Capturing Culture: The Practical Application of Holographic Recording for Artefacts Selected from the Heritage and Museums of the Arabian Peninsula

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Dedication

This thesis and all my academic achievements are dedicated to my beloved late mother Rahmah Fattah (may God's mercy be upon on her), for her unconditional love, encouragement and constant prayers for me and the whole family, and for always being there for me. There are no words to express my gratitude to her.

To my beloved late father Darweesh Abed (may God's mercy be upon on him).

To my husband Khalid Alsalmi for his unconditional love and support and for believing in me.

To my soul, my beloved family members: Dareen, Mohammad and Lama Moaber and Fahad Nazer, for their help, endless love and understanding through the duration of my studies.

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Abstract

Recording cultural heritage is one of the most important issues for consideration in the twenty-first century. Safeguarding, protecting and preserving heritage, through effective mechanism, is of crucial importance. Holographic technology has the potential to offer an appropriate solution to solve issues in documenting, cataloguing and replaying the original optical information of the artefact in three-dimensional imaging.

This thesis investigates the relationship between art and technology through holograms recorded as part of a practice-based research programme. It questions whether the holographic medium can be used to capture and disseminate information for use in audience interaction, and therefore raise public awareness, by solving the problem of displaying the original artefacts outside the museum context. Using holographic records of such valuable items has the potential to save them from being lost or destroyed, and opens up the prospect of a new form of virtual museum.

This research examines the possibility of recording valuable and priceless artefacts using a mobile holographic recording system designed for museums. To this end, historical, traditional and cultural artefacts on display in Saudi heritage museums have been selected. This project involves the recording of ancient Arabian Peninsula cultural heritage, and in particular jewellery artefacts that we perceive as three-dimensional images created, using holographic wavefront information. The research adopts both qualitative and quantitative research methods and critical review of relevant literature on the holographic medium to determine how it might provide an innovative method of engaging museums in Saudi Arabia. The findings of this research offer an original contribution to knowledge and understanding for scholars concerned with conservation of Saudi Arabia's cultural heritage.

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Abbreviations and Definition of Terms

Abbreviation	Definition/explanation
2-D	Two-dimensional image on flat sheet such as: photograph, painting, drawing etc.
3-D	Three-dimensional image, the viewer can view the image from different angles.
Analogue	3-D image (holographic image) seen without 3D glasses, where viewing angle changes the perception of depth.
Lenticular	3D image can be seen without 3D glasses (auto-stereoscopic).
Anaglyph	3D image must be seen with 3D glasses (stereoscopic).
Photogram	Shadow of the image (cameraless).
Diode Laser	Also known as an *injection laser*, a semiconductor device that produces coherent radiation.[1]
Emulsion	The layer above the substrate, composed of gelatin, which contains the silver halide particles.[2]
Exposure Time	Time of exposing the sensitive plate to the laser.
HIH	Hellenic Institute of Holography.[3]
RGB	Red, Green, Blue.[4]
LED	Light Emitting Diode.[5]
Holographer	Someone who records holograms, e,g, a photographer; "someone who makes or uses holograms".[6]
ICOM	The *ICOM* code Ethics for Museums, prepared by the International Council of Museums. [7]
SCTH	Saudi Commission for Tourism and National Heritage

1 Source: TechTarget, Whatis.com, *Laser diode (injection laser or diode laser)*. n.d. (updated 2005). [online] Available at http://whatis.techtarget.com/definition/laser-diode-injection-laser-or-diode-laser. [Accessed 17/1/2018].

2 Source: Stulik, D. C. and Kaplan, A. 2013. *Silver Gelatin*. Los Angeles, CA: The Getty Conservation Institute, p10. [online] Available at: www.getty.edu/conservation/publications_resources/pdf_publications/pdf/atlas_silver_gelatin.pdf [Accessed 2/3/2018].

3 Source: Bjelkhagen et al., 2015, p6.

4 Ibid.

5 See dictionary.cambridge.org/dictionary/english/led.

6 See collinsdictionary.com.

7 Source: Edson, 2017, p185.

Definition and translation of Arabic Terms[8]

Terms	Definition and translation
GCC	Gulf Cooperation Council (مجلس التعاون الخليجي)
KSA	The Kingdom of Saudi Arabia (المملكة العربية السعودية)
Burqua (برقع)	Veil made of thick material with eye openings, to cover a Muslim woman's face to prevent its being seen by foreign men
Herz (حرز)	A jewellery item for both male and female wear, in the belief it could protect the wearer from others' eyes
Hezam (حزام)	Belt or waistband worn by both males and females
Kaaba (الكعبة في المسجد الحرام)	A small stone building in the court of the Great Mosque at Makkah that contains a sacred black stone, which is the goal of Islamic pilgrimage and the point towards which Muslims turn to pray
Khatam (خاتم)	Ring
Khulkhal or Brabeesh (خلخال)	Anklet
Lubbah (لبه)	A jewellery item similar to necklace, worn by women: it can be very large in size
Mea'dhad (معضد)	A jewellery item worn by women on the high part of their hand, under their shoulders
Wadhah (وضح) (مسك/ وملويات)	Women's ornament worn on the wrist

8 Source: Al-Qahtani (2000) and Bin Jeniadel (2003) (both in Arabic).

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Chapter 1

Chapter 1
Introduction

1.1 Introduction

This research seeks to facilitate the development of an innovative method to visualise complex historical artefacts in three dimensions (3D). The Arabian Peninsula cultural heritage inspired the researcher to investigate forms of image capture, such as holography, and identify their potential to benefit museums and museum visitors. This research is influenced by the thoughts of MacDonald (2015, p1):

> *Digital imaging finds its perfect application in the domain of cultural heritage, enabling objects to be captured, rendered and displayed in many ways. It facilitates public access to objects that would otherwise be too rare, valuable or fragile to be widely seen*.

Bringing cultural heritage together with technology can attempt to bridge the gap between generations. I once heard a 5-year-old boy laughing out loud at his grandfather and telling him that he did not understand an electronic game (his grandfather tried to satisfy him by playing it with him). And that specific moment made me think of humans, how we began and what we have been through. How have we evolved to reach the moment of this 5-year-old child, from an artist's point of view?

1.2 Research background

The focus of this research is specifically on the area of recording heritage. The significance of choosing the Kingdom of Saudi Arabia (KSA) as the context for this study is because Saudi Arabia "*has a rich and ancient architectural heritage, which dates back to the Old Stone Age*" (Saudi Tourism.sa, 2017). Furthermore, it is the researcher's home country and its heritage has inspired and motivated this study. The wealth of cultural heritage that exists in the KSA is a result of its being the largest country in the Arabian Peninsula (see Figure 1.1) and being "*strategically located at the crossroad of three continents: Asia, Africa and Europe. KSA is one of the World's most important commercial, trading and religious hubs*" (Industrial Clusters, 2017). Furthermore, the

Kingdom has within it the Holy Cities of Makkah and Madinah, which are considered as having the highest spiritual significance for Muslims. Saudi Arabia is one of the Gulf Cooperation Council (GCC) countries and the largest in the GCC. It "*occupies four-fifths of the Arab Peninsula with a total area of around 2,000,000 square kilometers*" (General Authority of Statistics, 2016).

As an artist I thought of doing something to record a small part my country's heritage, and I chose the jewellery of the Arabian Peninsula, or what is referred to as traditional or Bedouin jewellery, particularly in Saudi Arabia (see Figure 1.1).

Figure 1.1 Map of the Kingdom of Saudi Arabia
(Source: World Atlas, 2015)

1.3 Museum display in Saudi Arabia

Hamed (2016, p293) considers that more studies are needed to widen Saudi society's appreciation of its heritage:

> *... to promote museums in the KSA effectively in order to enhance the museum culture in the KSA. Therefore, there is a need for more research in the KSA to commence such a challenge and to initiate more studies to provide more tangible results to improve the KSA society.*

Because of the importance of the role of museums in communities, and for creativity and development, technology plays an important role. Museums in Saudi Arabia are required to demonstrate their heritage through creative and contemporary means, which could be by technological methods in their display systems. To date, no published research studies have investigated the holographic medium in Saudi Arabia's museum display systems. Furthermore, there is a need to develop recording and display systems in Saudi museums. Mania (2014, p128) suggests that museum display should be improved and "*employ modern technologies in the management of the museum and museum materials*". So, as a result of her findings she suggests that "*High-technology should be introduced in museum display systems*" (Mania, 2014, p129).

Recent research states the importance of developing museum design in Saudi Arabia so that it:

> *... explores the development of a theoretical framework for the design of the web presence and how it can be usefully and practically employed with a view to increasing the number of visitors to cultural organisations such as museums in the Kingdom of Saudi Arabia* (Hamed, 2016, piii).

