ACM International Symposium on*, Lorraine, France. 154-163. doi:10.1109/ISMAR.2005.23
- Google goggles (labs): Overview*. (2010). Retrieved 05/5, 2010, from <http://www.google.com/support/mobile/bin/answer.py?hl=en&answer=166331>
- Google goggles for android*. (2010). Retrieved 08/22, 2010, from <http://www.google.com/mobile/goggles/#landmark>

Google maps API family. (2010). Retrieved 05/5, 2010, from

<http://code.google.com/apis/maps/>

Google maps for mobile. (2010). Retrieved 05/5, 2010, from

<http://www.google.com/mobile/maps/#p=default>

Google (Producer), & . (2007, 11/27). *Google maps for mobile with my location (beta)*.

[Video/DVD] Retrieved from

http://www.youtube.com/watch?v=v6gqipmbcok&feature=player_embedded#!

Gordon, J. (2008). *Erbil (hawler) citadel, iraqi kurdistan* | *NowPublic photo archives*.

Retrieved 6/19, 2010, from <http://www.nowpublic.com/world/erbil-hawler-citadel-iraqi-kurdistan>

Green, T. (2010). Think it overlay. *Mobile Entertainment (ME) for Everyone in Mobile Content*, (64), 14-15.

Gutiérrez A., M. A., Vexo, F., & Thalmann, D. (2008a). Cultural heritage. *Stepping into virtual reality* (pp. 173-180). Lausanne, Switzerland: Springer-Verlag London Limited.

Gutiérrez A., M. A., Vexo, F., & Thalmann, D. (2008b). Mixed realities. *Stepping into virtual reality* (pp. 117-122). Lausanne, Switzerland: Springer-Verlag London Limited.

Gutiérrez A., M. A., Vexo, F., & Thalmann, D. (2008c). *Stepping into virtual reality*. Lausanne, Switzerland: Springer-Verlag London Limited.

Haller, M., Billinghurst, M., & Thomas, B. (Eds.). (2007). *Emerging technologies of augmented reality: Interfaces and design*. Hershey, PA: Idea Group Inc.

HansMast.com: Iraq – erbil. (2010). Retrieved 08/24, 2010, from

<http://hansmast.com/2008/06/iraq-erbil-part-1/>

Harrington, T. (2008). iPhone user interface design. Paper presented at the *Colorado Software Summit 2008*, Monument, CO. Retrieved from

<http://www.softwaresummit.com/2008/speakers/presentations/HarringtoniPhoneUserInterfaceDesign.pdf>

HCI-RG: Technologies - vadinia. (2010). Retrieved 6/17, 2010, from

<http://martinweb.zobyhost.com/hcirg/en-prod-vadinia.htm>

Heckel, W., & Yardley, J. (Eds.). (2004). *Alexander the great : Historical sources in translation*. Oxford: Blackwell Publishing Ltd.

Henrysson, A., & Ollila, M. (2003). *Augmented reality on smartphones*. Tokyo, Japan

Henrysson, A., Ollila, M., & Billinghurst, M. (2007). Mobile phone based augmented reality. In M. Haller, M. Billinghurst & B. Thomas (Eds.), *Emerging technologies of augmented reality: Interfaces and design* (pp. 90-109). Hershey, PA: Idea Group Inc.

History of mobile augmented reality. (2009). Retrieved 05/15, 2010, from

<https://www.icg.tugraz.at/~daniel/HistoryOfMobileAR/>

History unwired. (n.d.). Retrieved 6/17, 2010, from <http://web.mit.edu/frontiers/>

Holloway, R. L. (1995). Registration error analysis for augmented reality [Abstract].

