Augmented Reality in Museum Environments

A Case Study at Lund University Historical Museum

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AUGMENTED REALITY IN MUSEUM ENVIRONMENTS

A CASE STUDY AT LUND UNIVERSITY HISTORICAL MUSEUM

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To our families and Pakistan

ABSTRACT

Over the years, Human Computer Interaction has gone through remarkable change, starting from mere on/off switches to modern computer interface which is derived from typewriter. Recently, with the increased processing capabilities of handheld devices, a lot of new interaction methods are emerging, among them is Augmented Reality (AR). In this work, we have presented a study in which AR based interaction method is explored in context of Digital Cultural Heritage. A mixed method approach is used where at first; we have conducted a systematic literature review of the area to gain from other similar studies and later based on this we have developed a prototype AR application in a case study of Uppåkra temple exhibit with Active interaction and Passive interaction methods. We conclude from user evaluation that Passive interaction is the most favorable one and that the visitors are interested in enduring presence of such exhibits in Lund University Historical Museum.

Keywords: Augmented Reality, Museums, Cultural Heritage, Visualization, Handheld, Exhibit, Uppåkra

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1   INTRODUCTION

This thesis is part of ongoing research concerning the use of digital technology in Cultural Heritage at RE-FLEX, a research center at Lund University. *In this thesis work we have underlined the advances that have been made in the use of Augmented Reality in digital cultural heritage with primary focus on indoor museum environments. Furthermore, it is investigated that how commercial off the shelf components, both hardware and software, can be used to make an AR tool to visualize cultural heritage artifacts in museum exhibits.* In order to elaborate on the second part we have conducted a case study of an exhibit featuring Uppåkra temple in collaboration with Lund University Historical Museum.

During the timeframe of this thesis project, we have also got the opportunity to demonstrate the prototype we have developed in a seminar and a workshop featuring the use of our AR application to visualize Uppåkra temple. Those two occasions were a seminar on "Visualisering inom arkitektur och stadsbyggnad" (Visualization in Architecture and City Planning) and a workshop on "Virtual Heritage". On both events we got important feedback to improve our application and observe user behavior. Furthermore, we had communication with the museum curator and primary person responsible for incorporating digital technology in Lund University Historical Museum which also served as important feedback. It has also been our great pleasure to demonstrate our prototype for Swedish TV4 news report about virtual heritage. Last but not the least, in connection to our project we have also been interviewed by Swedish Radio regarding the use of Augmented Reality and its future prospects.

1.1   A word about RE-FLEX

RE-FLEX[1] (Flexible Reality Centre) is based in IKDC (Ingvar Kampard Design Centrum) at Lund University, Lund, Sweden and is the coordinating point for different fields of research when it comes to visualization technologies. RE-FLEX groups together state of the art laboratories at Lund University including The Virtual Reality Lab (IKDC), The Humanities Lab (SOL), Full Scale Modeling Lab (Architecture), CMS - Center for Medical Simulation (Malmö University Hospital) and Practicum (Lund University Hospital). It is a major hub for visualization in south of Sweden.

1.2   Lund University Historical Museum

The Lund University Historical Museum situated in Lund city center, is Sweden's second largest archaeological museum. The museum has a variety of exhibits. Among these exhibits is the '*BARBARICUM*' exhibit which is about the city of Uppåkra and

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[1] http://www.lth.se/reflex/

Scanian Iron Age. The city of Uppåkra discovered in 1930 was the largest historical settlement in southern Sweden. The city is believed to be a place of complex activities for almost 1000 years ranging from first year B.C. to 1000 A.D. The BARBARICUM exhibition features the marvelous artifacts and remains from the city of Uppåkra. This exhibition has been key source of information during the case study in this thesis work. A visitor's guide named after this exhibition and distributed by the museum has also been a reference to latest interpretation of the archaeological finds.

1.3 Motivation

Over the years museums evolved from mere presenter of artifacts to interactive environments for the visitors. Museums are employing new technologies (as presented in chapter 2) and quantum leaps in technology are opening new frontiers. In similar lines Lund University Historical Museum has employed digital media which includes both audio and visual technologies and displays. Augmented Reality is one of the upcoming technologies whose realization has become easier due to the ground breaking handheld devices offering all the components required by an AR application. Lund University Historical Museum is interested in exploring new methods of interaction with the exhibits to embrace the new age of digital cultural heritage that could increase the interest of visitors and we believe Augmented Reality could be instrumental in realizing this.

1.4 Aims and Objectives
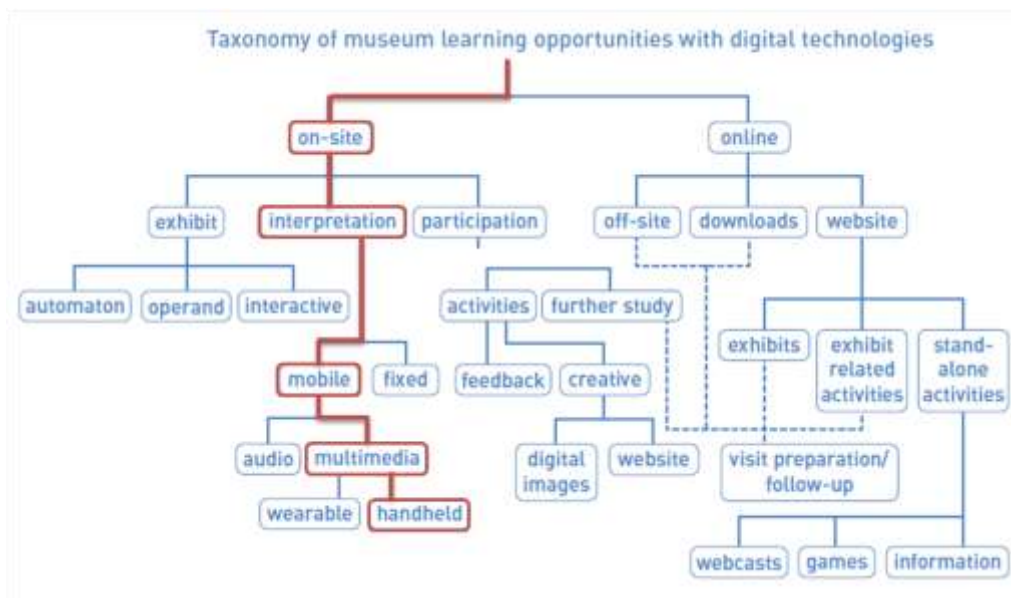
Figure 1-1 Our focus area highlighted in taxonomy of digital
technologies in Museums by Hawkey [1]

In this study our aim is to build upon AR related studies conducted in digital cultural heritage and demonstrate the application of AR in context of the BARBARICUM exhibit in Lund University Historical Museum. In contrast to the conventional AR systems which are using specialized hardware (See Table in

Appendix A) in museums, our study's objective is to use open source commercial off the shelf components to build an AR based prototype and to evaluate it in current museum environment. The hardware for our prototype is to be based on a commercial handheld device. Hawkey [1] has reviewed and classified the current digital technologies used in museum exhibits. Our focus area can be seen highlighted in his taxonomy in figure 1.1.

1.5   Research Questions

In due course of this study we have tried to answer the following questions:

- What is the state of the art in Augmented Reality systems for museum environments?
- How can an Augmented Reality application for the Uppåkra exhibit be designed and developed using open source commercial off the shelf components?
- Would the museum visitors be more attuned to Passive Interaction or Active Interaction in Augmented Reality?

The third question has arisen as a result of our case study to answer the second question and it is described in detail in section 5.7.

1.6   Methodology

Our study's initial phase was to frame the problem into proper context and then deal with the Augmented Reality based interaction in case of Uppåkra exhibit. This is done in this thesis work by using a mixed methodology in which a Systematic Literature Review of Augmented Reality is conducted and a Case Study follows afterwards. The prototypes resulted at the end of the case study are evaluated in the museum environment to answer the third research question. The essence of the case study is not to present a generalizable result but rather to explore a particular case and how and due to what reasons the decisions have been made in applying AR technology in an indoor museum environment as argued by Schramm and Roberts [2],

> *"The essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result"*

At the same time the outcome and the results in this study could be used to direct other similar studies as Flyvbjerg [3] argues,

> *"One can often generalize on the basis of a single case, and the case study may be central to scientific development via generalization as supplement or alternative to other methods. But formal generalization is overvalued as a source of scientific development, whereas "the force of example" is underestimated."*

1.7   Research Contribution

In this thesis work, we have systematically reviewed the area of Augmented Reality including its current trends and its future prospects. We have presented the research that has been done in using AR in museum environments (section 4.8) and in light of that work; we have conducted a case study (chapter 5) and presented our experiences with the available technologies both hardware and software. In our study we have considered an actual exhibit at Lund University Historical Museum, the constraints it posed on using the AR technology and the measures we have taken to overcome those. As a part of our work we have developed a working prototype of an AR application to elaborate our choices in the case study. We have also presented user evaluation of Active Interaction and Passive Interaction with our prototype in AR (chapter 6).

1.8   Terminologies, Acronyms and Abbreviations

Active Interaction   Active Interaction in context of this thesis implies interaction with the AR application by manipulating the 3D model holding the marker in front of the camera.

API   Application Programming Interface

Applied Technologies   In context of this work, the Applied Technologies are Interfaces, Interaction and Visualization which are considered once enabling technologies are established for an AR system.

AR   Augmented Reality

EMI   Electromagnetic Interference. Sometimes also called Radio Frequency Interference or RFI.

Enabling Technologies   Set of core technologies which are required to develop an AR system [4].

GUI   Graphical User Interface

HITLabNZ   Human Interface Technology Lab New Zealand

HMD   Head Mounted Displays

MR   Mixed Reality

OpenGL   Open Graphics Library is a cross platform library for 2D and 3D computer graphics

Passive Interaction   Passive Interaction in context of this thesis implies interaction with the 3D model in the AR application while holding the device.

PDA   Personal Digital Assistant

TUGraz   Graz University of Technology, Austria

VR   Virtual Reality

XML   Extensible Markup Language

1.9 Thesis Outline

This section gives an overview of the chapters in this thesis work by briefly mentioning the contents.

Chapter 1 (Introduction) sets the tone of this thesis work by discussing the context of this research work, its aims and the way the work has been carried out and its contributions.

Chapter 2 (Background) presents the history of museums and the digitization of museums along with the review of VR technologies that have been in use.

Chapter 3 (Augmented Reality: An Overview) elaborates what Augmented Reality is and discusses the enabling technologies in AR.

Chapter 4 (AR: A Systematic Literature Review) sheds light on the steps taken to perform the systematic literature review. Afterwards, it presents the prominent researchers in the field and, the current and future trends. This chapter also reviews the leading projects that have used AR in cultural heritage.

Chapter 5 (Uppåkra Temple Exhibit: A Case Study) discusses the steps taken in realizing the prototype AR application, the environmental constraints, the software considerations and the hardware considerations.

Chapter 6 (Evaluation of Prototypes) presents details of experiment conducted to evaluate the Active and Passive interaction with the prototype AR application. It also illustrates the analysis of the results.

Chapter 7 (Epilogue) concludes the thesis with discussion and Future work.

2   BACKGROUND

Museums serve as the link between past and present. For more than 2000 years, museums have preserved and restored cultural heritage of human kind and facilitated the transfer of this heritage to future generations [5,6] thus undertaking two principal functions.

- Acquire and preserve the *past*
- Educate the *present* using exhibits

In this chapter we will go through the history of museums, how the digitization in museums has occurred over time, and what technologies are currently in place to give interactive experiences in museums.

2.1   History of Museums

The conception behind the study of Archaeology and Museum exhibits is the inherent human nature to question, "why humans behave the way they do" and the correlation towards their social and physical environment [7]. Museums are "RE-PRESENTATION" of the history. Before the opening of the first public museums during the 18th century in Europe, early museums were the private collection of individuals [8,9]. Even though the public museums were opened, but they were accessible by small percentage of the population, for instance, to gain entrance to the British Museum, one had to apply in written for admission. The first truly public museum was the Louvre Museum in Paris. It was opened in 1793 and free access was granted for the first time. Soon after other European museums and American museums also followed the trend and became leading centers for knowledge. The late 19th and early 20th century is often termed as "The Museum Period" or "The Museum Age" [8,9]. Today museums are classified as:

- Archaeology museums
- Art museums
- History museums
- Maritime museums
- Military and war museums
- Natural history museums
- Open air museums
- Science museums
- Specialized museums
- Virtual museums
- Zoological parks
- Botanic gardens

2.2   Digitization of Museum Experience

Initially museums offered static experience to their visitors. It was hard for the visitors to interpret from the exhibits. For a large number of audiences, they were merely source of entertainment rather than knowledge. Earlier museums usually did not use to offer physical contact with the artifacts. However, a new way of interaction is emerging, between artifacts and visitors with the use of digital technologies. Use of these technologies gives entirely new dimension to the interactive experiences i.e., learning from the objects rather than learning about them. For decades now, museums are using portable electronic guidebooks, earliest of which can be traced back to late 1950s when Acoustiguide used reel-to-reel tape players for guided tours [10]. A wide range of digital technologies are used in the museum environments today, ranging from multimedia simulations and presentations to the internet. Technologies like handheld devices are also being experimented. They provide interactive activities that would not be possible otherwise and can adapt to different type of audiences [1].

2.3   The Need for Digital Experience

Earlier museums were solely places for collection and preservation of artifacts. They exhibited the artifacts in racks and behind glass. The diaphanous purpose was to educate the visitors about the exhibits by displaying the text labels and descriptions of experts beside the artifacts often in elusive language [1]. Another common practice in museums (still in most museums) was using group counseling to describe the historical significance, technical details, scientific magnitude or cultural impact of the exhibits. Often the audiences in such group sessions are school children or group of diverse people visiting the exhibits. The problem with this experience is that the visitors are expected to learn for themselves from educators' eyes and they are lacking their active involvement in such exhibit's experience. The museum exhibits eventually began to change and visitor oriented museums emerged [11], more focused on the message rather than just displaying the artifacts behind the glass. Museum designs became more storytelling and started incorporating visitor's personal involvement in the learning process [12]. Use of 2D multimedia visualizations is common in almost all the big museums today. Along with this, a lot of research is being conducted in different institutes for the use of state-of-art 3D technologies [13,14].

Although digital technologies are widely incorporated in museums, most of the time focus is more towards the digital information rather than interactive experiences. An example could be the use of narration devices which convey good relevant information but the experience could be quite boring. The narration could be slow or the explanation in words could not replace equivalent visual solution. On the other hand, the visual devices currently used usually have complex interfaces and there is a high probability that the visitor is thinking more about the device than the

exhibit itself. So, can we really improve this deficiency by using some interactive technology which doesn't compromise the experience and yet the device is invisible? Yes, the answer is Augmented Reality which we will discuss in the next chapter. For now we will give a review of the Interactive Technologies currently used by museums.

2.4 Review of Interactive Technologies Used in Museums

In this section we present the review of the famous interactive technologies currently used in museums and cultural heritage research. Virtual Reality being closest to AR is discussed first followed by an overview of other technologies.

2.4.1 3D Virtual Reality

Virtual Reality is a technology in which virtual equivalent of the real world is created and simulated using 3D computer graphics. The notion of Virtual Reality (VR) emerged by Myron Krueger in 1974 when he termed artificial reality (or VR) as the prospective substitute of the real world [13]. The concept was to develop immersive experiences. In Virtual Reality, the interaction is achieved by immersing the user into the virtual environment using technologies like, haptic feedback, 3D sound and immersive displays. Haptic feedback is not usually used in visualization of cultural heritage rather 3D sounds and immersive displays are the commonly used technologies in this area. 3D sound experiences can be achieved by using surround sound systems or headphones. Much of the diversity in Virtual Reality technologies is based on the type of display technology used. Display technologies play the most vital role when it comes to immersion in VR. There are a number of display technologies that are in use for immersive experience in VR.

Figure 2-1 A user wearing HMD for interactive Virtual Reality experience with 3D Virtual Scene (Image courtesy: www.5DT.com)

Head mounted display is one of the display technologies which can be used to achieve immersive experience in VR. As the name suggests HMD has two displays mounted on as helmet positioned in front of the eyes. Displays can be CRTs, LCDs, OLEDs or micro-displays. HMDs can be used in cultural heritage to provide guided

tours of virtually created Historical places. Although good quality virtual models coupled with HMDs can provide a very immersive experience but from ergonomics point of view it can cause strain and fatigue to the user. Furthermore, this type of display can also cause hindrance to the flow of visitors due to the amount of setup time required for using such devices. A typical HMD is shown in figure 2.1.