The method used widely nowadays in KSA museums is to record and document original heritage items digitally, using photography. Photographing as a technique of recording is part of a long-held debate within the sphere of the culture of Saudi museums. As a result of conducting interviews with a number of official employees (directors and staff) in the Saudi National Museum in Riyadh, it was confirmed that an identification system is used for documenting artefacts and archaeological items. This system registers every heritage item digitally onto an electronic system, with each item being photographed, given a number, date, place and a description of the materials used in its creation.

The purpose of curation is to select and collect artefacts of cultural and historical importance and afterwards to find appropriate methods to record and display such items in museums. Museums are "*spaces where narratives about identity and history are performed for the public through the medium of material culture*" (Bucciantini, 2009, p1). The definition of curation is rooted in fourteenth-century practices mainly associated with museum artefacts. Since that time, the practice of curation has undergone significant changes, due to the influence of emerging technologies and the rise of interdisciplinary research and study (Sabharwal, 2015).

Emerging technologies have enabled digital curation, which focuses on accessioning digital content in the context of recording.

> *The overlap in the definitions and applications of digital curation in these related contexts brings archivists, digital humanists, and the public together, and thus enhances collaboration at various levels of curation* (Sabharwal, 2015, p11).

The involvement of the community and public feedback, using various social media platforms, aims to "*add meaning to the collections and enrich the public discourse on the collection of exhibition themes*" (Sabharwal, 2015, p11), which can be referred to as social curation. The researcher is intrigued by the traditional jewellery artefacts of the Arabian Peninsula cultural heritage and the awareness that they may be endangered or lost and therefore should be protected. The researcher considers that technology could offer additional methods to the current traditional methods used in museums, in particular in the KSA. The goal is to identify a technology that offers more than photography, and accurately captures the fine details of each artefact.

1.4 Research aim

The main aim of the study is to investigate and research a potential method of recording and displaying 3D images in museums. The secondary aim is to identify improvements in practical experimental research methods within the area of recording and displaying heritage artefacts in museums.

1.5 Research objectives

This research identified a number of objectives:

- to research, investigate and develop a mobile technique of recording heritage using a holographic process to capture three-dimensional presentations of historical artefacts, in particular the Arabian Peninsula heritage;
- to develop the technique of projecting holograms of historical artefacts within museums;
- to document examples of Arabian historical jewellery in a holographic and three-dimensional form;
- to identify current recording methods in Saudi Arabia's museums and to develop display systems for cultural heritage items;
- to explore the possibilities and impact of displaying holograms to enhance the aesthetics of heritage objects;
- to evaluate museum visitors' reactions, engagement and experiences of the project;
- to gather opinions and insights from professional Saudi museum directors and hall curators about improving the recording and display systems in the KSA;
- to raise awareness of the importance of museum recording heritage using technology, i.e. to renew the idea of documenting heritage to highlight museums' importance by inspiring and exciting visitors.

1.6 Research question

From the objectives above, the important research question that emerged was:

> *Can the holographic medium be applied as a method for documenting and displaying Saudi cultural heritage artefacts?*

1.7 Technology in recording and display

Rapid advances and development of technologies in all realms and increasing demand for these technologies has inspired research into the development of high-resolution 3D images. Technology is integrated into modern society worldwide and people in the twenty-first century expect and look forward to advancement of technological inventions (Althagafi and Richardson, 2015). Technological developments are accelerating at a rapid rate, with discoveries in different fields such as education, science, engineering, medicine and entertainment all working towards developing communities. "*Innovations stemming* *from scientific knowledge have been greatly beneficial to humankind*" (Cetto, 2000) and "[*t*]*hese inventions give a new vision and perspective on future accomplishments*" (Althagafi and Richardson, 2015, p2). In this era of technological advancements, numerous new technologies have been discovered to improve the lives of world communities, to allow a new way for people to interact and integrate with their environment, other people and information. Richardson (2012, p8) suggests that:

> *As technologies have evolved we have been able to record more performance. This has meant that we have been able to track performances in this modern day a lot easier than hundreds of years ago when cameras, cinema and social networking sites were not around. For this reason in spite of its extensive use the first history of performance wasn't published until 1979.*

Due to a hologram's high resolution and great accuracy, this was deemed suitable for achieving the aim of this research. Using holographic recordings of valuable artefacts can protect our heritage and provide a practical solution to the problems involved in transporting delicate items and displaying valuable objects. "*Photographs display objects 'frozen' in time. Holograms display objects 'frozen' in volume*" (Pepper, 2008, p3). Such technology can assist to preserve the heritage of war-torn regions such as Syria, Iraq and Egypt, where heritage items may be destroyed or stolen.

The holographic medium has a significant impact on a variety and number of fields, such as science, medicine and art. Holograms are used in many areas and for different purposes, such as optics, electronics, medicine, IT, architecture, museology, art, culture, industry, military and security, and are classified according to their use, such as medical holograms, art holograms and security holograms etc. (Işik, 2014). The holographic method enables viewers to explore artefacts in museums and wq1 closely the details captured by the holographic technique, without the danger of damaging the original artefact. Close inspection of items is therefore possible, as holography captures the minutiae and intricacy of the original. The procedure of integrating holographic technology means that one can step into a realm of combining an artistic medium, such as the realism of holography, with a practical application when recording historical heritage and maintaining the authenticity of heritage items at the same time. Benton and Bove (2008, pxiii) state that: "*Holography's importance is attested to by its continuing ability* *to inspire and excite those who encounter it for the first time*." Recording of valuable items, such as ancient jewellery artefacts, offers the potential for the creation of authentic and technically detailed images.

The advantage of the hologram technique is that the viewer can see every minute detail in depth. It is important to note that *true* 3D viewing is where the observer does not need 3D glasses, which means it is seen by the viewer as reality. More than 30 years ago, Collender (1986, p121) indicated that:

> *Television on standard bandwidth, theatre movies and sophisticated computer graphics-all in three dimensions without the need to wear special glasses are feasible with contemporary technology.*

Instead, the object is viewed with depth and size as light is shone onto the recorded sensitive plate. Omeltshenko (2010, p108) concludes that:

> *3-D-displays - is the real future. 3-D-displays make it possible to get new impressions. I think that the 3-D image, will soon replace television and computer monitors. And the shortcomings of this technology will be negligible and unnoticeable. And the audience will look at the world differently!*

Heritage items are considered as important items to be documented and catalogued for a number of purposes such as education, raising awareness of cultural heritage, entertainment when displayed in museums, recording history for future generations and memorising, meditating on and observing the culture optimistically. Technology, therefore, plays an important role in these activities. As a researcher with a fine arts background, I see the beauty of ancient jewellery from its design and its materials. This inspired me to investigate a potential method to record its importance by attempting to produce a visual 3D image physically capable of being displayed anywhere in the world. Reproducing it with maximum detail using a modern technology such as the holographic medium explored in this research could support the exchange of cultural heritage easily between countries, without risking damage to or loss of the original pieces through, for example, handling, theft or even as a result of wars and conflicts.

1.8 Why holography?

According to Dawson (1999, p24):

> *In 1968, artists Bruce Nauman and Margaret Benyon, who had been engaged with optical and technological imaging processes in other media, were the first to use holographic imaging as a visual art medium.*

Johnston (2006, p317) reveals that "[*i*]*nitial scouting for territory appeared hopeful. During the late 1960s and early 1970s, holography was a new medium like installation art and video and with seemingly equal potential*". Holography offers the potential to capture the features of an artefact in richer detail. In this way it can augment elements such as the artefact's value, conception, authenticity and history, which would certainly contribute to a successful retrieval and the use of documenting methods and display, which has not been adequately addressed in museums. Using technology to record these items of heritage is especially important for precious objects. Markov (1982) highlights that: "[*b*]*ecause holographic presentation removes all risk to the original object it offers wide scope for international cultural exchange*" (p170).

This thesis reviews the various discussions in the literature to present a framework, which makes obvious the various dimensions of context that have been identified as useful for recording and display methods. Furthermore, it offers a modern method to ensure the capture of an object's details that are often missed by traditional recording methods, such as two-dimensional (2D) photography, which is the current method used in Saudi museums (Althagafi and Richardson, 2015).

This research focuses on the use of modern holographic technology and the benefits that can be achieved by museums in using 3D holographic space to display their artefacts. The research uses examples of Arabian Peninsula heritage jewellery to document Saudi cultural heritage by utilising the high-level technology of holography for recording and display purposes in Saudi Arabia's museums.

1.9 The research process

The thesis followed two lines of investigation within an academic framework.