How does ARToolKit work? (n.d.). Retrieved 08/22, 2010, from

<http://www.hitl.washington.edu/artoolkit/documentation/userarwork.htm>

Howard, R., & Bo-Christer, B. (2008). Building information modelling – experts' views on standardisation and industry deployment. *Advanced Engineering Informatics*, 22(2), 271-280. doi:10.1016/j.aei.2007.03.001

Intangible heritage : UNESCO-CULTURE. (2010). Retrieved 06/08, 2010, from

http://portal.unesco.org/culture/en/ev.php-URL_ID=34325&URL_DO=DO_TOPIC&URL_SECTION=201.html

International architecture database. (2010). Retrieved 05/15, 2010, from

<http://eng.archinform.net/>

Internet map. (2010). Retrieved 08/22, 2010, from

http://cealdecoate.files.wordpress.com/2006/11/internet_map_1024.jpg

iPhone human interface guidelines: Creating custom icons and images. (2010). Retrieved 08/05, 2010, from

<http://developer.apple.com/iphone/library/documentation/userexperience/conceptual/mobilehig/IconsImages/IconsImages.html>

iPhone human interface guidelines: Table views, text views, and web views. (2010).

Retrieved 08/05, 2010, from

<http://developer.apple.com/iphone/library/documentation/userexperience/conceptual/>

mobilehig/ContentViews/ContentViews.html#/apple_ref/doc/uid/TP40006556-CH12-SW1

- Izkara, J. L., Pérez, J., Basogain, X., & Borro, D. (2007). Mobile augmented reality, an advanced tool for the construction sector. Paper presented at the *Proceeding of 24th CIB W78 Conference*, Maribor, Slovakia. 453-460.
- Julier, S., Lanzagorta, M., Baillot, Y., Rosenblum, L., Feiner, S., Hollerer, T., & Sestito, S. (2000). Information filtering for mobile augmented reality. Paper presented at the *Augmented Reality, 2000. (ISAR 2000). Proceedings. IEEE and ACM International Symposium*, Munich. 3-11. doi:10.1109/ISAR.2000.880917
- Karpischek, S., Magagna, F., Michahelles, F., Sutanto, J., & Fleisch, E. (2009). Towards location-aware mobile web browsers. Paper presented at the *Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia*, Cambridge, United Kingdom. (Article No.: 18)
- Kensek, K., Noble, D., Schiler, M., & Tripathi, A. (2000). Augmented reality : An application for architecture. Paper presented at the *Proceedings of the 8th International Conference on Computing in Civil and Building Engineering*, Stanford,CA. 294-301. doi:10.1061/40513(279)38
- King, R. (2009). *Best iPhone augmented-reality apps for business*. Retrieved 05/8, 2010, from http://images.businessweek.com/ss/09/11/1102_best_iphone_reality_apps/8.htm

Kirkpatrick, M. (2010). *First iPhone augmented reality app appears live in app store.*

Retrieved 05/30, 2010, from

http://www.readwriteweb.com/archives/first_iphone_augmented_reality_app_appear_s_live_in.php

Kiyokawa, K. (2007). An introduction to head mounted displays for augmented reality. In

M. Haller, M. Billinghurst & B. Thomas (Eds.),

Emerging technologies of augmented reality: Interfaces and design (pp. 43-63).

Hershey, PA: Idea Group Inc.

Kondo, T., Shibasaki, J., Arita-Kikutani, H., Manabe, M., Inaba, R., & Mizuki, A.

(2007). Mixed reality technology at a natural history museum. Paper presented at the

Museums and the Web 2007, San Francisco, California. Retrieved from

<http://www.archimuse.com/mw2007/papers/kondo/kondo.html>

Kuang, C. (2010). *Five to-die-for augmented reality shopping apps* | *fast company*.

Retrieved 06/04, 2010, from <http://www.fastcompany.com/blog/cliff-kuang/design-innovation/shopping-augmented-reality>

[innovation/shopping-augmented-reality](http://www.fastcompany.com/blog/cliff-kuang/design-innovation/shopping-augmented-reality)

Kutulakos, K. N., & Vallino, J. R. (1998). Calibration-free augmented reality. *IEEE*

Transactions on Visualization and Computer Graphics, 4(1), 1-20.

doi:10.1109/2945.675647

Lanning, M. L. (2005). *The battle 100: The stories behind history's most influential*

battles. Naperville, Illinois: Sourcebooks, Inc.