CAVE Systems on the other hand provide immersion in the virtual environment by allowing the user to enter in a cube whose walls, floor and ceiling act as displays. CAVE environments were introduced by University of Illinois-Chicago Circle. Contemporary CAVE systems consist of three to six faces of a cube with rear-projection screens having one single coordinated image generation system [15]. In contrast to HMDs, CAVE systems are more comfortable to use but they are mostly custom systems and are not very practical solution when considered from financial point of view. In addition to this, the space needed by a CAVE system would require special consideration from museums and its integration in already existing infrastructure is more or less impractical. CAVE Systems, however, have a very special role in research activities in digital archaeology. A typical CAVE environment is presently used in cultural, archaeological and museum research in RE-FLEX. In one of the projects, RE-FLEX is using a CAVE system to visualize Malmö city in year 1692 A.D. In this project, the virtual environment of the city of Malmö in year 1692 A.D. has been recreated using accurate hand written accounts of the city. A user can walk-in a CAVE wearing stereoscopic glasses and can experience the presence in virtual environment by moving in the life size streets of Malmö.

Figure 2-2 A User standing near a historical building in the
CAVE system at The Virtual Reality Lab of Lund University

For certain types of simulations, mostly in training and education, screens with a single coordinated image projection system are arranged in a **Panoramic Display** configuration. Common uses of such displays are in military simulations, flight training simulations, car training etc. These types of displays are used in simulators in science centers to give visitors the feel of different locomotives which are not

ordinarily available for public use, for instance, naval ships and space crafts. The experience in such systems is very realistic. These systems use highly customized hardware which is designed and developed for a specific scenario. It is usually not possible to develop such systems using commercial off the shelf components. They have limited applicability when it comes to general use in museum exhibits.

Figure 2-3 (Left) A user driving a car in training simulator which uses panoramic display technology (VR Lab, Lund University, Sweden) (Right) Ship bridge simulator at Warsash Maritime Centre [15]

2.4.2 Other Digital Technologies

Certain museums only use audio narrations about the artifacts which are displayed in the glass cabinets and description about the artifact is also placed in the form of text. The audio narrations are played by a digital audio player. One such exhibit is illustrated in figure 2.4.

Figure 2-4 A user pointing audio narration device towards the exhibit to have auditory experience [16]

The narrative devices start narration when a special sensor is aligned with a transmitter at the exhibit. The use of this device is not intuitive and requires some learning. Furthermore, it makes the museum experience solo even if the visitor has been with a partner. Grinter, R. et al. [10] discuss use of the Electronic Guidebook for museums which provides audio visual illustration to the visitors and addresses the isolation caused by the narration devices (figure 2.5). In this device they have included the possibility of shared experience to overcome the limitation of narration

devices which singles out the visitors even if they were visiting in pairs. The device allows users to share audio narrations and outlines artifacts that have narrations. Their study improves social experience due to sharing but still lacks interactive experience with artifacts.

Figure 2-5 Figure illustrating Electronic Guidebook which uses groupware software to provide user with cooperation based shared interactive experience [10]

On the other hand, Canadian Heritage Information Network (CHIN) took the advantage of 3D virtual worlds for the internet and launched in 2001 the Virtual Museum of Canada [17] where visitors can tour one or many museums online.

Figure 2-6 Virtual Model of Palaeo-Eskimo hall of CHIN project loaded in a Virtual World browser.

All in all the technologies described above have one or more drawbacks. Some of them cause solitude, fatigue and lack intuitiveness; others are not so cost effective and are very specific in their application and lack robustness. On the other hand, Augmented Reality can provide interaction as intuitive as handling normal physical objects. It can be used on commercial handheld devices and it can be adjusted according to ergonomic requirements.

2.4.3   From Virtual Reality to Augmented Reality

In contrast to Virtual Reality, where the interaction with 3D virtual objects is completely based in a virtual environment, Augmented Reality provides a medium of interaction where 3D virtual objects are part of the real world. In AR, mostly the purpose is to enhance the real world whereas in VR the idea is to give an equivalent of real world. Reality and Virtual Reality are in themselves homogeneous concepts whereas AR is a heterogeneous concept partly involving Reality and partly Virtual Reality. This has been best explained by Milgram and Kishino [18] by defining a Virtuality Continuum whose graphical representation is shown in figure 2.7.
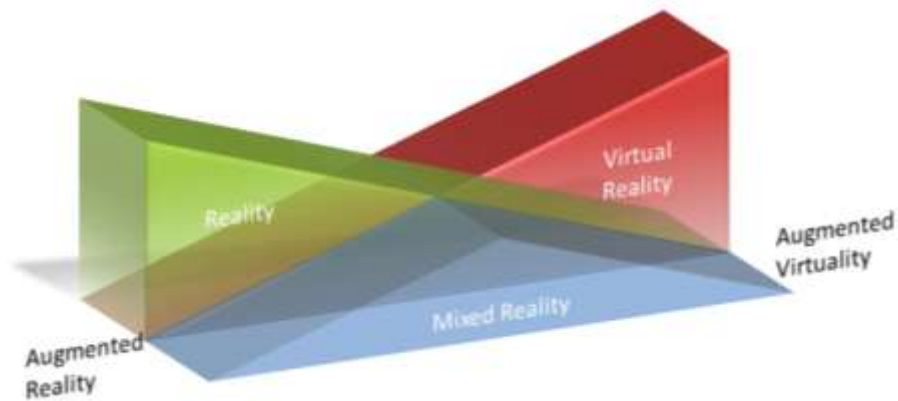
Figure 2-7 Adapted from Virtuality Continuum by
Milgram and Kishino [18]

In their representation they have defined Reality at one end and Virtual Reality at the other and the span between them defines 'Mixed Reality'. Augmented Reality is the most known form of Mixed Reality. The way these MR applications are realized by enabling technologies determines their exact location on the Virtuality Continuum. These enabling technologies are discussed in the next chapter. AR is also the most famous form of MR used in museums. A detailed discussion about AR in Cultural Heritage can be found in section 4.8.

3   AUGMENTED REALITY: AN OVERVIEW

In this chapter we will briefly touch upon the overview of the enabling technologies relevant to our thesis work. Augmented Reality is a technology that lies at the cross roads of Human Computer Interaction, Computer Vision, Image Processing, Computer Graphics and Ergonomics. An Overview of the typical steps involved in an Augmented Reality System is shown in figure 3.1. In this figure we have color coded the steps where a particular set of APIs are involved.
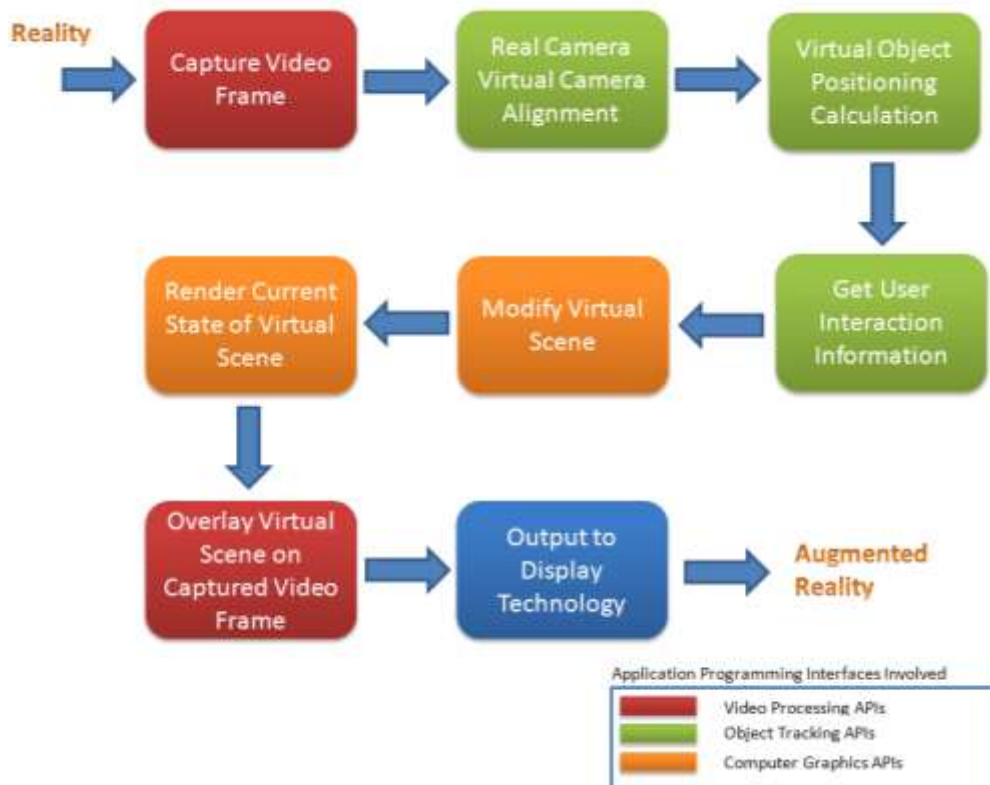
Figure 3-1 Overview of an AR System

3.1   The Concept

The most widely accepted definition of AR is by Azuma, R. et al. [4] where AR system is defined as a system that,

- *"combines real and virtual objects in a real environment;"*
- *"runs interactively, and in real time; and"*
- *"registers (aligns) real and virtual objects with each other."*

An informal definition derived by us from IBM's 1978 Virtualization poster is,

- If it's there, its tangible and you can see it -- its **Real**
- If it's there, it's not tangible and you can see it -- its **Augmented**
- If it's not there, it's not tangible and you can see it -- its **Virtual**
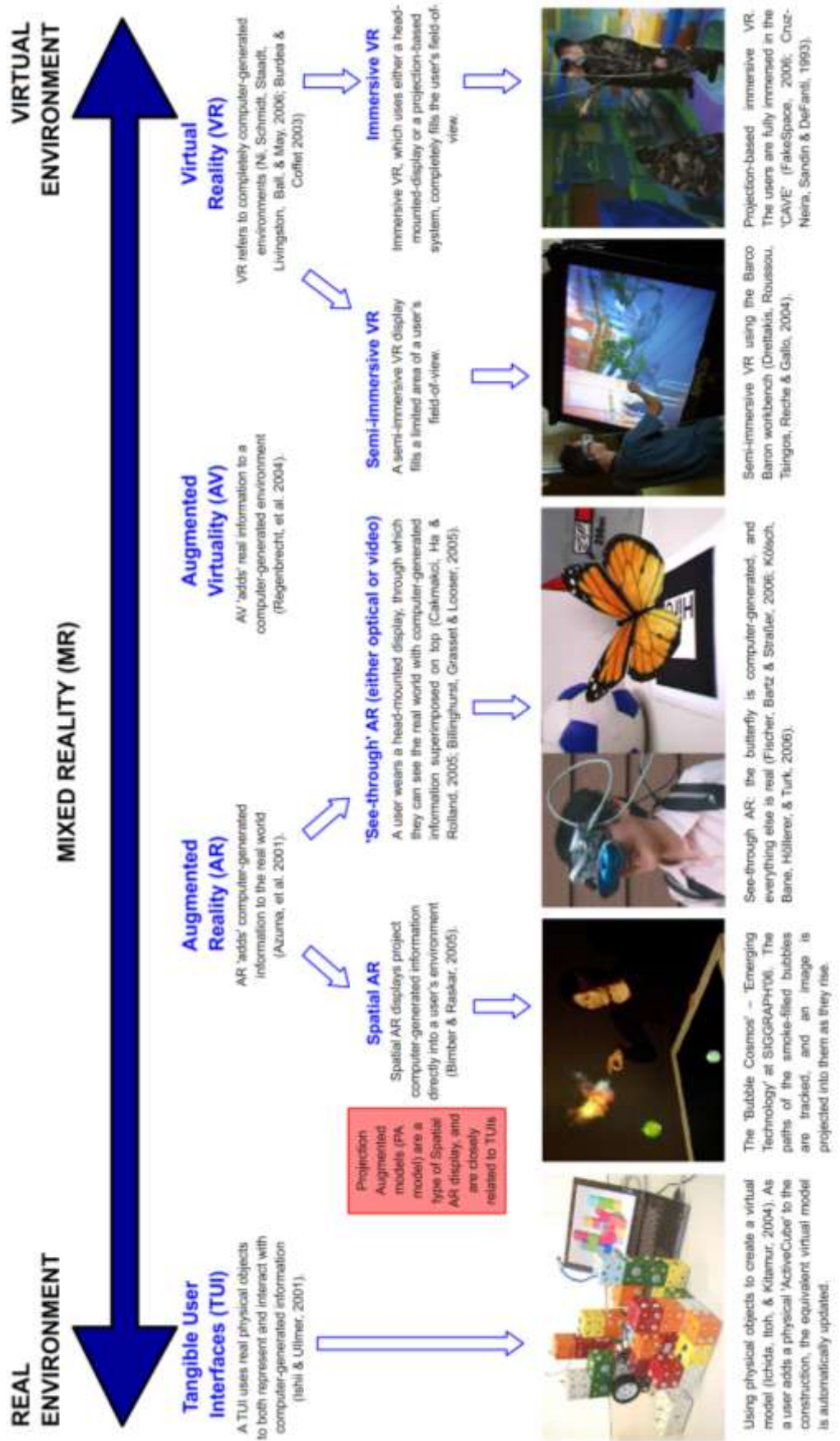
Figure 3-2 Milgram Continuum form Wikipedia Page on Projection Augmented Model (Can be copied under GNU License) (http://en.wikipedia.org/wiki/Projection_augmented_model)

In current museums we have **Real** artifacts on display which are important part of exhibits and provide us with useful historical information but lack interaction and cannot themselves reveal about their importance. On the other hand, we have looked into Virtual Reality where we have **Virtual** information which could provide immersion and more interaction but causes solitude and has its limitation as described earlier. A tradeoff between these experiences is **Augmented** virtual information in exhibits using Augmented Reality where we have real and virtual information present at the same time. Using Augmented Reality we can visualize additional information next to artifacts or we can visualize complete artifacts pasted in real exhibit environment hence avoiding solitude, complete virtuality and above all we can have an intuitive interaction as we have with objects surrounding us in normal life. An elaboration of this Virtuality Continuum by Milgram and Kishino [18] based on the display and tracking technologies is shown in figure 3.2.

Azuma, R. et al. [4] describe a set of core technologies which are required to develop an AR system. These technologies are displays, tracking, registration, and calibration and are called **Enabling Technologies**. Once the enabling technologies are in place, the efforts are toward the **Applied Technologies**. We categorize these technologies broadly as Interfaces, Interaction and Visualization. In rest of this chapter we will briefly present the enabling technologies relevant to our thesis work i.e. displays and tracking technologies.

3.2   Enabling technologies

3.2.1 Displays

Displays in AR are rendering systems that consist of a number of components to spawn images somewhere between the eyes and the physical object to be augmented [19]. See-through HMDs, projection based displays and handheld displays are mostly used in AR applications.

See-through HMD is a wearable display system. It has to be worn by the user to see the augmentation of 3D objects onto the physical environment. See-through HMDs are further classified as optical see-through and video see-through. **Optical see-through HMD** give natural instantaneous AR overlay through transparent or half silvered mirror display. In Optical see-through HMD the field-of-view for each eye is approximately 30 degrees [18,20]. **Video see-through HMD** unlike the Optical see-through offers better uniformity between real and super imposed virtual views. The video of real world is captured from camera which serves as the background for the AR. One advantage of video see-through over optical see-through is that the image quality of the real world images from video and computer generated 3D virtual images can be matched to one another [21].

One of the limitations of current see-through displays is that they don't offer wide field of view and good resolution resulting in less realism as compared to other technologies. Their size and dimension further add to the drawbacks. In case of

museums, such wearable displays are not a feasible option due to their setup time. As is the case for HMDs in VR, they can also cause fatigue and strain.

Figure 3-3 Architects using see-through HMD
for collaborative Augmented Reality urban
planning in the Arthur Project [22]

Projection Based displays use wearable and non-wearable projectors to project virtual information in the real world [18][4]. In this case users do not have to wear HMD displays to see the augmentation. These displays coupled with a wearable computer can provide a customized mobile solution for projective AR. Projection based displays usually display projected information on a 2D plane hence limiting the information to be in 2D as well. Even if we project a 3D model on a 2D surface, interaction with such object would not be similar to real three dimensional objects. In museum exhibits, one has to visualize artifacts as well as historical buildings in 3D and using projective displays is not the ideal solution for such situations.