- Theoretical framework.
- Practical and empirical approach.

The main areas included in the theoretical part:

- Literature review (Chapter 2).
- Research methodology (Chapter 3).

The main areas included in the practical part:

- Experiments in 3D techniques including holography (Chapter 4).
- Survey and interview (Chapter 5).

The main objectives of the theoretical element were to identify how previous projects are related to this research and to analyse how previous research has been explored, to help identify the gap in knowledge and cover all aspects in this investigation.

The practical element was mapped in two main areas that underpinned the research experiment. These were to:

- investigate the possibility to display holograms in museums;
- use the holographic medium to record Arabian Peninsula cultural heritage artefacts to be displayed in museums.

By integrating technology with the recording and presentation of Arabian Peninsula cultural heritage artefacts, the researcher endeavoured to build a bridge between technological and historical cultures. According to the Saudi Commission for Tourism and National Heritage (SCTH) the world celebrates World Heritage Day annually on 18th April because:

> *It aims to preserve the human heritage and recognize the efforts of all relevant organizations in the field. In 1982, the International Council on Monuments and Sites (ICOMOS) announced, 18 April as the "World Heritage Day", approved by the General Assembly of UNESCO in 1983, with the aim of enhancing awareness of the importance of the cultural heritage of humankind, and redouble efforts to protect and conserve the human heritage* (Saudi Commission for Tourism and National Heritage (SCTH) 2017).

In this research, 3D visualisation was investigated to record original items that could support interactive displays in museums.

This section introduces an overview of the research methodology and methods. A formal literature search strategy was devised, with key words identified and guidelines for the inclusion or exclusion of studies. For example, *holography, record and cataloguing 3D imaging, museums, scatter, analogue, exposure, digital holograms, stereogram, stereoscopic, laser beam, coherent light, emulsion, lenticular, ancient* and *heritage*. As a result, a structured review of the published literature was carried out to understand the history and development of 3D imaging, including holography and its application. Researching the published literature also identified areas where earlier studies were lacking. This research used available references in Arabic resources in relation to museums in Saudi Arabia and English resources in relation to holographic techniques and other subjects. No comprehensive Saudi studies about the holographic medium were found; as a result the present research can be identified as being a new area of study. This research also aimed to identify the gap in the study of heritage recording and its role in connecting Middle Eastern and Western heritage and the past with the present and the future in the context of curation.

The technology methods experimented with included: holography, digital holography, lenticular, anaglyph and photogram. To produce a display method that could effectively record and project holograms in museums, it was important to experiment with methods of recording holograms of artefacts and to establish the steps needed to determine the methods required. To devise a potential method of projecting 3D images of ancient heritage jewellery for application in museums in the KSA, the researcher conducted a number of experiments using different techniques and materials in the holographic laboratory to achieve the aim of this research and to answer the research question. These experiments were completed to prove scientifically the best way to obtain 3D images that would be able to record and display artefacts.

The researcher investigated various methods of using the holographic technique by conducting a number of experiments on the projection of images. This included the study of new display systems, such as the *Fog Screen*®, and other display systems. These were investigated to ascertain if a practical application would be feasible for the purpose of recording and displaying artefacts within the museum setting by the projection of holograms onto a mist display system. This was a central part of the investigation, which established the possibility of projecting a hologram using the mist screen, and what would be required to establish a display system that can display a 3D image. It was concluded that the mist screen approach was not feasible. This led the researcher to the next step, which was to conduct additional experiments and then modify the route of this research.

The research set out to assess museum visitors and museum hall curators' opinions regarding the use of display holograms in museums in Saudi Arabia. It also evaluated the link between art and science through holography by researching, investigating and devising a potential method of projecting 3D images for the purpose of displaying cultural artefacts in museums. The research sought to investigate the application of the holographic process in museums to assist in recording and display systems for historical artefacts.

> *Holography is the first technique, since the invention of linear perspective during the Renaissance, to offer a fundamentally different method of recording and displaying space and the objects within it* (Pepper, 2008, p1).

Oliveira (2013, p14) states that:

> *The use of such technology made it possible to understand the opportunities for creating artwork that takes the viewers to another level of realisation and interpretation, which would then empower them to explore new forms of art*.

As this research was about museums and display methods, it was necessary to gauge the views of general museum visitors. Therefore, this thesis included an exploratory research project with the aim of identifying the influence of holograms and the holographic technique on potential museum visitors. The questionnaire collected the views of the museum visitors. In addition, explorative research was undertaken with museum directors, curators and a museum owner. This required the use of mixed methods using qualitative interviews and quantitative questionnaire, which suited this research study, as its findings relied partially on verbal data and subjective analysis. The interviews were used to obtain the views of collectors of Arabian traditional ancient heritage, key figures in Saudi cultural and antiquity institutions, heritage experts and government officials charged with the traditional heritage in museums and museum hall curators.

This study is considered to be a practice-based study rather than a theoretical approach. Several final outputs, including an exhibition of the results, were published in conference proceedings and the thesis submission. A digital hologram and a lenticular deliverable also resulted from this research.

1.10 Originality of this research (contribution to knowledge)

To achieve the aim and objectives of this research, the researcher read papers in physics, chemistry and mathematics to gain a deep understanding of the holographic medium. Currently, in the KSA, to the best of the researcher's knowledge, there is no research exploring the holographic medium and 3D images to be displayed in museums and in particular no assessment of whether or not holographic methods are adopted in museum recording and display systems. There is no equipped holographic laboratory or the needed skills to meet the needs of developing recording methods in Saudi museums and to produce holographic images. As a consequence, this study set out to explore the use of the holographic technique to record and display Arabian Peninsula heritage jewellery artefacts in Saudi museums. It is intended that this study will increase understanding of the holographic technique and more importantly enhance the development of new recording and display systems for artefacts. This study makes a major contribution to the museology field in the KSA, where its findings could be used to contribute to future developments in museum recording and display systems in the country.

To the best of the researcher's knowledge, this PhD thesis is the first in the field of holographic that links 3D imaging and recording methods and display systems in Saudi Arabia's museums. During the journey through this PhD study, a number of questions surfaced regarding the recording of valuable heritage artefacts of the Arabian Peninsula and in particular how traditional Saudi heritage can be recorded and displayed in a novel and dramatic form in museums. Until this research is published, the holographic medium does not exist in Saudi research or even in museums (as identified in 6.2 Discussion, Chapter 6) as supported by interview comments by museum directors.

1.11 Significance of this research

The significance of this research is that it investigated the possibility of recording and displaying artefacts using holography. The research suggests the possibility of a new kind of museum display system in Saudi Arabia that showcases Saudi cultural heritage through a new twenty-first century medium to a wider, more technologically-aware audience.

1.12 Limitations of the study

There are a number of limitations that this study encountered regarding specialisation, tools, moving of items and travelling difficulties. These included:

- the distance between the KSA and the United Kingdom caused difficulties for the procurement of original heritage artefacts;
- a limited number of hall curators in the KSA's museums;
- no museum curators in Saudi museums due to the absence of this specialisation in the education system;
- lack of participant responses, which resulted in a decreased sample size;
- high cost of devices – a blue laser device could not be offered to record a true colour hologram (*OptoClones*).

1.13 Exhibition of holograms from the experiments

Choices were made in the recording processes, equipment and materials to obtain the goal of this research by conducting a number of experiments in the laboratory, darkroom and studio. As part of the full submission of a practice-based research programme, the researcher exhibited the artworks to show the examiners the results of the research experiments alongside the written thesis. The researcher intends to exhibit the artwork holograms in museums and galleries.

1.14 Outline of the thesis

Chapter 1 presents an overview of the entire research thesis, its background and research problems. This is followed by a summary of how the aim and objectives of the thesis are addressed. It also identifies the originality of this study, together with its contributions to the field of museology. The limitations encountered during its progress are discussed.

Chapter 2 highlights the research problem, informed by the direction of the literature review. The chapter starts by focusing on the theory of light and its role in the holographic medium. Furthermore, it studies current museum documenting and display systems in the KSA. The chapter also highlights 3D-imaging mediums as a possible method to be utilised in museums.

In ***Chapter 3*** the methods and research methodology that this research adopted are explained.

In Chapter 4 the experiments are described in detail.

In ***Chapter 5*** the survey questionnaire and interview results are analysed. The questionnaire data being statistically analysed and the interview data analysed are thematically and descriptively integrated with the findings of the literature review.

To conclude the thesis, ***Chapter 6*** summarises the research findings, draws conclusions, suggests future work and makes recommendations.

The next chapter presents the literature review.