Lars rasmussen on inventing google maps - science and technology - browse - big ideas -

ABC TV. (2010). Retrieved 05/05, 2010, from

<http://www.abc.net.au/tv/bigideas/stories/2009/07/10/2620279.htm>

Layar announces layar stream. (2010). Retrieved 05/16, 2010, from

<http://site.layar.com/company/blog/layar-announces-layar-stream/>

Layar launches world's first augmented reality content store – augmented reality

browser: Layar. (2010). Retrieved 06/01, 2010, from

<http://site.layar.com/company/blog/layar-launches-worlds-first-augmented-reality-content-store/>

Lee, G., Sacks, R., & Eastman, C. M. (2006). Specifying parametric building object behavior (BOB) for a building information modeling system. *Automation in Construction*, 15(6), 758-776.

Lehman, M. L. (2010). *The Future impact of augmented reality*. Retrieved 12/27, 2009, from <http://sensingarchitecture.com/2194/the-future-impact-of-augmented-reality/>

Lehra, W., & McKnight, L. W. (2003). Wireless internet access: 3G vs. WiFi? *Telecommunications Policy*, (27), 351-370.

Liarokapis, F., & Newman, R. (2007). Design experiences of multimodal mixed reality interfaces. Paper presented at the *Proceedings of the 25th Annual ACM International Conference on Design of Communication*, El Paso, Texas. 34-41.

lifeClipper. (2005). Retrieved 6/18, 2010, from <http://www.torpus.com/lifeclipper/>

- Lu, Y., & Smith, S. (2008). Augmented reality E-commerce: How the technology benefits people's lives. In I. Pavlidis (Ed.), *Human-computer interaction* (pp. 215-238). Croatia: In-Tech.
- MacIntyre, B., & Coelho, E. M. (2000). Adapting to dynamic registration errors using level of error (LOE) filtering. Paper presented at the *Augmented Reality, 2000. (ISAR 2000). Proceedings. IEEE and ACM International Symposium*, Munich. 85-88.
doi:10.1109/ISAR.2000.880927
- MacIntyre, B., & Julier, S. J. (2002). Estimating and adapting to registration errors in augmented reality systems. Paper presented at the *Proceedings of the IEEE Virtual Reality 2002*, Orlando, FL. 73-80. doi:10.1109/VR.2002.996507
- Maurice. (2010). *Layar's new week: Outdoor advertising layer for Walt Disney's Prince of Persia*. Retrieved 05/25, 2010, from <http://site.layar.com/company/blog/layar-announces-layar-stream/>
- Metro paris subway (subway) iPhone and iPod touch application*. (2010). Retrieved 05/30, 2010, from http://www.metroparisiphone.com/index_en.html
- Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented reality: A class of displays on the reality-virtuality continuum. Paper presented at the *SPIE Proceedings: Telem manipulator and Telepresence Technologies*, Kyoto , Japan. , 2351 282-292. Retrieved from http://vered.rose.utoronto.ca/publication/1994/Milgram_Takemura_SPIE1994.pdf

Millar, S. (2008). Spatial coding as integrative processing of inputs from vision, touch and movement. *Space and sense :Essays in cognitive psychology* (pp. 27-46). Hove ; New York: Psychology Press/Taylor & Francis.

Modelling and simulation of construction processes using VR technology - 4D. (2003).

Retrieved 05/28, 2010, from <http://cic.vtt.fi/4d/4d.htm>

Möhring, M., Lessig, C., & Bimber, O. (2004). Optical tracking and video see-through AR on consumer cell-phones. Paper presented at the *Mixed and Augmented Reality, 2004. ISMAR 2004. Third IEEE and ACM International Symposium*, 252-253.
doi:10.1109/ISMAR.2004.63

Montello, D. R., Hegarty, M., Richardson, A. E., & Waller, D. (2004). Spatial memory of real environments, virtual environments, and maps. In G. L. Allen (Ed.), *Human spatial memory : Remembering where* (pp. 251-285). Mahwah, N.J.: Lawrence Erlbaum Associates.