Figure 3-4 A virtual Dial pad is Projected and Augmented
with the user's hand in the MIT Sixth Sense project

Figure 3-5 Projective Augmentation used to display
interactively updated information on a weather forecast
page in a newspaper (MIT Sixth Sense project)

High resolution **Handheld displays** are available on current breed of handheld devices. The rapid increase in processing power has transformed these handheld devices from simple digital assistants to handheld multimedia gadgets ideal for AR applications. Built-in cameras are now integral part of mobile phones, PDAs and tablet PCs. Cameras are very essential for Augmented Reality applications since they provide real time video input of the physical world on which virtual models have to be overlaid. These devices coupled with their handheld displays and cameras act as natural devices for AR applications. Different handheld devices featuring AR applications are shown in figure 3.6 and 3.7.
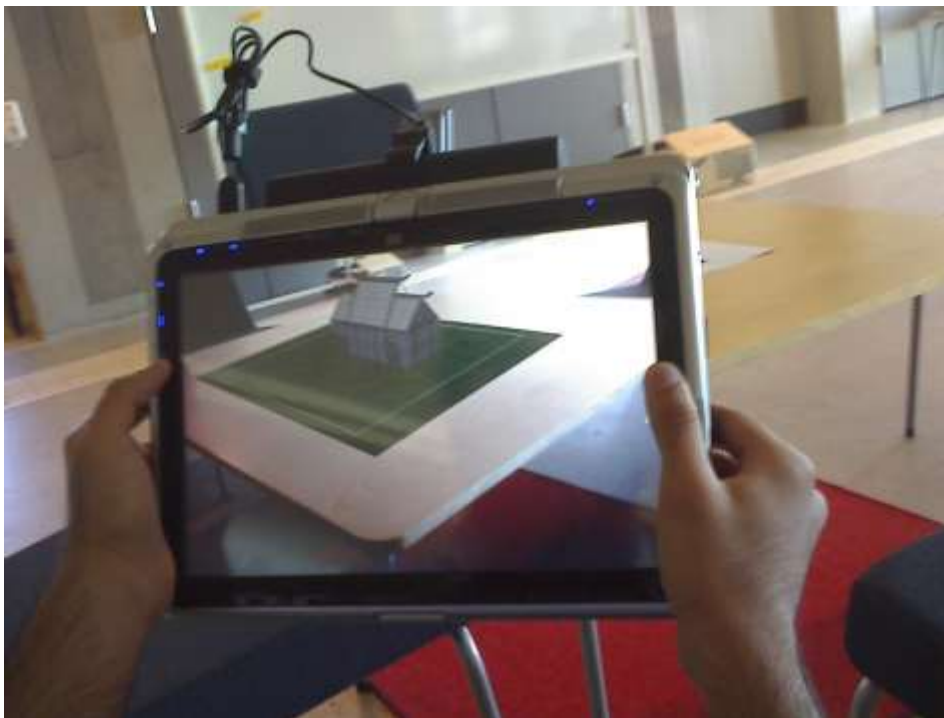
Figure 3-6 Marker-based AR on an HP Tablet displaying a
3D model of a historical place pasted on top of a table

Figure 3-7 (Left) A marker-based AR application on a commercial cell phone showing a 3D character pasted in reality (Right) A marker-based AR on PDA showing a 3D character explaining information about a church model in front of him [23]

Considering all of the display technologies discussed above, handhelds displays are the most readily available due to their commercial nature and they are most feasible for AR in museum exhibits due to their high mobility and their common use by ordinary people. They also involve less or no learning curve since most people are familiar with them contrary to the display devices discussed earlier which may require specialized training.

3.2.2   Tracking techniques

Tracking in terms of Augmented Reality is the process of tracing the scene coordinates of moving objects in real-time [24]. Real time tracking is essential in AR applications. Here we will discuss the techniques which can be used to track the 3D virtual objects in the real world. Tracking is usually followed by registration. In registration, the data from tracking is used to paste the virtual information in real world. Based on the application domain, applications could be indoor or outdoor which determines the tracking technique to be used. Position sensors, physical features or locators are used to associate a virtual object with a physical location in real world. The virtual object is than tracked using these features. Tracking can be classified as sensor based, vision based or hybrid.

In **sensor-based tracking,** as the name suggests, sensors are used to track positioning information for 3D virtual models. Sensors can be electromagnetic or acoustic. Transmitters are placed at the location where virtual model should be pasted. The signals from these transmitters are then detected by sensors to calculate their position relative to the user.

In **electromagnetic sensor based tracking**, electromagnetic fields are emitted by transmitters. These are not always precise because electromagnetic fields can easily be compromised [38] by Electromagnetic Interference or EMI. Electromagnetic

sensors for position calculation don't provide the ideal scenario when it comes to mobile devices, since mobile devices themselves are transmitters and receivers of Electromagnetic data which could definitely cause EMI.

Another sensor-based tracking technique is **Acoustics tracking.** The notion of acoustics in tracking techniques is to extend the real sound environment with virtual sound environments much similar to the physical world which is enhanced by super imposed 3D graphics. With this tracking, sound sensors are used which are in fact electromagnetic sensors with different frequency. The acoustic sensors are not meant for position tracking of virtual 3D models.

Vision based tracking techniques provide an alternative to sensor based tracking techniques described above. In these techniques, a camera is used to capture the real-time video of the scene. The frames from the video are processed to find artificial features or natural features in the video to which the 3D virtual objects should be aligned. Artificial features are the one which are specifically placed in the scene on purpose to get tracking information. On the other hand natural features are part of the actual environment. The Vision based tracking techniques are divided into Marker-based tracking and Natural Feature-based tracking depending on the type of features being used for tracking information.

Maker-based tracking uses artificial features tracking. As the name of the techniques says these features are custom made markers. A marker is usually a square shaped predefined image (figure 3.8) printed on a piece of paper and is placed in the scene. The AR application is already trained using AI (Artificial Intelligence) algorithms to recognize these markers. This predefined marker is detected in the captured video frame by an API and a transformation matrix is calculated. Depending upon the calculated position and orientation of the marker, the 3D virtual object is rendered relative to it in the video. One of the drawbacks associated with this technique is the modification of the environment with markers which could be a distraction for the user. For the time being, marker based tracking is used to realize most of the AR applications. This is partly due to availability of commercial off the shelf APIs for readily developing such applications. In addition to this, marker based tracking is also relatively fast and smooth as compared to other techniques. Custom images and shapes can also be used to make markers (figure 3.9) and most of the available API's provide the option to create your own markers.

(a)   (b)   (c)
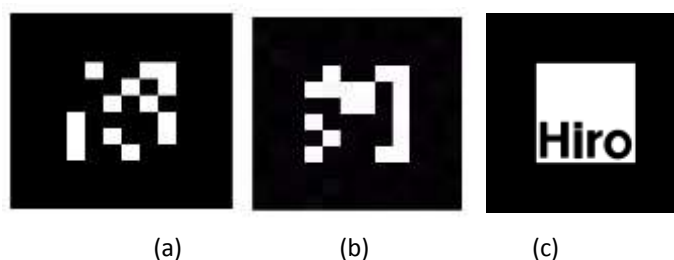
Figure 3-8 Predefined (a) marker 67 and (b) marker 68 from Studierstube framework and (c) the default Hiro Marker from ARToolkit API
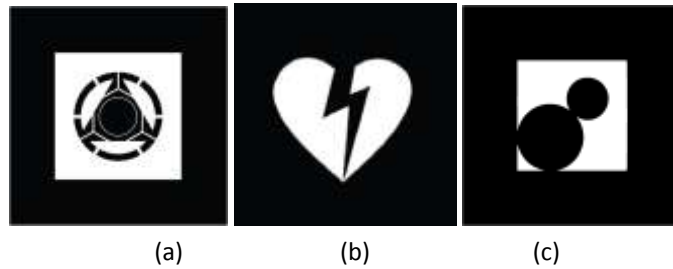
(a)   (b)   (c)

Figure 3-9 Custom made markers (a) Marker for online
Lego Atlantis AR experience (b) Marker used by John
Mayer in the Heart Break music video (c) Marker used in
IKEA case study by Nick Sjöström and Robin Westergren
(http://www.robinwestergren.com/)

Natural Feature-based tracking relies on the recognition of a whole object or distinct features in an object or image in the unmodified environment [25,26]. Since there could be unlimited possibilities of features in the natural environment, these techniques are usually more computationally extensive and the tracking algorithms require more extensive training.
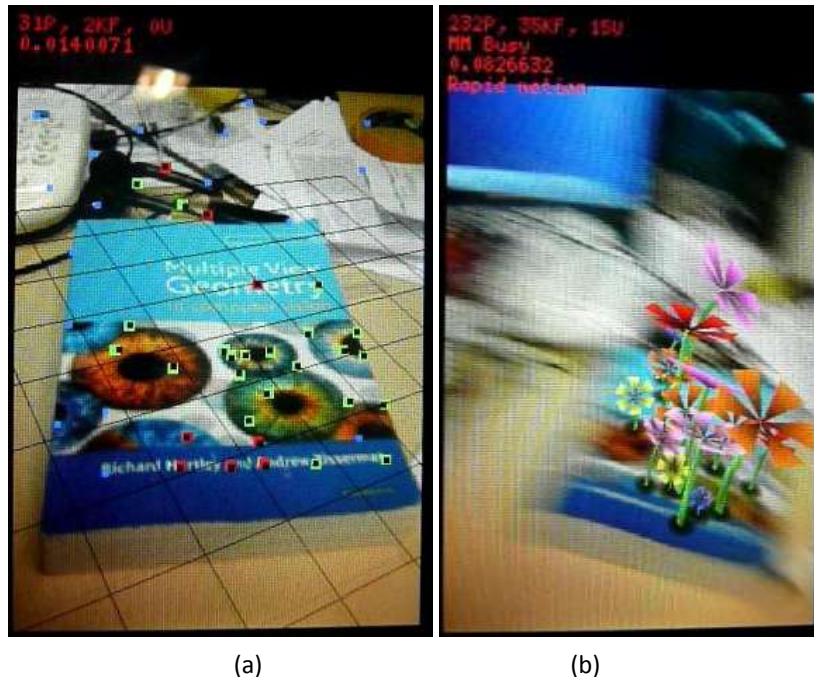
(a)   (b)

Figure 3-10 An AR Application detecting (a) natural features and (b)
inserting virtual flowers using Natural Feature-based tracking [27]

Hybrid tracking techniques involve more than one method to calculate the positioning information. It is considered useful in outdoor environments where fixed markers and other such systems cannot be employed. An intricate system of registration based on a hybrid approach can be found in the CINeSPACE Project [28]. Using a group of different technologies, this system is able to increase accuracy in steps. It starts with the GPS to locate the whereabouts of the user within 10 meters and then optical tracking to find more specific position and orientation [28]. ARCHEOGUIDE is another example of outdoor augmented reality system that uses a

hybrid tracking scheme for visualization of cultural heritage sites as they used to be once [29].

Figure 3-11 ARCHEOGUIDE system used to (b) render Hera Temple at (a) current ruins in ancient city of Olympia in Greece [29]

In most of the works involving indoor Augmented Reality applications, marker based techniques are used. Especially in indoor museum environments, there is good possibility of setting up the environment with these markers contrary to the outdoor archaeological sites where the environment cannot be modified and large scale models cannot be visualized in their true life size using markers. In such, cases hybrid techniques are used. The ideal scenario for tracking in indoor environments would be using smooth natural feature based tracking using handheld devices however current APIs and hardware systems only achieve frame rates of about 10 fps at the time of this writing.

4   AUGMENTED REALITY: A SYSTEMATIC LITERATURE REVIEW

In this chapter we have presented a systematic literature review of Augmented Reality. We have jolted down our keyword selection, search strategy and article selection. The purpose of this literature review is to extract the pioneers in this field, current prominent researchers, current state of the art and future prospects. We have extracted the works that involved museums and archaeology in later part and tabulated them according to distinguishing factors in those studies. The final aim is to gain from the already conducted research work and to frame the specific details of the problem and available options to direct our case study in chapter 5.

4.1   Keyword Selection

In order to search the databases for AR related articles, we have selected a set of keywords. These keywords are presented in the table below.

Search Query
Augmented Reality
Mixed Reality
Augmented Virtuality

Table 4-1Initial Selection of Keywords

Since we were not strictly adhering to a particular display technology at this stage, we also used the alternative terms like Mixed Reality and Augmented Virtuality. Another reason for this was to extract the works where researchers have used keyword Mixed Reality interchangeably with Augmented Reality. At first we were not specific to an applied field in AR since we didn't want to remove the works that used certain technologies that have not already been employed in cultural heritage related works and could possibly be used. Afterwards, to consider the museum and cultural heritage related works that could have been missed out, we run another iteration of search with the following keywords.

Search Query
Augmented Reality && Cultural Heritage
Augmented Reality && Museum
Augmented Reality && Archaeology
Augmented Reality && Exhibit
Mixed Reality && Cultural Heritage
Mixed Reality && Museum
Mixed Reality && Archaeology
Mixed Reality && Exhibit
Augmented Virtuality && Cultural Heritage
Augmented Virtuality && Museum
Augmented Virtuality && Archaeology
Augmented Virtuality && Exhibit

Table 4-2Revised Search Query

4.2   Search Strategy

In our endeavor to search the articles we have used the databases shown in figure 4.1. We started our search by using the keywords presented in table 4.1 and finished the first phase of search. From these articles we have filtered out the false positives and extracted the works in turn referenced by these articles. From the remaining, we have filtered the articles related to cultural heritage and extracted the museum and archaeology related projects. In second phase we have used the keywords in table 4.2 to check for any missed articles related to cultural heritage. We have used Harzin's Perish and Publish [30], and Google Scholar to count most cited authors and their h-index [31] and g-index [32] to check their authority in the field.
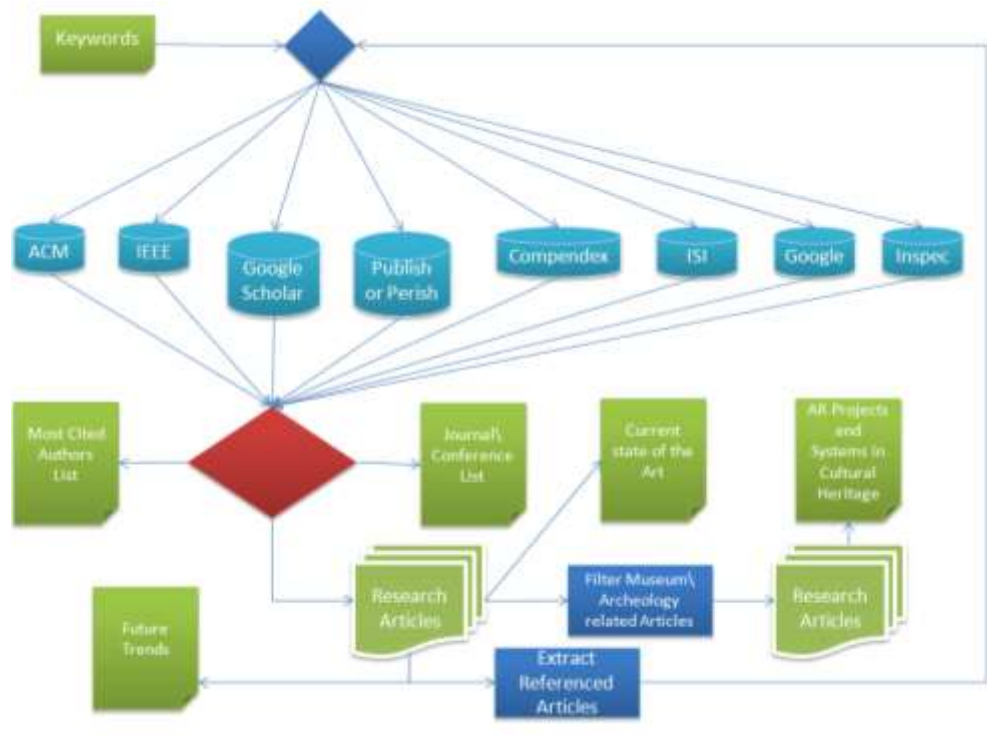
Figure 4-1 Search strategy overview

4.3   Authors List

Our initial selection of authors was based on the Hirsch's h-index [31] and g-index [32] where h-index is defined as;

"A scientist has index h *if* h *of his or her* N_p *papers have at least* h *citations each and the other (*N_p *–* h*) papers have* ≤h *citations each."* [31]

and g-index is defined as;

"[In a set of articles,] If this set is ranked in decreasing order of the number of citations that they received, the g-index is the (unique) largest number such that the top g articles received (together) at least g^2 *citations."*[32]

Our exclusion criteria were to remove the researchers who have an h-index and g-index of less than 10. The resulting list at the time of review is shown in table 4.3.

Author Name	No. of Research Articles	Citation Count	h-Index	g-Index
Ivan Sutherland	151	5557	28	74
Mark Billinghurst	357	5333	33	68
Ronald Azuma	69	4390	18	66
Hirokazu kato	335	3495	23	57
IVAN Poupyrev	79	3170	22	56
Dieter Schmalstieg	304	3452	30	52
Martin White	341	1445	19	32
Krzysztof Walczak	94	524	14	24

Table 4-3List of prominent authors

4.4   Pioneer in the Area

Among the earliest mentions of pasting virtual information onto real world is Ivan Sutherland's work from 1968 in which a simple wireframe was overlaid on the physical world [33]. The system was based on a CRT based head mounted display. Sutherland demonstrated the use of mechanical and ultrasonic head position sensors for tracking the orientation and position of head in 3D space. His ultimate thought is shown in his work titled *"The Ultimate Display"* [34], in which he speculates the increased use of keyboards in future systems as he mentions,

"As more and more on-line systems are used, it is likely that many more typewriter consoles will come into use. Tomorrow's computer user will interact with a computer through a typewriter. He ought to know how to touch type."