Chapter 2

CHAPTER 2
Literature Review

2.1 Introduction

This chapter reviews relevant literature to provide a background context for this research thesis, which considers the potential of holography in museums. It starts by discussing the need for preserving cultural heritage and the purpose and function of museums. Then it discusses museum practices, museum display and the interactions that museums need in order to keep visitors engaged and increase their support. The question is, how is this to be done? In this modern age of online possibilities, the role of visitor engagement, both in person and online, is a significant process, and this chapter reviews aspects of museum visitor engagement. The chapter then focuses on museums in the KSA and discusses the cultural heritage of the Arabian Peninsula and the need to document Arab heritage jewellery. Next, the history of light, its properties and its use in modern holography and the artistic nature of holography are addressed. The history of light is researched in the context of both science and art to understand the way people have used light and art to tell a narrative or to capture history.

Light is a fundamental characteristic of the holographic medium and one could argue that light plays the most important role in the holographic process. Modern holography is also explored in terms of practical applications for curation as well as the advantage of different three-dimensional methods for museum application. The types of three-dimensional images investigated are hologram (analogue), stereogram (digital hologram), lenticular (autostereoscopic), anaglyph (stereoscopic) and photogram. The artistic element in holography is examined to explore its capacity to capture an object's realism and the use of light in modern holography.

2.2 Preservation of Cultural Heritage

The driving force behind all definitions of 'cultural heritage' is that "*it is a human creation intended to inform*" (Feather, 2006). Recently, attention has been drawn to the preservation of cultural heritage due to regional conflicts and wars, in particular in Iraq, Libya, Syria and Egypt. The loss of parts of Palmyra (in August 2015) shocked the world; however, through the use of 3D printer technology, archaeologists reproduced a facsimile of the iconic Arch of Triumph monument (see Figure 2.1), which was displayed in Trafalgar Square in London, UK (*The Guardian*, 2016).

It has become clear that the heritage world, and surely the world in general, would benefit greatly from a solution that would protect areas of cultural heritage from damage, theft and destruction. The British Council has funded a project aimed at creating and developing a national record for Syria's heritage, as one does not exist at present. In this project, Syrian archaeologists will be trained in digital documentation techniques in order to digitally document heritage sites at risk and:

> *Photographic data will be collected ... in order to generate 3D models and accurate pictures of threatened sites, resulting in a new digital record of heritage at risk in the region* (British Council, 2017).

Furthermore, the Museum of Islamic Art, Berlin (MIK) and the German Archaeological Institute (DAI) are working on a scheme to "*implement a digital cultural heritage list for Syria, the so-called 'Syrian Heritage Archive Project'*" (Deutsches Archäologisches Institut, 2012–16).

Figure 2.1 Palmyra's Arc of Triumph in front of what is left of the historic monument
Photographer: Joseph Eid
(Source: *The Guardian*, 2016)

Events such as the Syrian conflict have highlighted the importance for curators and directors of finding solutions in order to document cultural heritage. Three-dimensional images are considered as the best method to document and catalogue cultural heritage as "[*w*]*ithin the museum and built heritage sector of archaeology, three-dimensional recording technologies are now comfortable additions to the analytical toolset*" (Horne, 2017, p4). The diverse nature of the artefacts and their locations around the world can be ideally served by 3D technologies, which can provide accessibility and have a positive impact on the interpretation and understanding of cultural heritage. With forethought and planning, 3D recording can gather and record more data in a shorter period of time, which must be a target for any new technology brought to archaeology (Horne, 2017).

Before they disappear or are in danger of destruction, as in the recent case in Syria, archaeological sites and items need to be recorded as completely and accurately as possible, however it is accomplished. For example, Figure 2.2 shows a stereo image taken in Syria; the significance of this can be explained by the views of Kichanov et al. (2018, p25):

> *One of the most important tasks of archaeology and other history-related sciences is the comprehensive study of cultural heritage items. The results of*

these studies have a significant application value, because they provide a way to penetrate into the far past and allow us to understand the formation and evolution of civilizations and ethnic groups.

Figure 2.2: Anaglyph (stereo) image of the Roman remains at Shahba in South West Syria taken by a local volunteer photographer
© Institute for Digital Archaeology
(Source: British Council, 2017)

Every nation has its own heritage, philosophy, imagination and stories to tell according to its geographic location – whether it be jungle, desert, mountains or plains – and the type of life that existed and still exists there. These individual characteristics have an influence on the type of art that emerges from individual nations. Cultural heritage can be distinguished in:

- "*built environment (buildings, townscapes, archaeological remains);*
- *natural environment (rural landscapes, coasts and shorelines, agricultural heritage);*
- *artefacts (books and documents, objects, pictures*" (Heritage for Peace, n.d.).

Museums have become the place where nations present their stories, show their heritage and their ancestors' achievements. Museums preserve cultural objects for the future, open them to the public and ensure their continuing relevance.

2.3 Museums

> *Museums provide deep, comparative knowledge. They help people understand how values and ways of living have changed over time, and why* (Lord and Blankenberg, 2015, p24).

Lewis (2000) indicates that "*the idea of an institution called museum and established to preserve and display a collection to the public was well established in the 18th century*". The term 'museum' is defined by the Cambridge Dictionary as: "*A building where objects of historical, scientific, or artistic interest are kept*" (Cambridge Dictionary, 2017), whereas the Oxford Dictionary defines it as: "*A building in which objects of historical, scientific, artistic, or cultural interest are stored and exhibited*" (Oxford Dictionary, 2017a). Furthermore, the United Nations Educational, Scientific and Cultural Organization (UNESCO) defines museums as places that:

> *... foster an integrated approach to cultural heritage as well as the links of continuity between creation and heritage. They also enable various publics, notably local communities and disadvantaged groups, to rediscover their roots and approach other cultures* (UNESCO, 2017a).

The most commonly accepted definition of a museum is that put forward by the International Council of Museums (ICOM):

> *A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment.*

Bucciantini (2009, p1) points out that:

> *The stories that museums are able to tell about the past depend on the collections and artefacts that they hold, but also on the ways in which those objects can be manipulated.*

Preservation, archiving, recording heritage protection, cataloguing, education and display systems are the most significant issues and concerns for museums in their pursuit to record history for future generations and to display artefacts for development purposes.

In this regard Ambrose and Paine (2012, p21) point out that a significant role of a museum is to develop the education system, so that it can:

> *... provide opportunities for the appreciation, understanding and promotion of the natural and cultural heritage. Museums have an important duty to develop their educational role and attract wider audiences from the community, locality or group they serve.*

Younan (2015b, p232) add that:

> *One of the services of museums has long been to provide artists with rich material to inspire their art making […]. Digital 3D technologies have potential to support this function of museums. Through the creation and release of digital 3D models from their collections, museums can continue their role as sources of artistic inspiration in a digital arena.*

In fact, experts, collectors, governments and those who are interested in museum development are thinking, arranging, attempting and funding projects to invent solutions that will aid the protection of and record cultural heritage. Around the world, projects, research papers, conferences and meetings have constructively attempted to develop museums as well as achieve these ends. Younan and Treadaway (2015, p240) highlight that "… *an increasing number of museums and other heritage institutions are now undertaking 3D digitisation of their collections*". However, they also suggest that many researchers and practitioners in the field of museums, heritage and archaeology "*see the creative use of digital 3D models of heritage materials as anathema to the established uses of digital heritage materials in research and education*" (p241). In a similar vein, Abdelmonem (2017a, p5) expresses concern and maintains that:

> *... legal and technical frameworks that govern the management of digital heritage are crucial to prevent manipulation or intentional alteration of digital heritage as well as to deal with the reproduction of national heritage in digital and virtual formats. These would ensure that the 'content, functionality of files and documentation be maintained to the extent necessary to secure an authentic record'.*

The presence of such legal frameworks may ensure that truthful and authentic digital records, without alteration or manipulation, are made. The advanced technology available has two features: one to record national heritage in particular detail; and also, however, to be a tool for manipulation and copying. As a result of these capabilities "*national preservation policies define and set guidelines on how digital and legal deposit in libraries, archives, museums and other public repositories should embrace the digital heritage*" (Abdelmonem, 2017a, p5). The questions in point here are what is acceptable, how much manipulation is acceptable and is it acceptable as long as the original is preserved? Morris (2001) discusses the views of Benjamin Weil, curator at the San Francisco Museum of Modern Art, who watched with interest the commissioning of new media cutting edge art and its effect on museums. Weil considered that this effect depends on the mission of the museum. However, Aaron Betsky, his former colleague, thought it inappropriate because:

> *museums, by their very nature, are conservative institutions. They are about finding work that has been made, showing it, and allowing it to be seen by future generations. Should experimentation happen in an art museum? No, not necessarily. Art museums are, by their very nature, half a step behind. And that's absolutely fine* (Morris, 2001, p4).