Museum of london: Streetmuseum for iPhone, iPod touch, and iPad on the iTunes app store. (2010). Retrieved 6/18, 2010, from <http://itunes.apple.com/us/app/museum-london-streetmuseum/id369684330?mt=8#>

N building featuring augmented reality. (2010). Retrieved 06/05, 2010, from <http://www.buzz-beast.com/2010/01/n-building-featuring-augmented-reality.html>

N building.app – iPhone meets architecture. (2010). Retrieved 08/22, 2010, from <http://www.sonasphere.com/blog/?p=1288>

- N building.app [iPhone]*. (2010). Retrieved 08/24, 2010, from <http://www.creativeapplications.net/iphone/n-building-app-iphone/>
- Nilsson, S. (2008). Having fun at work: Using augmented reality in work related tasks. In I. Pavlidis (Ed.), *Human-computer interaction* (pp. 57-74). Croatia: In-Tech.
- Pablo valbuena*. (2010). Retrieved 06/05, 2010, from <http://www.pablovalbuena.com/>
- Pablo valbuena: Augmented space*. (2010). Retrieved 08/24, 2010, from <http://www.flickr.com/photos/todaysart/3284513762/in/photostream/>
- Panoramio - photo of citadel of erbil*. (2008). Retrieved 08/24, 2010, from <http://www.panoramio.com/photo/8443793>
- Panoramio-kurdistan-hawler castle*. (2010). Retrieved 08/24, 2010, from <http://www.panoramio.com/photo/34169144>
- Papageorgiou, D., Ioannidis, N., Christou, I., Papathomas, M., & Diorinos, M. (2000, ARCHEOGUIDE: An augmented reality based system for personalized tours in cultural heritage sites. *Cultivate Interactive*, Retrieved from <http://www.cultivate-int.org/issue1/archeo/>
- Pausch, R., Crea, T., & Conway, M. (1992). A literature survey for virtual environments: Military flight simulator visual systems and simulator sickness. *Presence: Teleoperators and Virtual Environments*, 1(3), 344-363.
- Proctor, N. (2007). When in roam: Visitor response to phone tour pilots in the US and europe. Paper presented at the *Museums and the Web 2007*, San Francisco,

California. Retrieved from

<http://www.archimuse.com/mw2007/papers/proctor/proctor.html>

Rashid, H. (2005). Entering an age of fluidity. In G. Flachbart, & P. Weibel (Eds.), *Disappearing architecture: From real to virtual to quantum* (pp. 236-247). Basel, Boston, Berlin: Birkhauser - Publishers for Architecture.

Raskar, R., & Low, K. (2001). Interacting with spatially augmented reality. Paper presented at the *AFRIGRAPH '01: Proceedings of the 1st International Conference on Computer Graphics, Virtual Reality and Visualisation*, Camps Bay, Cape Town, South Africa. 101-108. doi:<http://doi.acm.org/10.1145/513867.513889>

Reid, D. (2005). *BBC NEWS | programmes | click online | beyond virtual reality*.

Retrieved 6/18, 2010, from

http://news.bbc.co.uk/2/hi/programmes/click_online/4472491.stm

Reitmayr, G., & Schmalstieg, D. (2003). Location based applications for mobile augmented reality. Paper presented at the *Proceedings of the Fourth Australasian User Interface Conference on User Interfaces*, Adelaide, Australia. , 18 65.

Richards, G. (Ed.). (2001). *Cultural attractions and european tourism*. UK: CABI.

SecondSite – BIM visualization. (n.d.). Retrieved 05/27, 2010, from

<http://www.bimviz.com/Index.html>

Segal, M., Akeley, K., Frazier, C., & Leech, J. (1998). The OpenGL graphics system: A specification (version 1.2). *Silicon Graphics, Inc*,

Sheppard, R. (Ed.). (2008). *Alexander the great at war : His army, his battles, his enemies*. Oxford ; New York: Osprey.

Shibuya.jpg. (2010). Retrieved 08/22, 2010, from

http://i275.photobucket.com/albums/jj306/ventti_2008/Japan/Shibuya.jpg

Simmons, D. (2009). *BBC NEWS | programmes | click | handsets enhance the real world*.