At the end of his work he presents his vision of the ultimate interaction in the real world as he describes the ultimate augmented reality,

"The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked."
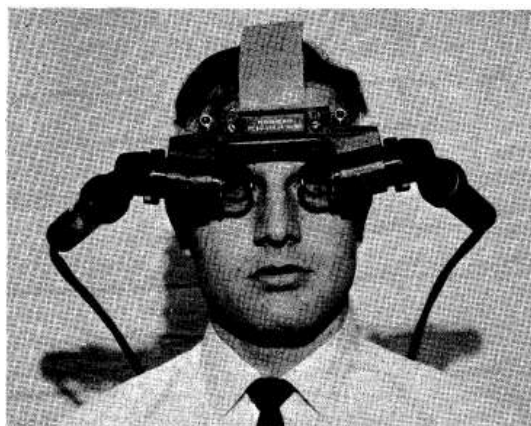
Figure 4-2 Ivan Sutherland's CRT based HMD [33]
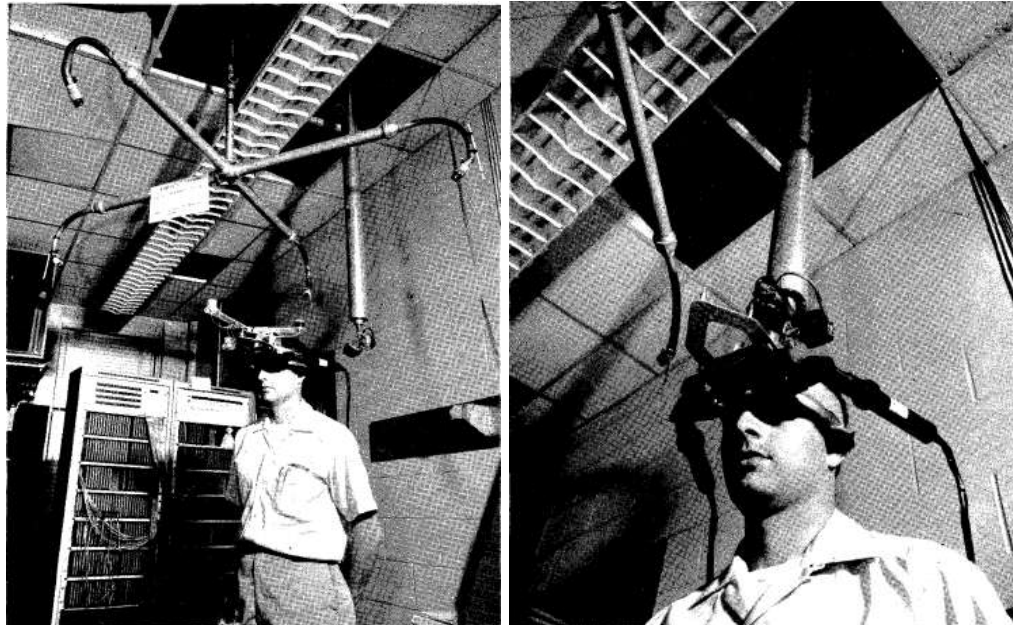
Figure 4-3 (Left) Ultrasonic head position sensor (Right) Mechanical head position sensor [33]

4.5   Important Conferences and Journals

The conferences related to Augmented Reality started in the last decade. Prior to that AR related work has been presented in conferences relevant to the enabling technology or applied technology discussed in that work. ISMAR is the leading conference on AR according to the work presented by prominent authors (section 4.3). The articles gathered in this research were presented in the following conferences:

- ISMAR: International Symposium on Mixed and Augmented Reality
- IWAR: International Workshop on Augmented Reality (Started in 1998, merged with ISMAR)
- ISAR: International Symposium on Augmented Reality (started as IWAR, became ISAR in 2000 and later merged with ISMAR)
- ISMR: International Symposium on Mixed Reality (Started in 1999, merged with ISMAR)
- IEEE Virtual Reality Conference
- IEEE Computer Graphics and Applications
- International Conference on Virtual Systems and Multimedia
- International Conference on Machine Vision

At the time of this writing we haven't been able to find a single journal specific to Augmented Reality. However, works related to AR have been published in journals related to Machine Vision, Entertainment and Arts, Human Computer Interaction, Virtual Reality and in journals related to the enabling or applied technology discussed in specific work. The prominent AR related research works have been published in the following journals.

- MIT Press Journals - Presence: Teleoperators and Virtual Environments 1992
- International Journal of Human-Computer Interaction (Publisher: Lawrence Erlbaum Associates)
- IEEE Transactions on Visualization and Computer Graphics
- IEEE Computer Graphics and Applications
- Elsevier - Computers & Graphics
- Computer Animation and Virtual Worlds (John Wiley & Sons Ltd)
- Personal and Ubiquitous Computing (Springer-Verlag)
- IEEE Transactions on Multimedia

4.6 Active and Influential Researchers

As mentioned earlier, in our study we have used the g-index (global citation performance) as the criteria for finding the most active and influential researchers in AR. Considering the value of this index, we have found four most active and influential Researchers namely Ronald Azuma, Mark Billinghurst, Dieter Schmalstieg and Hirokazu Kato. Ronald Azuma is currently research leader at Nokia research center at Hollywood, USA. His main focus is on enabling technologies in AR and is well known for his definition for AR and his ground breaking works for reviewing the technology. Mark Billinghurst is director of Human Interface Technology Lab NewZealand (HITLabNZ). HITLabNZ is working on state of the art interfaces with most of its current projects related to AR and its application in variety of disciplines. One of the projects relating to mobile platforms is Android AR which is also relevant to our case study. Dieter Schmalstieg leads the research on Studierstube [36] at Graz University of Technology (TUGraz). Hirokazu Kato is from the Graduate School of Information Science at the Nara Institute of Science and Technology. He, working alongside Mark Billinghurst, has created marker based ARToolkit that has been ported to different platforms and different programming languages.

4.7 Current Research

The current research in AR has remarkably shifted to handheld AR, partly due to the new hardware for handheld devices incorporating almost all of the enabling technologies in a single device and partly due to the consumer focus on handheld systems as well. The consumers are interested in these devices due to ease of availability and affordability. Studierstube [36] which started as a project for collaborative AR has shifted its focus from 2005 to handheld AR and Studierstube ES [37] has been released which is commercial product optimized for handheld devices. Android AR from HITLabNZ also gives hint to this shift. The discussion of the other APIs currently available and the aspects of AR system they cover are presented in more detail in section 5.2.

In core enabling technologies, the focus is on making tracking more efficient on mobile platforms. In addition, efforts are being made in markerless tracking and tracking in unprepared environments [38].
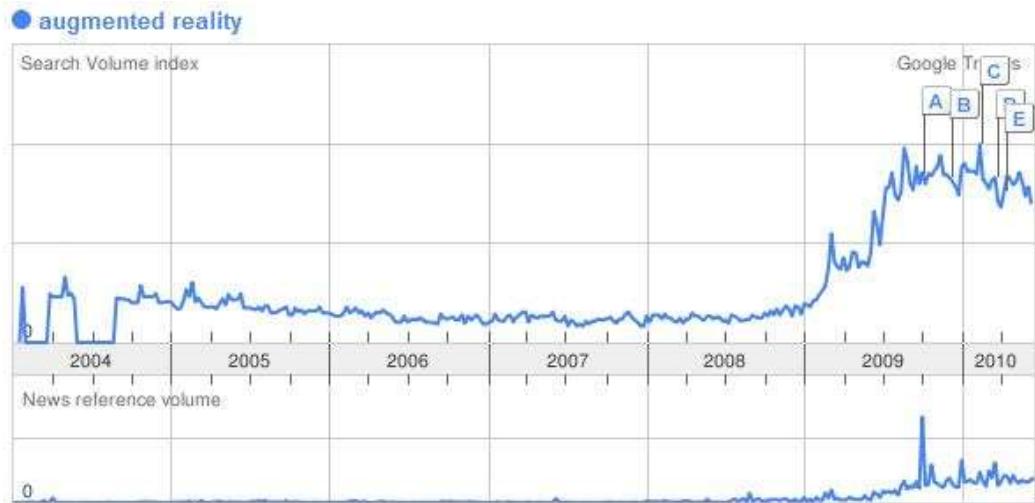
Figure 4-4Search Volume Index and News Reference Index of
Augmented Reality in Google Trends as of 27 June 2010

Apart from the current research trend, years 2009 and 2010 have seen remarkable increase in interest in Augmented Reality. This is apparent from Google Trends which shows considerable increase in Search Volume index and News Reference Index (figure 4.2).

4.8   Current AR Research in Digital Cultural Heritage

Among the articles gathered as a result of systematic literature review, we have filtered out the works which were specific to applying AR in Digital Cultural Heritage. We have reviewed these systems based on the *System Type*, the *Software Technologies used* to realize the system, *Devices used*, *Registration Method, Interaction Method* and *Evaluation Method.* An overview of these projects in tabular form can be found in Appendix A. These works are discussed one by one below:

4.8.1   AR guide [39]

System Type: AR guide is a Prototype system developed for *Museum of Fine Arts in Rennes, France*. The aim of this system was to augment virtual information relating to the paintings in the exhibits of the museum.

Software Technologies used: The software technology employed to realize the system was MAGIC Engine Software Frame work which includes, OpenCV to capture and analyze the video, ARToolkitPlus for tracking, OGRE3D, an opensource object oriented 3D engine for rendering 3D objects, OpenAL for audio and XERCES for parsing xml.

Indoor/Outdoor: AR guide is primarily intended for indoor museum environment.

Devices Used: The Ultra Mobile PC (UMPC) Samsung Q1 was used for the AR guide software application. Archos 404 was used to record interaction of users for evaluation purposes.

Tracking Method used: AR guide uses the paintings themselves as the tags or markers.

Interaction Method: The interaction with AR guide is based on Buttons present on UMPC and its touch sensitive screen.

Evaluation Method: The researchers employed a number of evaluation methods. Among them are video recording using a camera placed in the center of the scene, Interviews, Judgments, surveys, workshops and questionnaires.

(a)   (b)

(c)   (d)
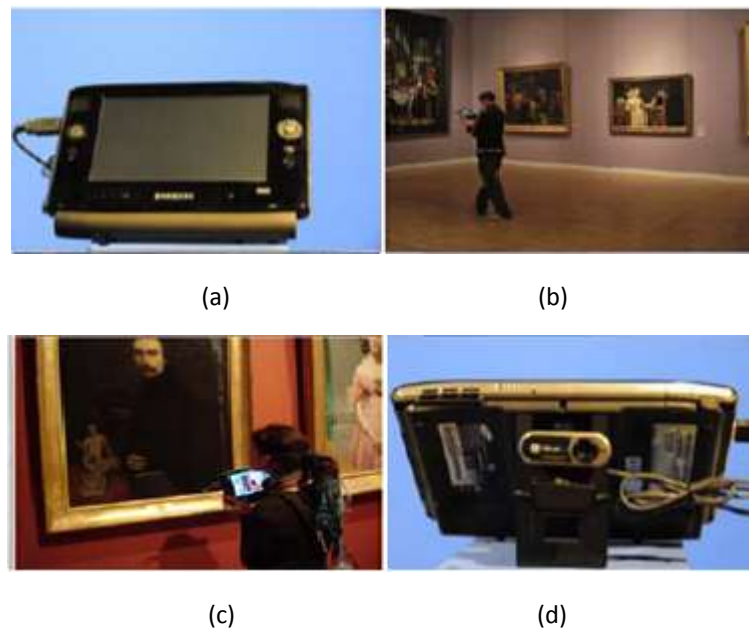
Figure 4-5 (a) UMPC Samsung Q1 handheld device front (d) and rear with camera attached to it.(b)(c) User experiences AR guide system on handheld device and its use in the art gallery at Museum of Fine Arts, Rennes, France [39]

4.8.2   MR System - Cretaceous life at Orlando Science Center [40]

System Type: MR System is a complete system developed as a result of the research conducted by University of Central Florida in participation with Research in Augmented and Virtual Environments (RAVES). MR System presents the visitor with an augmented experience of ancient sea life at Orlando Science Center. It is based in an existing dinosaur exhibit. The system can also be configured to use for collaborative experience in Augmented Reality.

Software Technologies used: MR System is based on MR Engine which uses Open Scene Graph for scene management and Cal3D for character animation. Port Audio is used for sound and a DMX chain communicates with special effects devices.

Indoor/Outdoor: MR System is an indoor system for a museum environment.

Devices Used: Mixed Reality Dome has been used along with transmitters, trackers and a custom designed sound system.

Tracking Method used: The authors mention their preferred method as acoustical in general, however they haven't discussed the tracking in context of MR System they have developed.

Interaction Method: The MR System uses a story telling approach in which a virtual guide appears at the start of the experience, the hall fills up with water and sea creatures appear. The virtual character guides them through the journey of the past.

Evaluation Method: No specific evaluation method mentioned.

Figure 4-6 The mixed reality view showing sea creatures
that user can experience using the MR System at Orlando
Science Center, Florida, USA [40]

4.8.3   Visualization of Broken or damaged objects [41]

System Type: In this project, a prototype system is developed which augments the broken historical artifacts with virtual reconstructed parts. The system used similar architecture as ARCO[42] system.

Software Technologies used: The project used IMMR (Interactive Model Refinement and Rendering) tool from ARCO[42] project for model creation. The system is developed using Augmented Reality Interface Toolkit [43]. Photomodeller by EOS systems is recommended by authors for reconstruction of complex objects. In addition to this Matlab Camera calibration Toolkit was used to calibrate the web camera.

Indoor/Outdoor: The system is intended for use in indoor environments.

Devices Used: The hardware used by the system includes cy-visor color HMD for display of the augmented model, a web camera to capture the video, a Digital Camera (Canon EOS – D30) for photo capturing required for 3D content generation. The augmented reality application runs on HP workstation (equipped with two 2.4GHz Xeon processors and 1024 MB of memory).

Tracking Method used: The system uses marker based tracking.

Interaction Method: The interaction is with a reconstructed augmented model of the artifact on Table top augmented exhibition. The interaction is based on keyboard, mouse and markers.

Evaluation Method: The authors suggest future user studies to evaluate the system and refine accordingly.

Figure 4-7 A damaged cup with its virtual handle
recovered in augmented reality [41]

4.8.4   AR-museum guide [44]

System Type: This AR system is developed as part of the 'The Louvre - DNP Museum Lab' (LDML) project. It is developed for 'Musée du Louvre' in cooperation with a Japanese company DNP (Dai Nippon Printing Co. Ltd). The project consists of two systems, the presentation room system and the guidance system.

Software Technologies used: The project used Unifeye SDK which is a commercial AR platform developed by a German company named Metaio. The software is developed in C# programming language and uses ActiveX Controls. For non- AR exhibits, the system uses Flash technology for audio presentations.

Indoor/Outdoor: The system is intended for use in indoor museum environments.

Devices Used: The hardware used by presentation room system includes LCD Screen with an attached camera connected to a PC via cable. The guidance system uses a mobile LCD based handheld system, Fujitsu BIBLO LOOX-P (Intel Core 2 Duo 1.2 GHz)(0.96 KG) 8.9" screen.

Tracking Method used: The system uses markerless hybrid tracking.

Interaction Method: The interaction is incorporated using a virtual character representation of a historical personality who guides the visitor through the museum exhibits. Virtual floating balloons are used to guide user to specific point of interest.

Evaluation Method: The evaluation methods used in this project include aural, questionnaire, observation, analysis of action logs and interviews.

Figure 4-8 A visitor using Mobile guidance system
from AR-museum guide project to move around
in the museum [44]

4.8.5   ARCO [45]

System Type: ARCO (Augmented Representation of Cultural Objects) is a project whose objective is to develop technologies related to content production, content management and content visualization for museums. This project has presented architecture of ARCO system and built tools for each of the integral parts. The project aims to present virtual exhibits online and AR exhibits inside the museum environment.

Software Technologies used: The constituent technologies of the ARCO system are ARCO database, ARCO Content Management Application (ACMA), IMMR (Interactive Model Refinement and Rendering)[13]. ARCO AR Application is developed using MFC, ARToolKit, DirectShow and OpenVRML. The VR part of the project was intended to be used on any standard browser with VRML plugin for visualization of exhibits on the web.

Indoor/Outdoor: The system is intended for use in indoor museum environment and for online web users.

Devices Used: No particular hardware is mentioned. However ARCO project refers to some scenarios in which a camera and display can be built into kiosk for interaction or the application can be used using a touch screen display.

Tracking Method used: The system uses marker based tracking.

Interaction Method: ARCO system allows using contemporary devices like mouse, marker and keyboard to move virtual objects with 6 DOF. The user can control which objects can appear in scene. Since this is a framework, it also allows museum staff to create their own learning scenarios. ARCO system can be used to engage user in interactive scenarios like exercises, quizzes and games.

Evaluation Method: The evaluation methods used in this project include feedback by museum users and museum user trials.