Morris (2001, p12) questions the displaying of new media work and whether "... *the work be shown in the physical gallery space of the museum, or can it be exclusively online? Most museums have played it both ways*". Althagafi, Richardson and Azevedo (2015, p133) suggest that "*museums have also moved on from being a place where people walked through to also interacting with digital technology within the venues*". Those responsible for recording and preserving the cultural heritage of a nation should be responsible for determining what is acceptable within their own limits and institutions. The following comment from the Museum Plantin-Moretus (2017, p23) clearly explains this thinking:

> *With this new museological concept we hope we have succeeded in striking the right balance between our role as a museum in the context of a historical house, and the need to introduce contemporary trends to broaden our audiences and enhance accessibility and storytelling.*

As long ago 1997, Markov (1997, p31) was suggesting the importance of the usage of the holographic technique in museums:

> *The holograms of the individual museum items have been recorded in several laboratories around the world. However, only after multiple presentations at the exhibitions did it become evident that holographic techniques can be as helpful as the other optical methods systematically used in museums.*

Museums now have the ability to draw on a wide range of technologies including holography to address preservation, recording and presentation of cultural heritage items. Artefact items recorded in museums, using the holographic medium, might be the most authentic example to show the relationship between art and technology working together to create displays in museums. The holographic technique offers three-dimensional images on a two-dimensional surface and it may possibly lead to "*a revolution in the means of image presentation*" (Wilhelmsson, 1968, p161). Hess and Robson (2012, p1) highlight that:

> *Museum objects can be characterised as individually handcrafted artefacts with finest detail. The ultimate requirement for 3D digital documentation in the museum has the aim of creating a 3D digital surrogate of the real object.*

And Markov (1992, p83) verifies that the image of holography:

> *… may be an optical replica of a "real" object, or an image produced without such an object, a creation in itself resulting from holographic diffracted light-beam synthesis. Holographic mosaics have been made that stand on their own, while in other cases holograms have been used as elements of interior decoration*.

Markov (2009, p83) confirms that "[*t*]*he spectral and selective properties of holography lend themselves particularly well to the production of pictures that are very rich in colour.*

Bucciantini (2009, p1) points out that "*a continuous series of decisions about how and where* [an *artefact*] *will be displayed, what it can be expected to say, and how important it is*". It is not only important for museums' directors and staff to make decisions about which artefacts are of importance, but also in their pursuits to connect the past, the present and the future in a historical sense, they need to make decisions on methods to display these artefacts.

Markov (2011, p66) provides a suggestion to replace the fragile item by 3D holograms:

> *Replacing the original object with a holographic copy can provide a partial solution to the problem of latency of museum collections. This is of particular advantage when temporary exhibitions are of interest. In this case, such issues as difficulties with transporting museum items due to their fragile state, and environmental requirements or security concerns, can be resolved by using 3D holographic twins.*

In the KSA, as museums integrate technology, as well as develop display systems, the researcher seriously considers that the holographic medium is a good solution that can provide a future direction in heritage preservation. Hooper-Greenhill (2013, p6) considers the position of the role of the museum within this cultural shift:

> *As electronic media move center-stage, what is the function of the three-dimensional object? As the importance of knowledge and information grows, how can museums play a genuine part in the production and dissemination of knowledge? How should museums renegotiate and redefine their function? What is the way forward for the twenty-first century?*

The holographic medium might be an appropriate solution for this cultural shift in museums in order to attract a new generation of younger people who have become more familiar with technology, more so than learning about their heritage. Wavell et al. (2002, pvii) point out that museums input from "[*y*]*ounger people making connections with existing knowledge, particularly when there is appropriate mediation to facilitate the learning process*". Consequently, the importance of employing technology is that it can serve to offer an additional means of presentation in museums to broaden their appeal to all generations and enhance the visitor's experience.

The University of Sussex research and enterprise project's (2018, p1) overview is that:

> *Access to fragile historical sites and monuments is often restricted, collections are often far larger than can be presented within the confines of the physical space of a museum or gallery, and curators have to balance the sometimes conflicting priorities of preservation and public access. Technological advances mean that museums can now archive and catalogue material digitally.*

Museums acquire objects that are historical, religious, economic, technological, and so on, and create collections because the objects communicate a significant message or messages to museum visitors. A part of this communication is dependent on how effective a museum is in its practices, which include documenting, display and interaction, with many museums worldwide being developed from being places to display heritage items to being virtual. This can mean that museums can insert analogue and digital techniques for the digital generation in the technological era.

> *The significance of the online museum -to institutions and to their audience- has been debated from the Internet's earliest days. The second generation of Web tools has only intensified that debate. In the early 1990s, museum professionals worried about the role of the "virtual" museum online* (Din and Hecht, 2007, p3).

According to Younan and Treadaway (2015, p240):

> *Digital 3D models of heritage artefacts are used in a continuation of the traditional activities, which scholars and professionals in cultural heritage institutions have been pursuing for centuries; to document museum artefacts, heritage sites and archaeological finds, to study heritage materials without the need for physical access, to simulate real-world scenarios and to test restoration and hypothetical reconstructions.*

Abdelmonem (2017b) confirms that preservation of virtual heritage can be considered as an important application of state-of-the-art technologies, providing scope for interdisciplinary application. Abdelmonem (2017b, p5) suggests that "[*v*]*irtual reality is sometimes referred to as immersive multimedia, as a computer-simulated environment that can simulate physical presence in places in the real world*". For example, architecture and archaeology students can feel transported to another world and made to feel as if they are present at an actual site, with all its past details. A virtual heritage can help develop a rich library and digital record of details, information and data necessary in restoring historical sites. Heritage preservation can be supported by 3D virtual models that contain accurate data and help for restoration (Abdelmonem, 2017b). These models can include representations of cultural artefacts, if required.

2.4 Why document artefacts?

A catalogue contains documentation of an object that is an "*accurate and detailed description of an object such that it can be distinguished from other similar objects*" (UNESCO-ICCROM, 2009). Ideally this documentation should conform to the international standard of object ID. "*Documenting collections is a professional duty, without which a museum does not deserve to be called a museum*" (Avaro et al., 2010, p18). "*When an object is moved from its place of origin and its context, its significance is reduced and becomes more reliant on the documentation linked to it*" (Avaro et al., 2010, p2).

The ICCROM-UNESCO (Avaro et al., 2010) guidance explains that when an object arrives at a museum, it begins a new life and goes through a number of procedures, that include its being studied, positioned, exhibited, restored, loaned and conveyed. Most importantly, it will be positioned beside numerous of items. Thus, it is essential to be identified in a 'unique' system and organise its accessioning in inclusive ways for public. The significance of historical collections for education purpose, clarification or research, its approachability and its safety should imply the accessibility and availability (Avaro, et al., 2010).

> "*Documentation is thus the organization of information. Basic documentation is needed for the administrative management of a collection. It enables the museum quickly and effectively to:*
>
> - *establish proof of ownership;*
> - *locate a specific object;*
> - *find out the total number of objects making up the collection;*
> - *carry out an inventory;*
> - *establish the (always unique) identity of an object;*
> - *link information to an object;*
> - *access information in an efficient and economical way (saving space, time or effort);*
> - *contribute to the safety of collection;*
> - *carry out an insurance valuation.*
>
> *It is possible to supplement this basic documentation, if so desired, in order, among other things, to:*

- *understand an object and bring it to life (history, use, social or religious value, etc.);*
- *present it in a permanent or temporary exhibition;*
- *make it of interest to the public or researchers;*
- *analyse collections with a view to making acquisitions;*
- *have a record of the acts of conservation/restoration that the objects have undergone;*
- *plan preventive conservation, organisation of stores, etc*" (Avaro et al., 2010, p2).

Through experience, museums have developed practices that are to a greater or lesser extent shared. The documents containing information should together form a documentation system, which is organized in order to manage the objects in the museum's collection. The different information media of a museum's documentation system are interdependent and enable cross-reference searches to be carried out. The information they contain is often duplicated, but organised in a different way (Avarol et al., 2010).

Younan and Treadaway, 2015 comment that museum objects can support a wealth of associated ideas which can contribute to generating entirely new concepts. In the same way, "*digital 3D models of museum artefacts can inspire and promote the exchange of ideas.* Furthermore, "*digital 3D models of heritage objects can provide speedy interaction and translation from the physical form to the virtual form that can help create imaginative thought*" (p241).

Younan and Treadaway, 2015, p241) also note that "[*m*]*emories of personal or cultural stories that are linked to prior knowledge or experience can be stimulated by physical characteristics of objects (Annis, 1986; Kavanagh, 2000)*". For example, personal cultural heritage items, such as jewellery, can create sensory and cognitive stimulation (Treadaway, 2004b).