Retrieved 05/06, 2010, from

http://news.bbc.co.uk/2/hi/programmes/click_online/8214219.stm

Solecki, R. S. (1954). Shanidar cave, a paleolithic site in northern iraq. *Smithsonian*

Institution. Annual Report, , 389-425. illus., 7 plates, maps.

Sparacino, F. (2002). Narrative spaces: Bridging architecture and entertainment via interactive technology. Paper presented at the *6th International Conference on Generative Art*, Milan, Italy. Retrieved from

<http://alumni.media.mit.edu/~flavia/Papers/NarrativeSpaces.pdf>

Strauss, W., & Fleischmann, M. (2005). Implosion of numbers _Performative mixed reality. In G. Flachbart, & P. Weibel (Eds.), *Disappearing architecture: From real to virtual to quantum* (pp. 118-131). Basel, Boston, Berlin: Birkhauser - Publishers for Architecture.

Sutherland, I. E. (1965). The ultimate display. Paper presented at the *Proceedings of IFIP Congress*, New York, USA. 506-508.

Sutter, J. D. (2010). *New phone apps seek to 'augment' reality*. Retrieved 05/15, 2010, from

<http://www.cnn.com/2009/TECH/08/05/augmented.reality.phone.apps/index.html>

Tamura, H., Yamamoto, H., & Katayama, A. (2001). Mixed reality: Future dreams seen at the border between real and virtual worlds. *Computer Graphics and Applications, IEEE*, 21(6), 64-70. doi:10.1109/38.963462

Thin client. (2008). Retrieved 05/20, 2010, from

<http://www.techweb.com/encyclopedia/defineterm.jhtml?term=thinclient>

Van Grove, J. (2010). *Layar's plan to monetize augmented reality*. Retrieved 06/01, 2010, from <http://mashable.com/2010/04/28/layar-content-store/>

Virtual sets. (2009). Retrieved 01/05, 2010, from

<http://www.virtualsetworks.com/Docs/BroadcastPix/BroadCastPix-Virtual-Set-Tutorial.pdf>

Vlahakis, V., Karigiannis, J., & Ioannidis, N. (2003). Augmented reality touring of archaeological sites with the ARCHEOGUIDE system. *Cultivate Interactive*, Retrieved from <http://www.cultivate-int.org/issue9/archeoguide/index.html>

VTT technical research centre of finland - business from technology. (2009). Retrieved 05/28, 2010, from <http://www.vtt.fi/vtt/index.jsp>

Wagner, M. (2006). Cognitive maps, memory, and space perception. *The geometries of visual space* (pp. 189-222). Mahwah, N.J.: Lawrence Erlbaum Associates.

- Wakefield, J. (2009). *BBC news - mobiles offer new view of reality*. Retrieved 05/05, 2010, from <http://news.bbc.co.uk/2/hi/technology/8421684.stm>
- Wang, X., & Dunston, P. S. (2007). Design, strategies, and issues towards an augmented reality-based construction training platform. *Journal of Information Technology in Construction (ITcon)*, 12, 363-380. Retrieved from <http://www.itcon.org/2007/25>
- What is layar?* (2010). Retrieved 05/16, 2010, from <http://site.layar.com/download/layar/>
- Whitaker, R. T., Crampton, C., Breen, D. E., Tuceryan, M., & Rose, E. (1995). *Object calibration for augmented reality* (Technical report No. ECRC-95-04). Maastricht, NL: Eurographics '95 Proceedings.
- WIKITUDE for iPhone 3G, iPhone 3GS, and iPhone 4 on the iTunes app store*. (2010). Retrieved 08/22, 2010, from <http://itunes.apple.com/ca/app/wikitude/id329731243?mt=8>
- Woodward, C., Hakkarainen, M., & Rainio, K. (2010). Mobile augmented reality for building and construction [Abstract]. *Mobile AR Summit at MWC*,
- Yelp, inc.* (2010). Retrieved 05/30, 2010, from http://www.yelp.com/faq#what_is_yelp