Figure 4-9 Augmented Reality based Interface for ARCO project displaying artifacts on marker while running on a desktop system. [45]
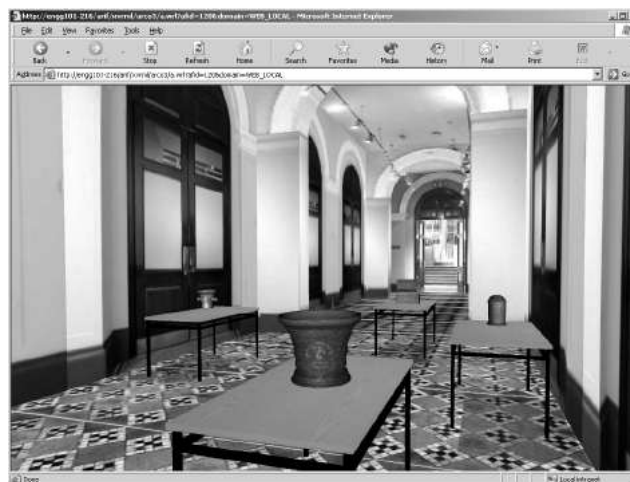
Figure 4-10 Virtual Reality based interface for ARCO project displaying artifacts in a Virtual Museum while running in a browser on a desktop system [45]

4.8.6 AR Exhibits [46]

System Type: AR Exhibits groups the five different AR related projects developed by HITLabNZ for different Museums, Libraries and Science Centres. These five projects are:

- BlackMagic Kiosk (Telecom Technology Pavilion,New Zealand,2003)
- S.O.L.A.R System (TeManawa Science Centre ,Palmerston North, New Zealand)
- AR Volcano Kiosk (Science Alive!, Christchurch, New Zealand)
- Digital Archiving of Historical Artefacts (The Canterbury Museum Christchurch, New Zealand)
- The eyeMagic Virtual Story Book (South Public Library, Christchurch, New Zealand).

Software Technologies used: All of the exhibits above used customized software developed using ARToolkit.

Indoor/Outdoor: The systems are intended for use in indoor museums, science centres and library environments.

Devices Used: AR Visor has been used in these projects. It consists of a video-see through display with a camera attached to it.

Tracking Method used: The system uses marker based tracking.

Interaction Method: According to the theme of the projects, each used different interaction technology. Details can be found in [46].

Evaluation Method: The evaluation methods used in this project were observations and workshops.

| (a) | (b) | (c) |
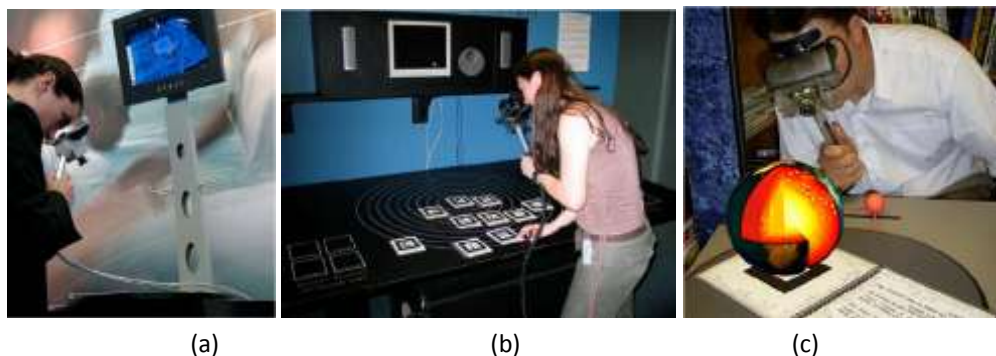
Figure 4-11 (a) BlackMagic Kiosk presents the history of America's cup using animated Augmented Reality , (b) S.O.L.A.R System is an edutainment based AR to interact with planets in solar system using markers, (c) AR Volcano Kiosk presents the scientific details of different aspects of volcanoes [46]

(a)   (b)
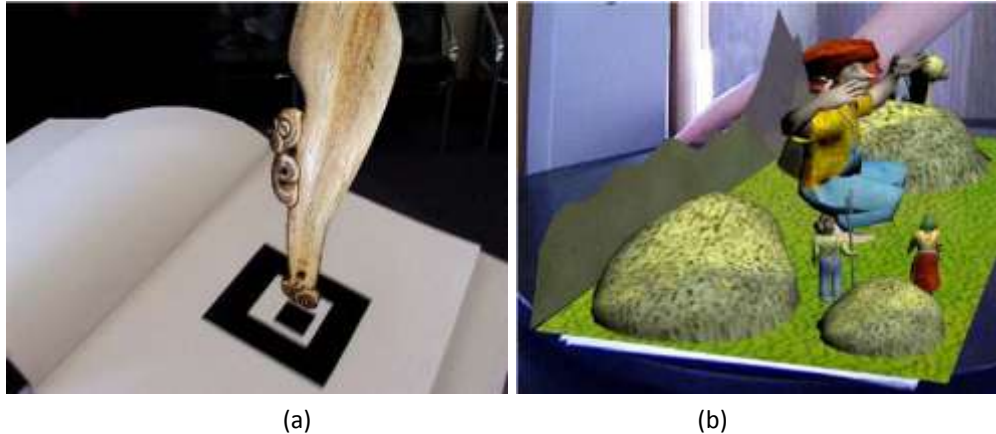
Figure 4-12 (a) Digital Archiving of Historical Artifacts presents AR representation of Artifacts in a Magic Book (b) eyeMagic Virtual Story Book presents children with augmented and animated virtual characters and story narrations [46]

4.8.7   ARCHEOGUIDE [48]

System Type: ARCHEOGUIDE aims at providing AR based tours to visitors of archaeological sites. The system reconstructs remains, provides the users with audio narration and recreate ancient life scenarios. It was tested at the remains of cultural heritage site of Olympia, Greece. It is developed for mobile and wearable computers.

Software Technologies used: The backbone of this system is ARCHEOGUIDE Site Information Server (SIS) which provides, audio, Visual, 2D and 3D data [29]. The system is developed using JAVA. VRML has been used to store 3D scene information.

Indoor/Outdoor: The system is intended to use for outdoor archaeological site visits.

Devices Used: The devices used by the system include WLAN devices, HMD (AR binocular unit nVision VB-30), Laptop (800 MHz Pentium III processor, 256 MB RAM, 20GB hard disk, nVidia graphics card), GPS devices (Garmin 35-HVS GPS receiver), Compass (Precision Navigation TCM2 digital compass), Pen Tablet (Fujitsu Stylistic 3500R pen-tablet, 500 MHz Celeron Processor, 256 MB SDRAM, 15 GB hard disk, 10.4" reflective SVGA TFT monitor) and PalmTop (Compaq iPAQ PDA, 64 MB RAM, touch screen, Dual PCMCIA card expansion jacket). GPS used for Pen Tablet was PCMCIA GPS and the compass used with it was Precision Navigation TCM2.

Tracking Method used: The system used hybrid technique for tracking which includes GPS, DGPS and digital compass along with optical tracking.

Interaction Method: The interaction methods included multimodal techniques. The movement of the user at the archaeological site was in itself interactive. The specific techniques also varied according to the display device in use. Furthermore, the recreation of ancient life scenarios was another interactive technique.

Evaluation Method: User Reviews (ordinary users, site staff, archaeologists, and technology experts) [21] were used for evaluation of the system.

Figure 4-13 A user experiencing AR based tour of the archaeological site of Olympia in Greece while wearing ARCHEOGUIDE system [48]

4.9   Cutting Edge and Future Prospects

In case of museums, Damala A. et al. [39] argue that with increasing processing power of devices and increase in efficient handheld mobile systems, the future visitors of museums would possibly be able to experience AR with their own mobile devices. According to Liarokapis and White [41], the major problem currently is with the tracking which is one of the enabling technologies and needs to be explored further. Schmalstieg and Daniel [37] present their experiences with handheld AR. They argue that the marker based tracking in handheld devices is not suitable for many real applications and suggest efforts toward natural feature based tracking for handheld devices. Dieter Schmalstieg as the director of Studierstube [36] project at TUGraz has shifted project's focus from collaborative AR to handheld AR which also aligns with current trends and future prospects of AR towards mobile devices.

From current research and trends, it's clear that future AR systems would be mostly using handheld platforms and work is required to make tracking techniques more efficient. In addition to this, as stated by Woods, E. et al [50] in a study about AR exhibits, the user studies for such systems would help refine future designs. But in contrast to the vision of future by Ivan Sutherland [51], the current systems are far from the Wonderland into which Alice walked.

5 UPPÅKRA TEMPLE EXHIBIT: A CASE STUDY

After careful investigation of the literature on Augmented Reality and its application in cultural heritage, in this chapter we illustrate how we have proceeded with the case of Lund University Historical Museum in implementing AR in context of the Iron Age city of Uppåkra. Uppåkra is located five kilometers away from the city of Lund. It is an ancient city that existed around 1st century BC and flourished for around 1000 years. Since the discovery of the site in 1934 excavations have continued intermittently. The artifacts found number more than 20000 [52] and most prominent of them are on display in the BARBARICUM exhibition in the museum.

In an initial meeting with the museum we decided upon the particular exhibit we have to deal in the BARBARICUM exhibition. We made a detailed analysis of the exhibits and the artifacts they were featuring. The floor plan of the BARBARICUM exhibition is shown in figure 5.1. The visitors enter from point 1 shown in the figure and proceed to point 5 on the left which features the exhibition about temple and sacrificial rituals. Moving forward from this point, the visitors go clockwise on this floor plan to visit the whole exhibition.
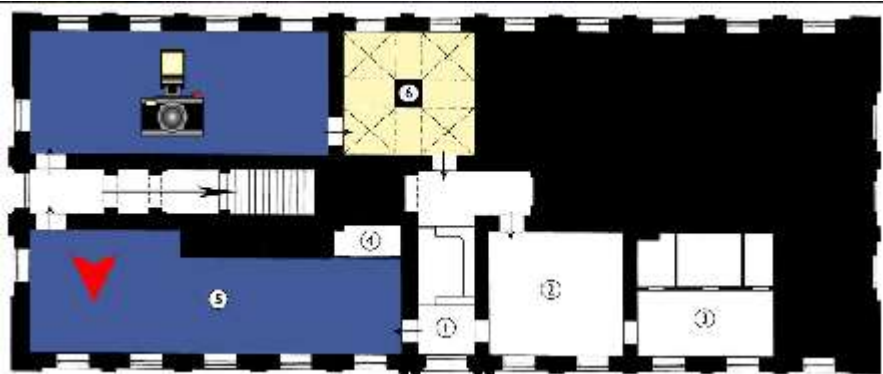
Figure 5-1 Floor plan of BARBARICUM exhibition in Lund University Historical Museum (Image from http://www.kulturportallund.se)

The first exhibit at point 5 in the figure above is about Uppåkra temple which had been a place of religious significance in the city of Uppåkra. At this exhibit the user gets his/her first impression about Uppåkra and the exhibition. The Uppåkra temple had been of significant importance in the ancient city. The best explanation to this building and its importance can be observed by the explanation of archaeologist Lars Larsson [52] as he explains about its remains,

"The building's remains were so well preserved that the plan could be established immediately after being exposed by the initial topsoil clearing. The house had straight gables and slightly convex walls. It was 13.5m long and 6m wide, and four large interior post-holes, placed in pairs, had supported the roof (Figure 3) [figure 5.2]. *The dark post-hole fills as well as the fills for the wall-trenches were clearly visible against the yellow clay of the floor surface. The house had three entrances, one facing north and two facing south. The south-*

west entrance had two enlargements that probably relate to a small entrance structure. In the centre of the house were the remains of a fireplace. Obviously, this was a distinctive building."

According to current interpretations of the archaeologists, the temple hosted the sacrificial rituals. In our observation, the temple building has been least visible to the visitors since it has not much left in remains that could be placed in the museum as compared to other exhibits where one can see the remains of the actual objects. Within the temple walls, archeologists have recovered, gold figure foils, remains of wooden pillars, a beaker, a bowl and a fire place. A detailed plan of the temple is shown in figure 5.2. In the following section we have discussed the current exhibit environment.
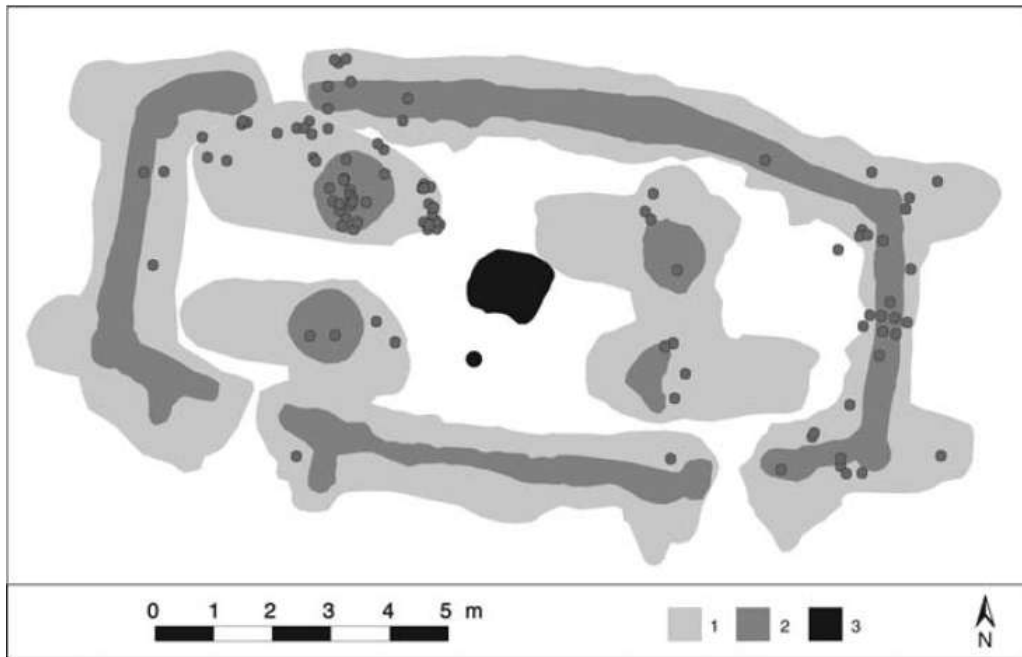
Figure 5-2 Plan of the Uppåkra temple by Larsson [52], (1) Digging done by the Archaeologists (2) the walls and the posts of the temple (3) the fireplace and small dot representing the place where the beaker and the bowl was found. The smallest dots represent places where gold-figure foils were found

5.1 Assessing Exhibit Environment

The exhibit environment featuring Uppåkra temple is right at the start of the exhibition. The current environment is established as a low light environment to mystify and create sensation of being at a ritual place. There are background sounds to simulate the acoustics of the conceived environment. Right in the middle of the exhibit is a wooden pillar which signifies one of the pillars that used to be inside the temple. This wooden pillar has attached to it actual gold figure foils that have been recovered in the excavation. There are displays showing mystical digital animation videos, which again give the feeling of being in actual temple.

Figure 5-3 The current temple exhibit environment with a central post representing post of the temple and an animated display on the right

The interpretation of the outside of the temple is presented to the visitor with pictures on the wall of the exhibit. One picture features the foundations of the Uppåkra temple (figure 5.2) and another its rendered reconstruction. However, the lack of proper featuring of the outer portion of the temple can be included with augmented reality. Our initial concerns regarding the exhibit environment were the lighting conditions which could have affected the choice of software API to be used to develop this application.

Since this is an indoor museum environment and the environment can be prepared in a specific manner, our study in section 4.8 points at the use of marker based API, as it has been used in previous such studies. However, as mentioned earlier, the low lighting conditions could cause poor tracking and registration for markers. In order to mitigate this problem there could be two alternatives. One solution was displaying the marker in an LCD display with low glazing and brightness rather than printing it. An LCD with highly glazed surface could also cause problems when viewed from different angles due to light reflections. So another alternative considered was to project the light on printed markers. We considered the second alternative. To choose from the available marker based APIs, a review of these APIs was conducted and is presented in next section.