2.5 Virtual Museums

The future museum developments are promising, thanks to a variety of features including results of studies, cooperation, projects and research. "*In the twenty-first century, the greatest challenge facing museums is to recognise that museums are for people, and that future success depends on identifying and meeting their needs*" (Ambrose and Paine, 2012, p28). In this technological era, digitised museums will be fundamental to convey information, concepts and ideas to meet people's requirements and expectations.

Falk and Dierking (2013, p25) highlight that:

> *Twenty years later one cannot ignore the increasing importance of the virtual world to museums; we recognize this new reality and have tried to address it as much as possible given that this aspect of the museum experience falls by and large outside our area of expertise.*

Virtual time in a museum setting could be considered as reality; that visitors might spend time and wander between cultural heritage items, in virtual museums, can be similar to real time. Treadaway (2004a, p1) considers that:

> *... creative practice can be explored through a sharing of imagination in virtual space and the resulting material artefact is a phenomena of both individual and shared expressive responses.*

The development of digitised museums and virtual museums cannot ignore the need for accessibility, as this will be a key aspect for the future of museums. Abdelmonem (2017b, p5) points out that digitised museums and virtual museums can enhance the visitor's experience through their interaction with the technology. An example of this concept is where, according to Miller and Millican, cited by Abdelmonem (2017b):

> *... the project enables user experience to be optimised for simple and accessible technology that exists in the visitor's pocket. It makes virtual time travel a reality that is available to both local, foreign and even global audiences. This method of interacting with the past enriches the visitor experience whilst providing insights into the past that are comprehensible for the ordinary user.*

An example of what could be achieved through the use of technology is conveyed in the "Virtual Roman Project" started in 2008, and funded by Leicester City Arts and Museum Service, De Montfort University and the University of Leicester. Higgett et al. (2012, p1) highlight the demand to find innovative methods for audience engagement:

> *This paper presents progress on the Virtual Romans project which was intiated in 2008. The aim of this project is to explore the potential for creative technologies to*

> *increase the understanding of life in Roman Leicester (Ratae Corieltavorum) in the 1st to 4th Centuries A.D.*

The project consists of a number of virtual heritage reconstructions. The first is the creation of a collection of interactive 3D visualisations of Roman artefacts and characters based on a combination of archaeological findings and historical research. The creation of virtual artefacts is aimed at producing and displaying "*3D models of archaeological artefacts on the web*". Higgett et al. (2012, p4) added that their paper "*provides a valuable resource and case study for other researchers and developers working in this rapidly evolving field of digital heritage*". Although this part of the project is still in early development, it is anticipated that this set of characters will be modelled, animated and integrated into the game environment using the same 3D tools, Autodesk MAYA and Unity 3D. Another development in the project is an augmented reality mobile phone application, which is clearly an example of using the museum visitors' own technology.

2.6 Visitor engagement

A number of elements that play an important role in museums, such as visitors' experience and requirements, helping discovery and engagement. In addition, museums have a number of duties towards society, one being that museums need to understand visitors' desires, behaviours, preferences and reactions to technology experiences to attract them to successful engagement. Ambrose and Paine (2012, p26) emphasise that "*Museums need to explain the rationale for their mission and their core values to their users, and engage their visitors and users in helping them shape their mission and values*". Abdelmonem (2017a, p9) indicates how this can be achieved:

> *Cultural institutions ... are immersed in connecting with aspects of history and tradition. Their prime purpose is to bridge time, space and experience between the past and the contemporary audience and visitors. Technology offers new frontiers that help widen both platforms of engagement and number or type of regular audience.*

Annis (1986) identifies three theoretical areas in which visitors interact with museums; the *cognitive space, the social space and the dream space*. The cognitive space engages with factual information, such as signage; the social space is provided by the interactive nature of the museum visit; and the dream space creates the personal and emotive responses to museum objects. These responses stimulate associations, memories and emotions, and popular media, personal experiences and thoughts can all influence how viewers make sense of their cultural heritage (Annis, 1986; Kavanagh, 2005).

> *In a recent article in the Guardian newspaper, Mia Ridge and Danny Birchall (2015) suggested that while people may no longer be missing out on all that cultural heritage has to offer online because of their lack of internet access, there may be a new "digital divide" focused on social media platforms of display. Museums and exhibition managers are therefore contemplating whether the contemporary technology-hungry younger generation, or "digital natives", are receiving appropriate content* (Abdelmonem, 2017a, p9).

Ambrose and Paine (2012, p27) explain that a museum's role is not only to display its collections, visitor engagement is also important to encourage exploration:

> *Museums have to engage interest through active involvement with their users and build on this to achieve their objectives. Museum managers should encourage users to explore and discover the museum's collections and services for themselves.*

Black (2005, p55) suggests that communities and museums must cooperate jointly to overcome barriers in order "*to eradicate past and present inequalities of access and build a new culture of inclusion*". Moreover, light must be shed on the role of museum staff, who play an important role in the visitor experience. "*The museum staff are the most important element of all in the visit experience. According to how efficient, smart, helpful and friendly they seem, the museum will be judged*" (Ambrose and Paine, 2012, p35). With the technology development of the digitised museum, the museum staff's role will extend and change. According to Ambrose and Paine (2012, p33), people visit museums for a number of reasons:

> *Some are straightforward, such as seeking information or having somewhere to meet their friends, somewhere to take visitors or children when they are on holiday; some are more complex, such as to discover the history and heritage of a place, to find a sense of personal identity, to spend time exploring the significance of a collection.*

Consequently, museums must work hard to offer a variety of facilities and activities to meet visitors' requirements in order to attract large numbers. Falk and Dierking (2013, p83) point out that "[*s*]*ome visitors learn best when they touch things, others from reading*". This view is supported by Lenton (2013), who explains the Samsung Digital Discovery Centre project, started in 2009. This project aims to help young visitors to learn and interact with collections in the museum. "*Young visitors to the British Museum in London will be able to use augmented reality, 3D printing and touch tables to find out more about key exhibits [...] to bring to life artefacts from Buddhist sculpture to Egyptian paintings*" (Lenton, 2013, p14). According to Neil MacGregor, director of the British Museum, families and schoolchildren found these marvellous digital instruments *irresistible* (Lenton, 2013).

To create profound experiences for museum visitors and reach a broader audience Ambrose and Paine (2012, p49) consider that "[*e*]*very museum should carry out regular visitor surveys to find out who their visitors are*". To meet Annis's (1986) museum visitors' cognitive and social space needs, research and surveys undertaken regularly could realise visitors' needs: what kind of visitors, how to attract them, their aspirations and to why museums have not previously met visitors' requirements. The results should identify the services and facilities that need to be adopted, or to be improved upon. Consequently, by offering improved physical comforts such as cafes, gift shops, disability services and car parking etc., the museum experience for the visitor will be eased, made more comfortable and support the dream space (Annis,1986) that creates the personal and emotive responses to the museum and its displays.

2.7 Museums in Saudi Arabia

The present research focuses on the use of technology for documenting, accessioning and cataloguing purposes of museum collections, particularly in the KSA. In this section, to shed light on the current situation in the KSA, museum practices and display systems, related to interaction and visitor engagement will be discussed.

The President and founding member of the Saudi Commission for Tourism and National Heritage (SCTH) is His Royal Highness Prince Sultan bin Salman bin Abdul Aziz. This

Commission, based in Riyadh, the capital city of Saudi Arabia, has a number of branches in different cities throughout Saudi Arabia. According to the SCTH website "*the main objective of the establishment of SCTH was to take care of the tourism sector in the Kingdom with respect to its organization, development, and promotion*". In view of the KSA's vast tourism potential, the SCTH also works to enhance the role of the tourism sector through overcoming obstacles that may prevent its development. SCTH's efforts include preservation, development and maintenance of antiquities and promoting the contribution of antiquity in the cultural and economic development. In Saudi Arabia there are two types of museums:

1. Government (national) museums - located in various cities and regions of the Kingdom. There are 23 museums as listed in the SCTH directory (Saudi Commission for Tourism and National Heritage, 2015).

2. Private museums - operated by the owners who collect artefacts and display them through their own means; some in their homes and some in special areas under SCTH supervision. There are 113 private museums in different cities and regions in Saudi Arabia. The researcher identified that recently three more private museums have gained permission from the SCTH to open in Makkah (Muslims' holy city).