5.2   Considered APIs

Our assessment of the environment reduced the potential APIs to consider before the actual prototyping. Different APIs address different aspects of the AR system development, ranging from registration and tracking to complete framework solutions. MacWilliams et al. [53] present in detail a formal design pattern for an AR

system and describe relationship between specific components. Some APIs can cover all the components involved in this design pattern and others are specific. If an API covers most of the aspects of MacWilliams design pattern, it could significantly improve the development time. In the sections below we will go through the prominent AR APIs and explore which of the aspects of the MacWilliams design pattern they cover.
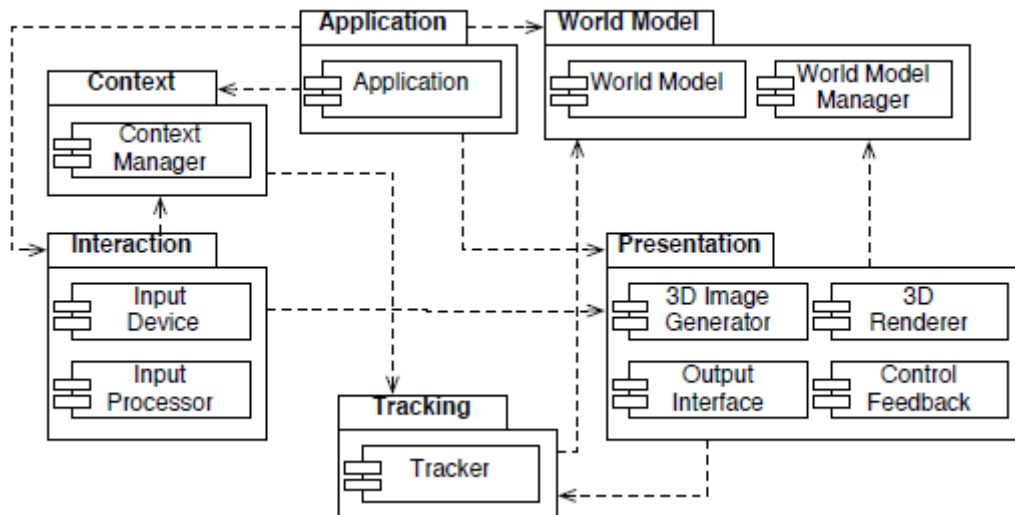
Figure 5-4 Overview of Architecture of AR System by MacWilliams et al.[53]

5.2.1 ARToolkit

ARToolkit is one of the earliest APIs available for development of AR applications. It provides support for tracking and registration of objects and is a marker based API. The rendering and manipulation of the 3D virtual models has to be done in a third party API like OpenGL or any other rendering API. It has been developed by Hirokazu Kato working alongside Mark Billinghurst. It is also ported to other programming languages with its implementations available as FLARToolkit for Flash and JARToolkit for Java. The latest open source version of ARToolkit is ARToolkit 2.7. Its ongoing development is done by ARToolWorks Inc. and has been commercialized with ARToolkit v4 Professional onwards which is the commercial version available under license. Another commercial version of this API currently available is ARToolkit NFT v3.2 which provides natural feature based tracking.

For more complex scenes where OpenGL based low level programming becomes time intensive, an OpenSceneGraph based port of ARToolkit called osgART is also available in both standard and professional versions where the former is open source (GPL license) and the later is commercial. With osgART, one can use all the features of OpenSceneGraph API in an AR application.

ARToolkit itself covers only tracking subsystem in MacWilliams design pattern but the OpenSceneGraph based osgART extends it to cover the Presentation and World Model subsystems as well. The developer, however, still has to take care of Application, Interaction and Context subsystems.

5.2.2 ARTag

ARTag is another marker based API for tracking markers in real time video. It is inspired by ARToolkit and is developed to enhance tracking using more complex image processing techniques. It was developed by Mark Fiala to make use of increased processing power of computers. One of the APIs that is based on ARTag includes Goblin XNA (A Platform for 3D AR and VR) which also incorporates OpenCV, DirectShow and InterSense APIs. Goblin XNA can be used to develop AR applications for Windows platform and Xbox consoles. ARTag, at the time of this writing, is not available for download due to licensing issues.

Similar to ARToolkit, ARTag only provides tracking and registration and virtual object rendering has to be purely done in OpenGL. In MacWilliams design pattern, it only covers the tracking subsystem and the rest has to be developed depending upon the application.

5.2.3 ARToolkitPlus

ARToolkitPlus is a marker based tracking API that contains revised code from ARToolkit and has a new API which is incompatible with ARToolkit. It has been developed as a separate project by Daniel Wagner at Christian Doppler Laboratory, TUGraz. It is no longer an active project and ARToolKitPlus v2.1.1 is the last version. It has also incorporated concepts from ARTag. It is followed by Studierstube Tracker which has been developed from scratch with Handheld AR under consideration.

Similar to ARToolkit and ARTag, ARToolkitPlus covers only the tracking subsystem in MacWilliams design pattern.

5.2.4 NyARToolkit

NyARtoolkit is a language port of ARToolkit. NyARToolkit is available for Java and C#. This project is based in Japan and to date its documentation is in Japanese. It has been used in first phase of our prototype development along with OpenGL. NyARToolkit doesn't provide any further subsystem in MacWilliams design pattern as it originally inherited from ARToolkit.

5.2.5 Studierstube

A more complete solution for rapid building of AR applications is the Studierstube framework. Studierstube [36] was first developed for collaborative AR applications and its focus has been switched to mobile handheld applications. Studierstube for desktop systems is open source and is available under GPL licensing. However, there is a commercial version for mobile platforms named Studierstube ES. Studierstube uses a component based approach of building applications. Studierstube is in turn based on different APIs which include Coin3D for scenegraph manipulation and higher abstraction for rendering, OpenVideo for Video source and sink handling, OpenTracker for tracking device handling, QT for cross platform windowing and ARToolkitPlus for tracking and registration.

Use of Coin3D in Studierstube allows one to use Open Inventor based scenegraphs (*.iv files) in Studierstube AR applications. OpenTracker allows tracking systems other than marker based to be incorporated in AR applications. Due to its component based architecture, other APIs can be easily incorporated in Studierstube. Studierstube covers Tracking, Presentation, World Model, Application, Context and Interaction subsystems of the MacWilliams design pattern. Therefore it provides the fastest way to develop AR applications among the APIs considered so far.

5.2.6   DWARF

DWARF is Distributed Wearable Augmented Reality Framework. It provides a concept of collaborating distributed services in AR applications and requires modeling of applications as distributed systems. CORBA is used for communication between these components. DWARF provides a complete solution for AR applications but due to the requirement to model each application as distributed application makes it harder to utilize than Studierstube, however for large systems, however, DWARF could provide a viable solution. DWARF also covers all the subsystems in the MacWilliams design pattern.

5.3   System Development Process

From the APIs considered above, we decided to use Studierstube due to the scale of the application at hand and due to its full conformance to MacWilliams design pattern. If we had to consider an AR based guidance and visualization system for whole museum, we could have chosen DWARF. The prototype AR System development process took place in phases where each phase added value to the prototype. At the start of each phase, a meeting was held. According to the agreed upon factors and the software and hardware platform, the prototype was worked upon and the difficulties documented.
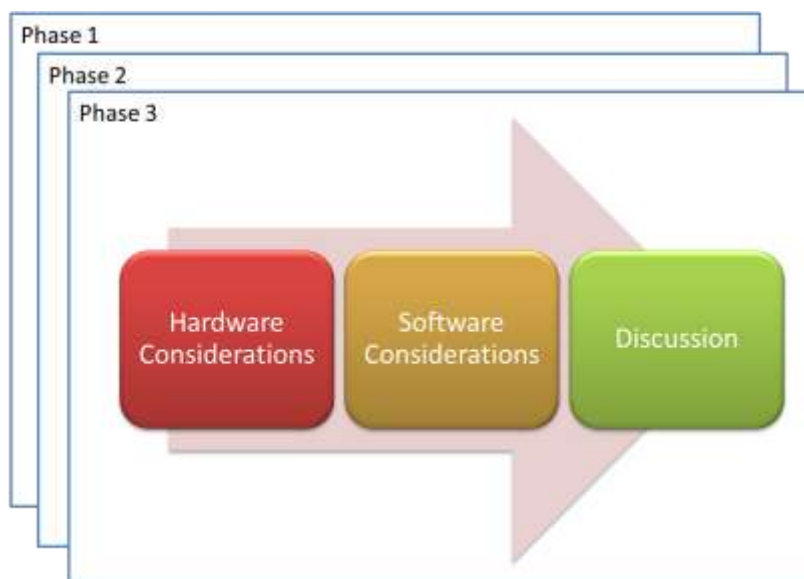
Figure 5-5 Phases and steps in System Development Process

5.4   Phase 1

In first phase of this case study we considered a smart phone based target platform. The hardware considerations, software considerations and the limitations faced in this phase are discussed below.

5.4.1   Hardware Considerations:

For hardware, we have considered Android DevPhone (commercially called HTC Android G1) with 528 MHz processor speed and 192 MB of RAM (figure 5.6).

Figure 5-6 Android DevPhone (Android G1)
(http://www.androidg1.org/)

5.4.2   Software Considerations

Android DevPhone uses Google Android platform which is an open source mobile operating system. The application logic development for this platform is done in JAVA. The GUI can be developed using XML in a declarative fashion. The completely developed applications are deployed as platform specific APK packages. To include marker tracking capability in our application we had to choose the only available option of NyARToolkit. It is the only free AR API for Android. Android AR, developed by HITLabNZ, is another AR framework for the Android platform but it is not available for the time being. In our prototype we have created a CamDemo Android Activity class which is the main class launched by the Android platform. It contained a Preview object which extends SurfaceView and it implements SurfaceHolder callback to receive events from the SurfaceView. The Preview class also contains the onPreviewCallBack() function that provides captured frame data using the Android Camera API. The Preview class has a NyARSingleDetectMarker object which allows us to track a single marker in the captured frame. The development environment used in this phase was Eclipse ADT with NyARToolkit.

5.4.3   Discussion

In this phase we were able to build a demo application which displays a simple cube on a traditional 'Hiro' marker. However, we were unable to achieve interactive frame rates. Our demo application ran at 1 frame every 3 seconds.

We later figured out that its due to the problem in onPreviewCallBack() function which is provided by the Camera API in Android platform v1.6. In this version of the Android OS, each time the callback is called a copy of the current frame is sent which requires to be cleared off before the next time this function is called. In order to do this, the garbage collector jumps in which takes a lot of time to clear off the previously copied data resulting in piled up heap of data causing more time for cleaning than gathering frames which ultimately results in application crash. This is described in detail in this thread [54] at Google Code. According to this thread, this defect has been solved in the platform version 7 that is Android 2.1 but it was still not visible directly through API (rather available in object code) at the time of this writing. Nevertheless, to access this function Java Reflection has been successfully used by some developers. Our current Android G1 phone supports only Android 1.6.

The work around for this could have been the use of JNI (Java Native Interface) library to call the functions of original ARToolkit in our Java based demo. The other work around could be to use Android NDK (Native Development Kit) which allows to build performance critical applications on the Android platform. Android NDK also provides the utility to embed libraries in Android platform native (.apk) packages.

5.5   Phase 2

After this crucial step, we shifted our focus to a Windows based handheld platform. At the end of this phase we had been able to present a working prototype that was demonstrated in a workshop on "Virtual Heritage" on April 12, 2010 and a seminar on "Visualisering inom arkitektur och stadsbyggnad" (Visualization in Architecture and City Planning) on May 10, 2010 at Lund University . The hardware and software considered and the decisions made in Phase 2 of the process are described below.

5.5.1   Hardware Considerations

In this phase the development platform and the target platform was the same. The hardware used was a Dell Studio 15 Laptop system with 2.0 GHz Core2Duo processor, 3GB of RAM and ATI Mobility Radeon HD 3400 Series graphics card with 256 MB of dedicated graphics memory. The built in 2 megapixels camera was used to acquire video. During the development process we kept in mind to preserve the processing requirements as low as possible since we intended to use a tablet device in next phase.

Figure 5-7 The Dell Studio 15 laptop which was used as
development and target platform in phase 2

5.5.2 Software Considerations

Studierstube API was considered for development at this stage. Studierstube provides a complete framework to build AR applications for handheld devices. One of the major advantage in using Studierstube is its built-in support for OpenInventor (*.iv) scene graphs. Studierstube also covers all aspects of MacWilliams design pattern (as discussed earlier) hence allowing rapid AR application development.

Modeling and Integrating 3D Scene

The 3D model we considered for our prototype application at this stage was an initial interpretation of Uppåkra temple that was modeled in 3Ds Max and had a plain terrain (figure 5.8). The 3D model had 1096 polygons. Since Studierstube uses OpenInventor format for scene description, we had to create a 3D model in confirmation with this standard. This allowed us to only use standard textures and materials on the temple.

Figure 5-8 Initial Interpretation of Uppåkra temple used in
prototype application

The 3D models required for the AR application can be built using any 3D modeling tool and can be exported to VRML format which can eventually be converted to 'iv' files using Inventor Tools (IVTools) [55]. These 'iv' files can be directly used in Studierstube based application. The steps involved in porting our scene from a modeling tool to AR prototype are illustrated in figure 5.3.

Figure 5-9 Steps required to port 3D scene from a modeling
tool to a Studierstube based application

Configuring Studierstube

In order to configure a Studierstube based application, the following files are required to be attuned:

- kernel.xml
- opentracker.xml
- openvideo.xml
- viewer.iv

In kernel.xml, we have modified the sceneFile parameter of application tag to include our scene file name. We have altered the simplescene.iv from example application to suite our needs for the scene file and to include our exported scene graph.

opentracker.xml can be modified to include multiple markers for tracking. Figure 5.4 shows an example code snippet to add an additional marker tracking support. We have used the default single marker configuration using marker with tag-id of 67. Studierstube uses ARToolkitPlus based marker tracking therefore it has the flexibilities of ARToolkitPlus.

```
<EventSink tracking="artTracker1">
    <!-- We add an extra tranformation -->
    <EventTransform scale="1 1 1" rotationtype="euler" rotation="3.141592654 0 0" translation="0 0 0">
        <!-- This source receives data from ARToolKit Plus -->
        <ARToolKitPlusSingleMarkerSource center="0 0" size="0.07 0.07" tag-id="68"/>
    </EventTransform>
</EventSink>
```

Figure 5-10 EventSink for marker with tag-id 68 in
opentracker.xml file

openvideo.xml can be used to refine video capture settings, however, in our particular case the default configurations worked out of the box.

The viewer.iv file contains the settings for adjusting the Studierstube viewer according to applications settings. It has been modified in our case to hide the extra toolbars and wheel widgets.

Integrating Character Animation

The 3D model of the temple augmented with reality seems impressive but it doesn't give the complete alternate to the textual description found in the exhibits. To make our prototype interactive, we had considered to include a character which could guide the user. To implement this interaction, we considered Cal3D character animation library at this stage. Cal3D character animation library describes its own format to store and load characters. The characters can be modeled in 3ds Max, Maya or Blender and can be exported using Cal3D plugins available for these modeling tools.

(a)   (b)

Figure 5-11 Walk animation of a (a) Cal3D Character model (b) and
its skeleton in Cally Demo by Cal3D

In this phase we have worked with the model shown in figure 5.11 which was later replaced in phase 3 with a more appropriate character suiting the context of Uppåkra. In order to load this model in our prototype we have to make it part of the OpenInventor scene graph. For that we need to have the Cal3D model in node kit format for Open Inventor. Luckily this work has been already done for Studierstube 3 in a Phd report about Ubiquitous Animated Agents for Augmented Reality [56] by István Barakonyi. In this study, ARPuppet framework for animated agents is presented to visualize computer system behavior by using mediating virtual animated characters in Augmented Reality. As a part of this study, a cal3DPuppet node had been implemented for OpenInventor that can load Cal3D character model in to scenegraph. The only problem is that this framework had been developed for Studierstube 3 and cannot be compiled in its existing state to Studierstube 4. So we have extracted the cal3DPuppet from ARPuppet project and compiled it with coin3d

version available with Studierstube 4 and Cal3D v0.10 to get a cal3DPuppet.dll library. We have used this library to include the 3D character in our prototype.

5.5.3   Discussion

In this phase our prototype was developed for a static target platform and the manipulation of the 3D model was based on Active interaction (figure 5.12). The Active interaction was not natural, which was also the input we had got while demonstrating our work in the workshop and seminar. Furthermore, to interact with our prototype, the user has to hold the marker vertically which made it impossible to rotate to other side of the temple. We have addressed this issue in phase 3.

Figure 5-12 A user having Active Interaction by holding the marker
(model) while the manipulated model is shown in the display pasted
over top of it.

In addition to this we have faced problems in loading textures for the Cal3D model but character animations worked fine. In figure 5.6, the character model is shown loaded in our application without textures.

Figure 5-13 Textureless Cal3D character model loaded in our
prototype AR application

At the end of this phase we had a meeting with the museum curator and according to his opinion interaction should be based on some storyline and interaction should not be so simple.

5.6   Phase 3

In this phase we have decided to work on Passive interaction with the marker and consequently changed our target hardware platform. In Passive interaction, the marker remains at one place and the user experiences interaction by moving around the marker holding the handheld device. At this stage, we have agreed to include a storyline to the application to see if we can make it more interactive. To do this we had to include sound to the application as well which is discussed in detail in software considerations. To make the temple according to the latest interpretations, it had also been modified. We have also noticed an exhibit of bones in the BARBARICUM which points to animal husbandry and the use of animals for ritual purposes in ancient Uppåkra (figure 5.14).

Figure 5-14 A display in BARBARICUM exhibit showing bones found
at the site of Uppåkra

The bones found at the excavation of of Uppåkra are in very large quantity which tells us about their significance [57]. An animated white horse was added to give an impression of the sacrificial rituals that were related to this place. Every place of spiritual significance has an associated religious personality. To visualize this, a more relevant character of a priestess has been added to the overall scenario on which the storyline has to be based. Another important discovery from the excavation site of temple is a beaker (figure 5.15) made of bronze and silver [52]. To relate this find to the site of the temple, we have made the beaker part of the story line where

priestess holds the beaker (figure 5.19) while explaining about Uppåkra, which is discussed in detail under software considerations in section 5.6.2.