Although the SCTH is considered to be a young institution, it has a vision, referred to as the "*2030 vision*", to develop the tourism sector and its elements, such as museums. The SCTH has stepped into the future by going to people instead of waiting for them to come to them, by starting a mobile exhibition to introduce Saudi culture and heritage to the world. According to SCTH:

> *The idea of the exhibition came into being in 2006 in response to the directives of the Custodian of the Two Holy Mosques King Abdullah bin Abdul Aziz (may Allah rest his soul in peace). It also came in response to the suggestion of the former French President Jacques Chirac on his visit to the Kingdom during the opening of the exhibition,* "*Masterpieces of Islamic Art*"*, which was organized by SCTH at the National Museum in Riyadh on 6th March, 2006* (SCTH, 2017).

In 2006, the SCTH started to organise a mobile exhibition for display worldwide, it was called "*Saudi Archaeological Masterpieces through the Ages*", also known as the "*Roads of Arabia*" expo (SCTH, 2017). It is stated that the *Roads of Arabia* expo is:

> *One of the most important mobile Saudi exhibitions highlighting the cultural heritage of the Kingdom all over the world. It has already visited several European countries, as well as the United States. It represents an important opportunity to display Saudi Arabia's national heritage to the world, as the Kingdom has a great cultural heritage and deep-rooted history in its fold* (SCTH, 2017).

The significance of this is expo is described as:

> *The importance of "Roads of Arabia" expo lies in its exposure of the Kingdom's great heritage and antiquities, which date back to ancient successive civilizations and great cultures that had taken place in Arabia through the ages. However, these invaluable archaeological treasures are not widely known to a large number of countries in the world. Thus, it becomes vitally important to introduce to the countries of the world to the Kingdom's great heritage and its leading role in the human as well as Islamic civilization* (SCTH, 2017).

Among the goals of the Saudi "*2030 vision*" related to this research, is to establish a number of new museums and to develop the existing ones. HRH President of SCTH indicated that "*SCTH seeks to create a quantum leap in the museum sector in the framework of the Custodian Program for Caring of Kingdom's Cultural Heritage*" (SCTH, 2017). The "*Roads of Arabia*" expo exhibition has travelled to a number of international locations including the Louvre, Paris, where at the time of this research thesis being written it is still being displayed, and on 29th January 2018 to Tokyo, Japan. In discussing the matter of sending priceless pieces of heritage to be exhibited around the world, I noted that most of the people who work in the museum industry agreed that these pieces could be exposed to the risk of loss, damage, or theft. The main goal for any museum is to keep their pieces of heritage safe and secure. The "*Roads of Arabia*" expo draws on the cultural heritage of the Arabian Peninsula, to which the next section provides a background.

2.8 The Arabian Peninsula

The Arabian Peninsula lies between the three continents of Asia, Africa, and Europe. It has its own taste in art forms, as a result of thousands of years of people's movement and the need to trade for life's necessities and luxuries. Traders took incense (*albakhor*) from Dhofar, daggers and swords from Yemen, tanned leather in Taef, dates from Al Madinah, etc., to the north, through what was called later the incense road or spice route, which took them from the south of the Arabian Peninsula to the north to reach the *Silk Road* that connected China with Europe (Figure 2.3 below).

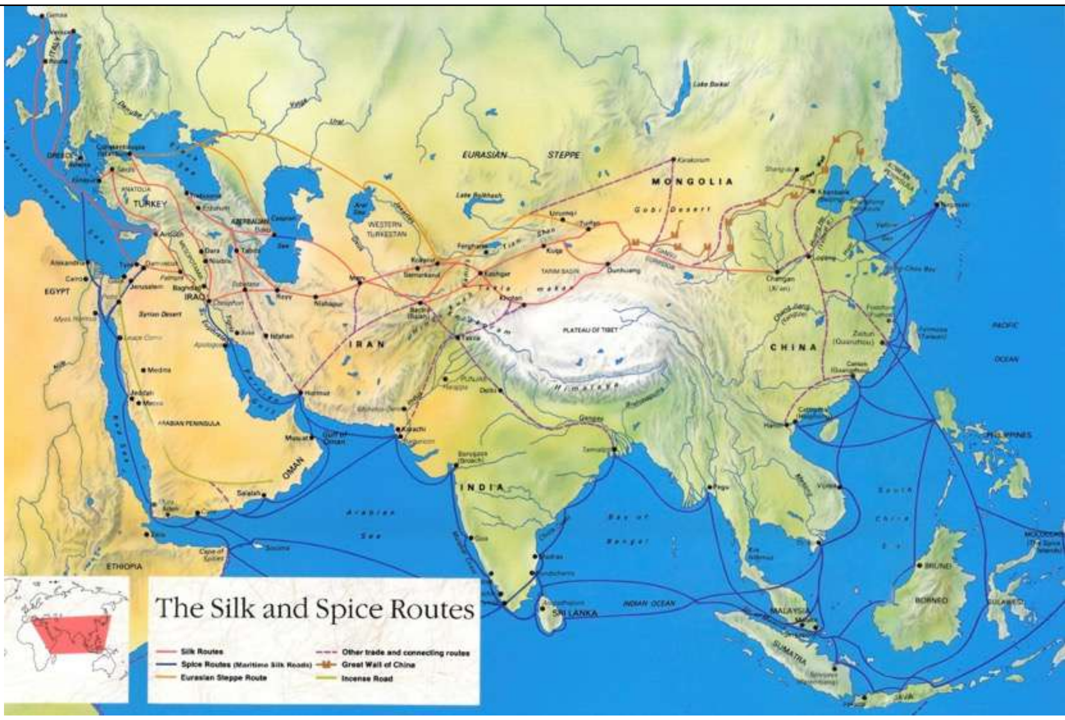


Figure 2.3 Map of the Silk and Spice Routes
(Source: UNESCO, 2017b)

In the north of the peninsula, in what is now known as Syria, Jordan, Lebanon and Palestine (Al Sham in ancient times) and Iraq, traders bought vines, oil, wine, raisins, and silk textiles in the Levant and elsewhere. Additionally, there was trade with the Persians through the Arab Gulf and with India through the Arabian Sea. There was also trade with the Kingdom of Aksum (also known as the Aksumite Empire, which existed in the area now known as Eritrea and Ethiopia) through the Red Sea. This trade was going on before Islam was founded and is recorded in the holy Quran (see Table 2.1).

106 Koraysh In the Name of Allah, the Merciful, the Most Merciful [106.1] For the custom of the Koraysh, [106.2] Their custom of the winter and summer journey. [106.3] Therefore let them worship the Lord of this House [106.4] Who fed them from hunger and secured them from fear.	(قُرَيْشٍ) (بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ) لِإِيلَافِ قُرَيْشٍ (1) إِيلَافِهِمْ رِحْلَةَ الشِّتَاءِ وَالصَّيْفِ (2) فَلْيَعْبُدُوا رَبَّ هَٰذَا الْبَيْتِ (3) الَّذِي أَطْعَمَهُم مِّن جُوعٍ وَآمَنَهُم مِّنْ خَوْفٍ (4)

Table 2.1 Quran Sura No.106
(Source: E-Quran, 2009)

Translating and interpreting the above indicates that there were different and varied types of crops and yields and seasonality. Traders travelled to the north in summer and to the south in winter connecting Asia with Africa and Europe through trade journeys. These connected with the civilizations that then existed, including the Babylonians, Romans, Persians, Egyptians, Chinese and Indians. The Arabs of the peninsula formed, through time, a unique different type of culture in this part of the world.

2.9 Existing artists documenting heritage in artistic works in Saudi Arabia

Saudi Arabian artists have depicted the beauty of an era through their paintings; one of these pioneer artists is Safeya Binzagr (صفية بن زقر) who has had her paintings displayed in the British Museum. Binzagr, known as a leader in documenting folklore and social, cultural, architectural and appearances in Saudi Arabia in her paintings, considers that "[*i*]*f we don't save the past it will disappear and go into oblivion like it did not exist*" (*Alyaum*, 2003). Naseem (2015) highlights that "*Safeya Binzagr is a pioneering artist in Saudi Arabia who successfully documented the country's customs and heritage in her art*". Fatany (2013) confirms that Safeya Binzagr should "… *be recognized for her dedication to record the history of the Saudi Hijazi cultural heritage and its customs and traditions*". Redazione (2016) considers that:

> *Safeya's imposing paintings transport the viewer to a time that has long since passed, they meticulously depict life in Harat al-Sham and the other neighbouring alleys, inside those cold stone houses, and behind those festooned wooden windows.*

The rich paintings of Safeya Binzagr are, in fact, a living testimony to a heritage that will never fade away. Another thing that never fades is the culture, and whoever joins one of the four big universities in Jeddah knows that well.