Figure 5-15 Beaker found from the excavation site of the
Uppåkra temple shown in its current state [52]

5.6.1 Hardware Considerations

In this phase our development hardware platform remained the same as in the previous phase. However, for Passive interaction we have switched to a target hardware platform that the user can carry around the marker and that is similar to upcoming tablet systems. The available option we had was a HP Pavilion tx1000 (figure 5.16) which is a tablet system with a 180 degrees turning display. It consists of an AMD Turion 64 x2 Mobile Technology 1.8 GHz with 4GB RAM and Nvidia Geforce Go with 64 MB of dedicated graphics memory. The touch screen of the system has allowed us to implement user interaction by touching the screen. Although the touch screen is designed for interaction with stylus but we have used it for interaction with finger tips for the time being.

(a)   (b)

Figure 5-16 (a) Our target platform in tablet form (b) Our
target platform in laptop form

For capturing video we have attached a Logitech V-UBV49 notebook camera to the USB port. The whole assembly of camera with tablet is shown in figure 5.17.

<div align="center">(a)   (b)</div>
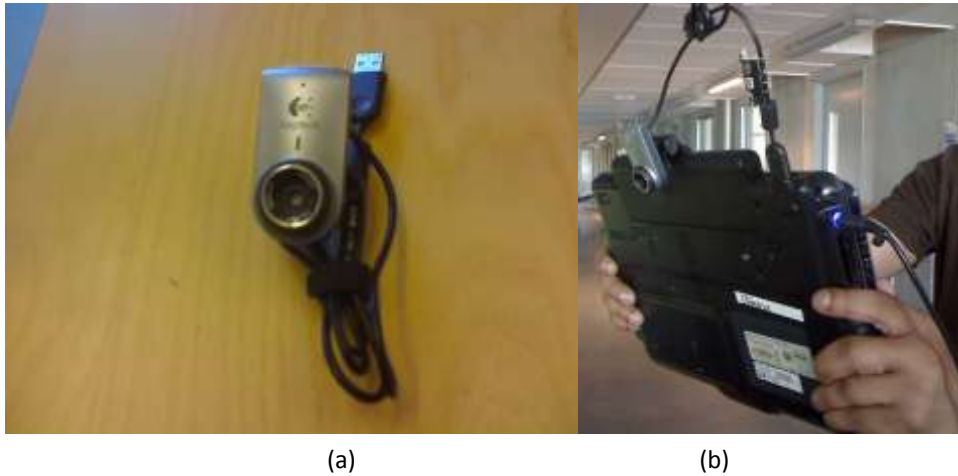
Figure 5-17 (a) Logitech Webcam that has been used to capture real-time video in this phase and (b) its assembly with our target platform

5.6.2 Software Considerations

In this phase we kept on adding value to the application developed in phase 2 using the Studierstube framework and we have tried to eliminate the problems discussed in Phase 2. The changes and additions made are presented one by one below.

Revisiting Temple Model

We have considered a modified version of the temple model in this phase which is the latest interpretation of the Uppåkra temple. An irregular terrain is used to increase realism (figure 5.18). The temple model is made up of 1991 polygons. Standard materials and textures were used to avoid conflicts while exporting the model from 3ds Max to OpenInventor 'iv' format.

Figure 5-18 Latest Interpretation of the Uppåkra temple modeled in 3ds Max and exported to our prototype application

Revisiting Character Integration

In Phase 2, we have ported cal3DPuppet from ARPuppet framework to Studierstube 4. However, as discussed, we were not able to load textures. To overcome this, we have considered shifting our focus to the MD2 format for characters which is available with ARPuppet [56]. MD2 is the character format which is used by Quake 2 to load 3D characters. Similar to cal3DPuppet, we have recompiled the md2Puppet from ARPuppet project with the current version of coin3d to use it in our application as md2Puppet.dll and as a result we successfully loaded fully textured models in this case. The models included in this prototype are a priestess and a horse (figure 5.19, 5.20).

Figure 5-19 Priestess Model included in our prototype holding a beaker which signifies the beaker found at the excavation site of Uppåkra temple

Figure 5-20 Animated Horse character included in our prototype signifying animal husbandry and sacrificial rituals related to the place

Incorporating Storytelling

One of the missing factors in the previous phase was the storytelling approach. Storytelling approach can indulge user into a more interactive experience. We have

decided to present a simple story line in which the priestess did the following steps in order.

- Idle
- Welcoming
- Telling about the surroundings; and later; Asking the user to open the temple door
- Showing an artifact from the temple
- Bidding Farewell

While each of these steps (except for the idle step) the priestess says the following;

1. *Welcome to our temple here in Uppåkra! We are very happy to have you here! Let me get you something…*
2. *Please say hello to our beautiful white horse in the meanwhile!... Could you help me open the door?*
3. *Here in Uppåkra we always offer our guests something to drink! Please drink from this beaker! Please drink from this beaker!*
4. *I hope you will have a good day here in Uppåkra! I wish you all the best! Bye!*

A background sound continuously runs to make user interact with the prototype, it echoes *"Touch the temple and experience the past…"* These sounds have been recorded in Swedish to localize the application.

The sounds have been added to the prototype by appending SoVRMLSound and SoVRMLAudioClip nodes to the scene graph. By default the support for these nodes is not compiled into simage library which is used by Studierstube. To do so we have to recompile simage library by including libsndfile.dll.

Animating Priestess

(a)　　　　(b)　　　　(c)　　　　(d)
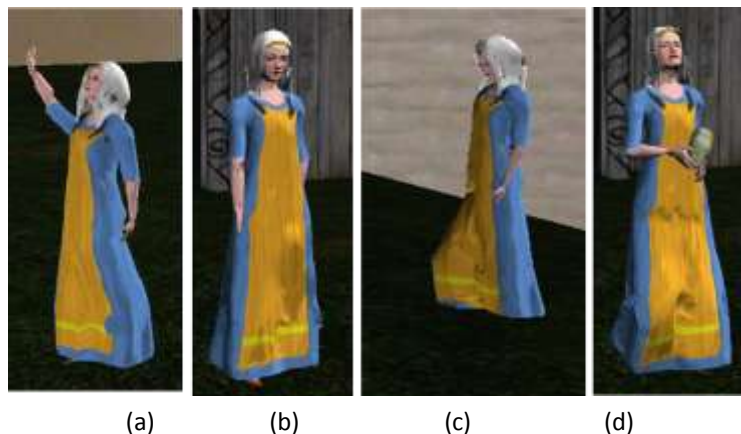
Figure 5-21 (a) 'Wave' animation of Priestess for welcome and farewell
(b) 'Idle' animation for all other possibilities (c) 'Walk' animation for
second step in the storyline (Tell state) (d) 'Walk holding beaker'
animation for third step in the storyline (Show state)

During each of the storytelling steps, the priestess needed to have a particular animation. We have defined four animation postures shown in figure 5.21. These included 'idle', 'waving', 'walking' and 'walking while holding beaker' animations. The 'waving' animation has been used for the first and the last steps of the storyline. The 'walking' and 'walking while holding' beaker animations have been used for second and third steps in the storyline respectively.

Animation States

In order to incorporate the storytelling animation in our prototype we have programmed a simple finite state machine with the five states corresponding to the five steps mentioned in the previous section. The change in state occurs when the user touches the screen. At the final state, the system automatically jumps to the initial idle state.

Figure 5-22 Animation States programmed in our prototype
application for interaction

The synchronization between states and the rotation and translation of the character has been achieved by using Open Inventor engines.

5.6.3   Discussion

At the end of the third phase we had a working Passive interaction based prototype. This prototype provided more natural interaction with the 3D model according to our experience. However, the visitors' experience was yet to be observed and documented (chapter 6). The inclusion of the character allows user to perform primitive interaction with the AR environment. Figure 5.23 shows the simple setup required for experiencing this prototype. We only need to print a single marker and place it on a table top in the museum environment. The user can hold our target platform and can easily move around the table setup to experience the virtual model

of the Uppåkra temple (figure 5.24, 5.25). In contrast to this, Active interaction requires a complete kiosk since the target system is static and it needs to be amended in the exhibit. In Active interaction, the user also remains static which makes him/her unable to experience the true spatial augmentation in reality.

Figure 5-23 A printed marker placed on table top for experiencing the augmented model by moving around it

Figure 5-24 A user holding the device horizontally to experience the table top augmented model

Figure 5-25 A user holding the device vertically to experience the table top augmented model

5.7 Revisiting Research Questions

The first research question has been answered in detail in chapter 4 which resulted in the Systematic Literature Review. The complete steps of our case study conducted have been presented in this chapter to answer the second research question. However, at the end of this case study, we have two forms of interaction at hand and a new question had risen:

- Would the museum visitors be more attuned to Passive Interaction or Active Interaction?

To assess the active and passive interaction with the model we had to evaluate it in a real museum environment. The details of the user evaluation conducted to answer this question are presented in the next chapter.

6   USER EVALUATION OF PROTOTYPES

As a result of the case study conducted for Uppåkra temple exhibit, we have come up with two prototypes of interaction with the exhibit in AR. One in which the interaction is based on a table top Augmented Reality and one in which it is based on kiosk. The table top Augmented Reality allows the user to experience, 'Passive Interaction' with the model and marker since the marker remains static and user moves around it. Instead the kiosk based Augmented Reality provides user with 'Active Interaction' with the marker since the marker is moved and the user remains static. To conclude about the usability of each of these interaction types, we needed to evaluate these prototypes in actual museum environment. For this we designed and conducted an experiment in actual museum environment.

6.1   Designing the Experiment

The systematic literature review conducted earlier (detailed in chapter 4) has grouped the previous notable research works conducted in this area. As shown in table A-1 in Appendix A, five out of seven of these works included an evaluation of the system developed. The techniques used included Objective observation, Subjective observation, Questionnaires, Interviews and Surveys. A more thorough investigation into user evaluation revealed the works by Swan and Gabbard [58] and Dünser et al. [59] where they have conducted survey of evaluation techniques used in AR related works. The former divided these works in to 1) study of user perception and cognition, 2) user task performance in AR applications and 3) examining user collaboration. The later grouped the articles based on the evaluation techniques used.

In our case we were more interested in studying user performance in Active and Passive Interaction with the model in the light of current technology used to realize the prototype and we were not interested in the cognition and perception which warrants a complete study in its own right. An overview of the references of surveyed articles provided by Swan and Gabbard [58], and Dünser et al.[59] prompted us to consider the following factors and evaluation techniques in our evaluation study.

6.2   Considered Factors

The factors that we had considered for each type of interaction in this evaluation include

- **Limitation of registration technology:** Effect of lighting in the museum environment, and effort required to keep marker in the camera view.
- **Realism:** Fast response, realistic 3d model
- **Fun Factor:** Whether the system encouraged longer time to stay at the exhibit, whether one would recommend it to friends?
- **Intuitiveness:** Whether the system requires pre-learning or the user can start to interact immediately?

- ▪ **Fatigue caused:** If there was what caused it?
- ▪ **User preferences:** Expected\missing functionalities

The discussion and analysis of the results presented at the end of the chapter are based on these factors.

6.3   Evaluation Techniques

In the light of these factors we had designed our experiment to include the following evaluation techniques.

6.3.1   Objective Observation

By means of objective observation we wanted to observe the user behavior while using each of the above mentioned interaction types. In our case we wanted to observe the following key points.

- ▪ How often is the user interrupted by misalignment of fudicial marker? (count)
- ▪ How many times does the user try to touch the 3d objects? (count)
- ▪ How does the lighting affect the augmented model and marker detection? (descriptive)
- ▪ Other miscellaneous observations.

6.3.2   Subjective Observation

In subjective observation we wanted to ask the user to perform a particular task and note down the observations for active and passive interaction type. One crucial thing to note here is that in subjective observation the user is asked to perform specific tasks in contrast to objective observation where the user is performing tasks at his/her own will. The following tasks were laid down for subjective observation.

- ▪ Move to the other side of the temple?
    - o Document user's reaction in descriptive form.
- ▪ Get closer, get farther?
    - o Document user's reaction in descriptive form.
- ▪ Count the number of doors of the Uppåkra temple?
    - o Document user's reaction in descriptive form.
- ▪ Other miscellaneous observations.

6.3.3   Questionnaire

Finally we wanted the user to fill in a questionnaire about his/her experiences with both type of interfaces.

- ▪ On which interface would you like to spend most time?
    - o Please motivate, why?
- ▪ What is this exhibit about?
- ▪ Would you like to tell others about the exhibit?
    - o Please motivate, why?
- ▪ How easy was it to move around? (For each interface, check on a scale of 5 from very easy to very hard)
- ▪ How easy was it to hold the device? (For each interface, check on a scale of 5 from very easy to very hard)

- To what extent did you feel the model was part of reality? (For each interface, check on a scale of 5 from very real to very unreal)
- Do you think the system is responsive? (For each interface, check on a scale of 5)
- Do you think the system caused fatigue?
  - (For each interface, check on a scale of 6) To what level.
  - Please, explain why?
- Do you think the system should be permanent part of the exhibit?
- Miscellaneous comments
  - Your thoughts\suggestions

6.4   Experiment Setup

We decided to setup the experiment in the Uppåkra Temple exhibit in Lund University Historical Museum. Before the start of the experiment we wanted to give each subject a 3 minute introduction about the experiment and research work and planned to ask for their consent for being part of the experiment. For the observations, we had prepared printed forms. (See Appendix C for evaluation forms)

In order to account for the learning bias, we initially planned to perform the experiment in two runs on different participants. In First Run, we decided to use Passive Interface first and Active Interface later and in Second Run vice versa. In each run we wanted to perform the following three phases.

Phase 1: Observe user interaction without hindering him/her and note down objective observation.

Phase 2: Ask the user to perform tasks mentioned in section 6.3.2 and noted down the subjective observation.

Phase 3: Ask user to fill in the questionnaire.

In the sections so far, we have presented how we planned and designed the experiment prior to its execution. In the sections to follow, we have detailed the steps we actually followed when conducting the experiment.

6.5   Pilot Tests

Prior to the actual experiment at the museum we had conducted two pilot tests with two subjects to observe our designed experiment. We got important feedback about the observation methods and the design of the questionnaire.

The subjects selected in this experiment had prior basic information about the technology. A brief introduction about the prototype was given to them before the actual experimentation.

The detailed subjective and objective observation was not so easy to document as it was originally perceived. We therefore had to resort to two or three words

description in these observations. The nominal scalar representation of queries on the questionnaires was more than useful. One of the subjects responded about the questionnaire as being *"pretty default"* and easier to fill. After these pilot tests, our general opinion was that the questionnaires could provide with the most useful information in actual experimentation.

In our pilot tests the lighting conditions didn't hinder the tracking thanks to the controlled environment. However the users were hampered by the misalignment of the marker and camera, experiencing three and four interruptions each. Apart from this, users tried to click different objects on the screen to interact. One of the users also reported difficulty holding the tablet device. Both of the users found passive interaction more convenient than active interaction. They stressed that the mobility around the augmented model was the primary reason for spending more time on the tablet. They found the tablet interface less responsive to movements as compared to the laptop based interface, the reason being that on battery power the processor on the tablet system operated slower as compared to the laptop which was connected to direct power supply.

One of the users suggested the loss in tracking as one of the major problems. The other user concentrated more on the idea of interaction with each and every scene object and suggested that *"a more dynamic non-linear story could lead to even better presence and immersion."* In contrast to the first user, this user mentioned the response of the system as impressive which is unlike most of the works he had seen on YouTube.

6.6   Preparing the Environment:

Figure 6-1 Table top Marker placement in Uppåkra
temple exhibit for passive interaction with the model
using our prototype

To conduct the actual experiment at the museum we had setup our active and passive interaction in the Uppåkra temple exhibit space. For the passive interaction we had placed the tabletop marker setup in the center of the exhibit so that the user could easily move around the temple model (figure 6.1). We had also focused the lights already present in the exhibit to the marker spot to ease the marker detection.

The kiosk for the active interaction had been placed next to the wall beneath the temple foundation depiction. A light source had been fixed to the laptop so that it could point towards the user to light the marker.

Figure 6-2 Kiosk in the Uppåkra temple exhibit for
Active Interaction with the model using our prototype

6.7   Analysis of Results

On the day of the experiment, visitors' turnout was not so good. In real scenario, we had also noticed that not everybody was interested in testing the new interaction methods. We got in total eight test subjects. Nevertheless, according to usability studies conducted by notable researchers, this number could be enough to find the majority of the usability problems. Especially, Nielsen and Landauer [60] have shown in their usability studies that with increasing number of subjects the proportion of usability problems found become constant.
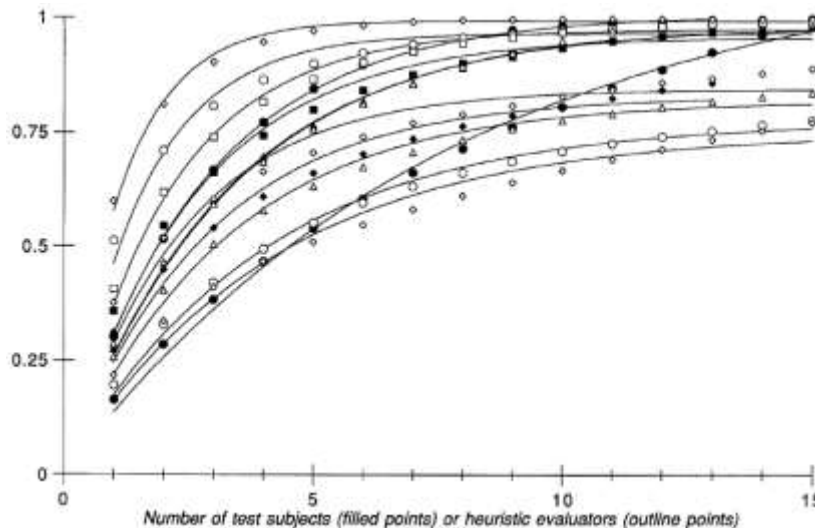
Figure 6-3 Proportion of usability problems found with increasing
number of subjects in an analysis by Nielsen and Landauer [60]

The graph in figure 6.3 shows their results. According to this graph, after 8 subjects there is no remarkable difference between the number of problems found in most of these case studies.

In the following sections, we will discuss the results of our objective observation, subjective observation and questionnaires according to the factors presented in section 6.2.

Limitation of registration technology

The overall objective observation has shown that during active interaction users were more interrupted by marker misalignment than passive interaction. In passive interaction users were quick to learn how to move around with less hindrance. By zooming in on the marker, at a certain point it went out of the view frustum of the camera. This resulted in limited zooming for the 3D model however the users wanted to further zoom in on the model.

Realism

In realism we considered two factors, the apparent detail of the 3D model and the response of the interface to the tablet movement and marker movement. Although both interfaces were using the same 3D model but we thought the way these models were presented in these interfaces might make a difference in their apparent details. However, contrary to our belief, only in one case the subject found the apparent detail of the 3D model in active interaction more real than in the passive interaction and yet in another case a user found it vice versa. So there was no effect of the way of presentation on the apparent detail of the 3D model in overall observations.

To account for the response of the interface to the tablet movement and marker movement we asked the user to express his/her views on a scale of five in the questionnaire. Half of the subjects found both of the interfaces equally responsive. Two subjects found interaction by marker movement more responsive than tablet movement and one subject found it vice versa.

Fun Factor

As was the case in the evaluation of Tabletop AR by Mathew et al. [61], there has been a 'wow' factor due to the uniqueness of the interface. Each subject at start seemed to be taken by surprise for a couple of minutes. Especially the kids and the young generation, being familiar with mobile technology and 3D gaming, appeared very interested.

All of the eight subjects replied with 'Yes' when asked, whether they would tell others about this exhibit. When asked why they would like to recommend, one of them commented, *'it was an interesting experience'*, the other commented, *'They would become interested'*, yet another said, *'it's interesting for me'*. One of the subjects also commented of it being *'A different and funnier exhibit'*.

Intuitiveness

After a preliminary introduction, the passive interaction was quite intuitive as compared to the active interaction. The users in actual experimentation always used the passive interaction first and active interaction afterwards. We were concerned about the learning bias but still the users felt more comfortable with the passive

interaction in contrast to the active interaction although the users had the edge of knowing the scenario beforehand. Seven out of eight subjects quickly understood the interaction and started moving around the 3D model as soon as they were given the device in passive interaction. Only one subject had some difficulty understanding how to move forward and how to zoom in Passive interaction. In Active interaction, the users required continuous guidance.

Fatigue

When questioned about moving and holding the device, none of the users responded that it was hard. Four out of eight users responded that the grasping and movement with the device was easy. Other three responded that it was normal. One user responded holding and moving the marker was easy and using Tablet was Normal.

Four out of the eight users responded that the system caused no fatigue. Two of these users commented that, *'It wasn't heavy'* and *'It wasn't heavy enough'*. One user didn't answer the question about fatigue. Two of the rest of the three users felt little (two on scale of five) and medium fatigue (three on scale of five), however they didn't mentioned its cause. One subject felt more fatigue in using active interaction and he mentions, *'It was a bit annoying that the laptop version [active interaction]) would react strongly to tilts making it lose the picture'*.

User preferences

When questioned whether they would like the system to be part of the exhibit two out of eight subjects responded with 'No'. One of these users commented that, *'Not in its current form but with some developments'* and the other said *'it seems difficult'*. Rest of the six subjects responded with 'Yes'. One of them commented, *'Yes, but with more possibilities to interact'*, another wrote, *'Yes, but with more information',* yet another said, *'Good way to make kids enjoy their visit'*. One of the subjects also commented that, *'it would help kids 2 [to] get more interested of history'.*

When questioned about suggestions, one user from the 40 and above age group wrote, *'I think it was little complex'*, two of the users were interested to have more information in the application. One of the users wrote, *'Seems to be a good way to make people feel like they are part of the history'.*

7   EPILOGUE

7.1   Conclusion and Discussion

The aim of this master thesis work was to devise an Augmented Reality application in Museum exhibit by using open source commercial off the shelf components. From our systematic literature review in the initial part of the study we have shown the state of the art in applied AR in current museum exhibits. A bird's eye view on these works showed that most of the works done in museums had usually been long term projects with extremely specialized hardware and software. We have shown in our study that an application with similar features can be achieved in less time with open source commercial off the shelf components. One of the reasons for this is the availability of frameworks like Studierstube which has been used in this work.

From the systematic literature review, it became evident that most of the current research in AR is focusing on handheld and mobile AR. The availability of high end mobile computing devices to ordinary users and the presence of necessary components required by an AR application in a compact mobile device have stimulated this trend. We believe the upcoming handheld devices like Apple iPad, HP Slate and Notion Ink's Adam tablet could be the ideal devices for such interaction scenarios.

To mimic these devices we have used a HP tablet tx1000 in the later part of our case study to achieve a passive interaction scenario. In earlier part of this case study, we demonstrated an active interaction scenario. The way the interaction can be done in these two scenarios provided an interesting aspect to study from end user perspective. As was the case in previous such works (chapter 4), the user evaluation presented a thought-provoking feedback in our case as well.

The visitors were mostly taken by surprise by the unprecedented first experience of AR, as discussed in the analysis of the evaluation results (section 6.7). Most of the visitors were interested in passive interaction due to the possibility of physical movement in the exhibit in contrast to active interaction of the static kiosk based experience. Overall analysis suggests the passive interaction is more desirable compared to Active interaction although it requires more physical effort. Some of the visitors also suggested that they would like to see more information regarding the exhibit in AR application.

The limitation in marker based registration technology (section 6.7) could have been avoided with some interactive technique to keep the user aware of the working distance. For example, on getting closer to temple, the priestess character might have asked the user to focus on something else or might have asked to follow her.

We learned from the user feedback that visitors would be interested in a non-linear scenario based on a story telling approach for better interaction. The users also requested to add more information about exhibit in the AR prototype. Mostly the visitors anticipated unpredictable interactive behaviors by 3D characters as are found in 3D games. In general, the visitors were positive about permanent presence of AR exhibits in Lund University Historical Museum which suggests that such technologies can greatly revive the number of visitors and their interest for historical museums.

7.2   Future Work

The work we have presented here can be further extended in a number of different directions. One of the leading ideas could be making this prototype more interactive using a life size priestess character to guide the user through the whole Iron Age exhibit of Uppåkra. Furthermore, interactivity can be improved by involving the user more actively with the displayed augmented model. Non-linear storytelling and game like interaction scenarios could improve on this factor.

Research can be done to make the application more adaptable to the environment using already present symbols rather than using markers for registration of AR models. We have observed that there are some black and white symbols already available in this exhibition that could be used as potential markers. One such symbol is in shown in the figure below.

Figure 7-1 A symbol in the exhibit that could be used as
potential marker

In addition to this, a detailed usability study of this AR prototype could be conducted in the future to observe user behaviors in depth. Especially, a study to observe usability and interest patterns in different age groups and how that compares with age group of museum visitors in general could be extremely helpful in determining the effectiveness of AR based exhibits in Lund University Historical Museum.

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APPENDIX A: COMPARISON OF AR RELATED WORKS IN CULTURAL HERITAGE

System Type	Software Technologies Used	Indoor/ Outdoor	Devices Used	Registration Method Used	Interaction Method	Evaluation / Analysis Method
AR guide, Museum of Fine Arts in Rennes, France [39]						
Prototype	MAGIC Engine Software Framework (OpenCV ARToolkitPlus OGRE3D OpenAL XERCES)	Indoor	Ultra Mobile PC (UMPC) Samsung Q1 Archos 04	Used Artifacts as tags	Buttons or Touch Sensitive Screen	Objective Observation with Digital video Interview, Judgments, Workshop, Survey, Questionnaires
MR System, Cretaceous life at Orlando Science Center [40]						
Complete System	MR System Open Scene Graph Cal3D Port Audio DMX chain	Indoor	HMDs Transmitters Trackers Sound Devices	Marker Based	Story Telling Approach	
Visualization of Broken or damaged objects (Partly had collaboration with ARCO) [41]						
Demo	IMMR tool AR Interface Toolkit Photomodeller by EOS Matlab Camera Calliberation Toolbox	indoor	cy-visor see-through color HMD, Web camera, Digital Camera (Canon EOS – D30) HP workstation (Two 2.4GHz Xeon 1024 MB RAM)	Marker Based	Reconstructed Augmented model of the artifact Table top augmented exhibitions	

System Type	Software Technologies Used	Indoor/ Outdoor	Devices Used	Registration Method Used	Interaction Method	Evaluation / Analysis Method
AR-museum guide (The Louvre - DNP Museum Lab) LDML - Musée du Louvre [44]						
Complete System	Unifeye SDK, C#, ActiveX Controls	Indoor	LCD Screen with an attached camera connected to PC via cable. Fujitsu BIBLO LOOX-P (0.96 KG) 8.9" screen	Markerless Tracking, Hybrid Tracking	Animated Character for guidance and interaction, Virtual floating balloons for points of interest	Aural, Questionnaire, Observation, Action logs
ARCO [45]						
Complete System VR + AR	ARCO Components	Indoor	Web Browser for VR. AR Browser for AR	Marker based	Engage user in Interactive scenarios Exercises, quizzes, game Table Top Augmented Reality	Feedback by museum users, Museum User Trials
AR Exhibits HIT Lab NZ [46]						
Independent Deployed Exhibits	ARToolkit	Indoor	AR Visor	Marker Based	Table Top with normal GUI components to interact	Observation, Workshops
ARCHEOGUIDE [48]						
Complete System	Archeoguide Site Information Server, JAVA,VRML	Outdoor	WLAN, HMD, Laptop, GPS device, Pen Tablet, PalmTop	Hybrid Technique	Multimodal, Movement in Environment	User Reviews: ordinary users, site staff, archaeologists, and technology experts

APPENDIX B: MOST CITED WORKS OF PROMINENT RESEARCHERS IN AR

Author	Papers	Co-Authors	Paper Title	Citations
Krzysztof Walczak	232	K Walczak, M White	"Building virtual and augmented reality museum exhibitions",2004	50
		M Patel, M White, K Walczak, P Sayd	"Digitisation to presentation-building virtual museum exhibitions",2003	18
		P Lister, K Walczak, R Wojciechowski	"ARCO—An architecture for digitization, management and presentation of virtual ",2004	15
		K Walczak, W Cellary, M White	"Virtual museum exhibitions",2006	14
		M White, M Patel, J Chmielewski, K Walczak	"AMS: metadata for cultural exhibitions using virtual reality",2003	12
		N Mourkoussis, K Walczak, R Wojciechowski	"Metadata requirements for digital museum environments",2005	11
		K Walczak, R Wojciechowski	"Dynamic creation of interactive mixed reality presentations",2005	7
		R Wojciechowski, K Walczak, M White	"Augmented Reality Interface for Museum Artifact Visualization",2003	5
		K Walczak, W Wiza	"Designing Behaviour-rich Interactive Virtual Museum Exhibitions",2007	3
		M White, K Walczak, N Mourkoussis	"ARCO—Augmented Representation of Cultural Objects",2003	2
		K Walczak, M White	"Cultural heritage applications of virtual reality",2003	1
Martin White	341	K Walczak, M White	"Building virtual and augmented reality museum exhibitions",2004	50
		M Patel, M White, K Walczak, P Sayd	"Digitisation to presentation-building virtual museum exhibitions",2003	18
		P Lister, K Walczak, R Wojciechowski	"ARCO—An architecture for digitization, management and presentation of virtual",2004	15
		K Walczak, W Cellary, M White	"Virtual museum exhibitions",2006	14
		F Liarokapis, M White, PF Lister	"Augmented reality interface toolkit",2004	13
		M White, M Patel, J Chmielewski, K Walczak	"AMS: metadata for cultural exhibitions using virtual reality",2003	12
		F Liarokapis, M White	"Augmented Reality Techniques for Museum Environments",2005	5
		R Wojciechowski, K Walczak, M White	"Augmented Reality Interface for Museum Artifact Visualization",2003	5
		M White, F Liarokapis, N Mourkoussis, A Basu	"ARCOLite–an XML based system for building and presenting Virtual"	5
		P Petridis, D Pletinckx, K Mania, M White	"The EPOCH Multimodal Interface for Interacting with Digital Heritage Artefacts",2006	5
		A Karoulis, S Sylaiou, M White	"Usability evaluation of a virtual museum interface",2006	4
		M White, F Liarokapis, N Mourkoussis, A Basu	"A lightweight XML driven architecture for the presentation of virtual cultural",2004	4
		P Petridis, D Pletinckx, M White	"A multimodal interface for presenting and handling heritage artifacts",2005	3
		M White, K Walczak, N Mourkoussis	"ARCO—Augmented Representation of Cultural Objects",2003	2

Author	Papers	Co-Authors	Paper Title	Citations
		M White, P Petridis, F Liarokapis, D	"Multimodal mixed reality interfaces for visualizing digital heritage",2007	2
		K Walczak, M White	"Cultural heritage applications of virtual reality",2003	1
Ronald Azuma	93	R Azuma	"A survey of augmented reality",1997	1898
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APPENDIX C: EVALUATION FORMS

Objective Observation

Name of Researcher		Experiment Run #	
Subject #			

How often user is interrupted by misalignment of fiducial marker? (count)

Active Interaction

Passive Interaction

How many times user tried to touch the 3d objects? (count)

Active interaction

Passive Interaction

How lighting affected the augmented model and marker detection? (descriptive)

Active Interaction

Passive Interaction

Miscellaneous Observations

Subjective Observation

Name of Researcher		Experiment Run #	
Subject #			

Move to the other side of the temple? Document user's reaction in descriptive form.

Active Interaction

Passive Interaction

Get closer, get farther?Document user's reaction in descriptive form.

Active Interaction

Passive Interaction

Count the no of doors?Document user's reaction in descriptive form.

Active Interaction

Passive Interaction

Other Miscellaneous Observations

Questionnaire

Participant #			Experiment Run #	
				For Official Use

1- Please Mention your age group

☐ 6-15   ☐ 16-26   ☐ 27-40   ☐ 40 and above

2- On which display would you like to spend most time?

☐ Tablet   ☐ Laptop

Why, Please Comment?

3- What is this exhibit about?

4- Would you like to tell others about the exhibit?

☐ Yes   ☐ No

Why, Please Comment?

5- How easy was it to move around?

Tablet Interface
☐ Very Easy   ☐ Easy   ☐ ok   ☐ Hard   ☐ Very Hard

Laptop Interface
☐ Very Easy   ☐ Easy   ☐ ok   ☐ Hard   ☐ Very Hard

6- How easy was it to move\hold device?

Tablet Interface
☐ Very Easy   ☐ Easy   ☐ ok   ☐ Hard   ☐ Very Hard

Laptop Interface
☐ Very Easy   ☐ Easy   ☐ ok   ☐ Hard   ☐ Very Hard

7- To what level did you feel the model was part of reality?

Tablet Interface
☐ Very Unreal   ☐ Unreal   ☐ In Between   ☐ Real   ☐ Very Real

Laptop Interface
☐ Very Unreal   ☐ Unreal   ☐ In Between   ☐ Real   ☐ Very Real

8- Do you think the system is responsive?

Tablet Interface

☐ Very Slow ☐ Slow ☐ Normal ☐ Responsive ☐ Very Responsive

Laptop Interface

☐ Very Slow ☐ Slow ☐ Normal ☐ Responsive ☐ Very Responsive

9- Do you think the system caused fatigue? (To what level, 1 specifies minimum, 5 specifies maximum)

Tablet Interface

☐ 1(None) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Too Much)

Laptop Interface

☐ 1(None) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Too Much)

Please mention cause for it in your opinion

10- Do you think the system should be permanent part of the exhibit?

☐ Yes   ☐ No

Why, Please Comment?

Your Thoughts or Suggestion about the system