Rather than just in a portrait, landscapes and life can "*... transport the viewer to a time that had passed*" (Binzagr, 2016). Binzagr, in her painting "*Al-Mahmal*" shown in (Figure 2.4) which shows:

A scene from the religion chapter, which the artist will not have witnessed herself, is named Al-Mahmal after a decorated camel litter which was used to ceremoniously carry the Kaaba covering for the Hajj into Mecca" (Green box Dictionary of Saudi Arabian Artists, n.d.).

She depicts meticulously what took place in Harat al-Sham, inside the houses and behind windows. The rich painting uses light to depict warmth, coldness and three-dimensions to portray an image of reality that will remain a living testimony to a heritage that will never be lost and is a reminder of a past era. Binzagr's painting keeps alive detailed images of the past for future generations, as Binzagr reflects "*Who said that good old times never come back?*" (Binzagr, 2016).

Figure 2.4: Binzagr *Al-Mahmal* (1972)
(متحف الفن السعودي المعاصر)
(Source: Greenbox Dictionary of Saudi Arabian Artists)

2.10 Why document Arab heritage jewellery?

The Arab traders traded almost everything, from the food that they ate to the tools they used and the textiles they wore, even the raw materials they used to make jewellery. The researcher was inspired to investigate technology solutions, in this research, as a method of improving and developing the recording, cataloguing and displaying of artefacts. The jewellery of the Arabian Peninsula has its own history, both design and aesthetic. The researcher considers that the Arabian jewellery designs reflect the heritage of the Arabian Peninsula and are synonymous with the KSA. It is not the researcher's aim to be an historian in this research, but to look at jewellery from an artist's perspective and investigate the best method to document its beauty.

2.11 Light as utilised in art

The phenomenon of light is something that has fascinated mankind throughout history. In an attempt to capture and record its beauty, it has been documented through exhibitions, museums, ornamentation and photography. Light is a fundamental tool for the artist as it also plays a vital role in illuminating a three-dimensional object. Light is used as a device, either as natural light or artificial, to draw the viewer's eye to a particular point in a painting. Sir Isaac Newton "*supposed rays of light to consist of minute particles of matter, which are constantly emanating from luminous bodies and cause vision*" (Snelling, 1849, p14). The universal creative objective for the artist is to capture a three-dimensional space that can be created on canvas or paper by recreating light and shadow on a two-dimensional surface, as an illusion. A hologram, however, is a three-dimensional image formed by the interference of focused coherent light beams and created with photographic emulsion on a sensitive plate or film that shows realistic three-dimensional images. On the other hand, incoherent light, described by Mc Elhinney (2009, p45) "*is a wavefront of light containing different phases and possibly different wavelengths (i.e. sun-light)*".

2.11.1 Properties of light

"*Without light there is no color*" (Fichner-Rathus, 2014, p82). Newton's prism experiment demonstrates that sunlight contains the full spectrum of light. This is why we can see the whole range of colours in a rainbow, as sunlight contains all the colours.

Sunlight travels through the prism at different speeds and it separates and disperses the light into its different colours, as it exists in the prism (see Figure 2.5). Passing through a prism disperses the range of colours of light.

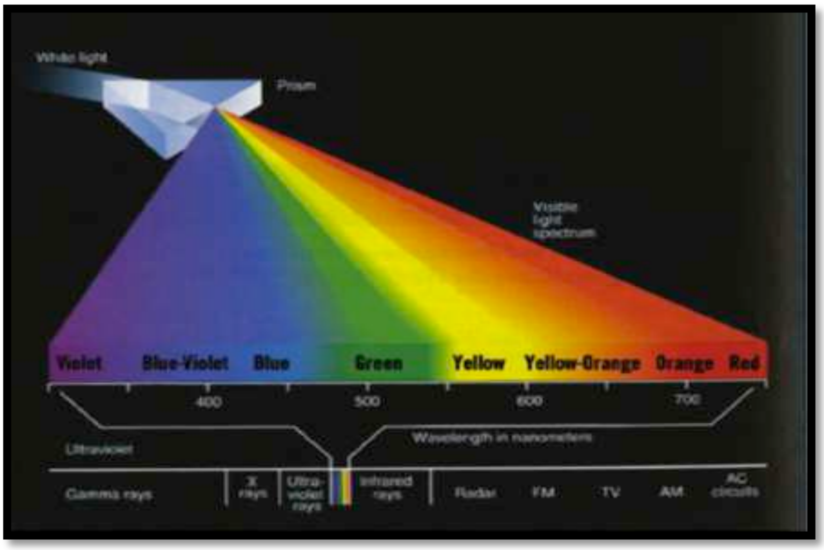


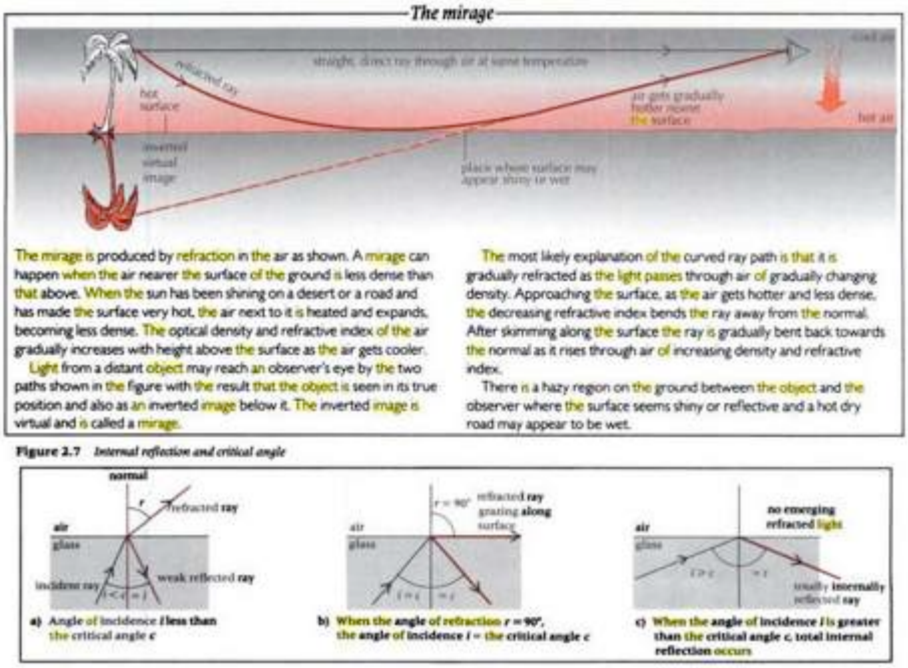
Figure 2.5 Refraction of white light by a prism into the visible spectrum – the colours of the rainbow. Reds have the longest wavelength and violet, the shortest
(Source: Fichner-Rathus, 2014, p82)

Using a triangular glass prism, Newton demonstrated that the phenomenon of white light contains different colours. Sabra (1981, p235) provides an insight into how this might have happened:

> *Having darkened his chamber and made a small (circular) hole in the window-shatters, to let in the sun's light, he placed the prism close to the hole so that the light might be refracted to the opposite wall.*

Sabra adds that what Newton found puzzling "*was the shape rather than the colours of the solar spectrum on the wall*" (Sabra, 1981, p235). The colour of an object is the wavelength of the visible light that is reflected from the object and received by the eye.

For this current study, it is important to understand what light is and how it reacts and behaves within different environments. According to NASA, "[*t*]*he color of an object that we see is the color of light reflected. All other colors are absorbed*" (NASA, 2007). "*Mirages are another example of optical phenomenon that occur naturally and are* *produced by refraction*" (Serway and Vuille, 2016, p763). Avison (2014, p27) states that "*the mirage is produced by refraction in the air ...*". A mirage is an image of an object that occurs when the light ray's refraction passes through atmospheric layers of variable density. Avison (2014, p27) explains that in "[*r*]*efraction* […] *light rays change direction air gets gradually hotter nearer the surface*", resulting in the ***object*** being seen in its true position and as an inverted *image* below it. Figure 2.6 explain the phenomenon of the mirage in detail.



The mirage is produced by refraction in the air as shown. A mirage can happen when the air nearer the surface of the ground is less dense than that above. When the sun has been shining on a desert or a road and has made the surface very hot, the air next to it is heated and expands, becoming less dense. The optical density and refractive index of the air gradually increases with height above the surface as the air gets cooler.

Light from a distant object may reach an observer's eye by the two paths shown in the figure with the result that the object is seen in its true position and also as an inverted image below it. The inverted image is virtual and is called a mirage.

The most likely explanation of the curved ray path is that it is gradually refracted as the light passes through air of gradually changing density. Approaching the surface, as the air gets hotter and less dense, the decreasing refractive index bends the ray away from the normal. After skimming along the surface the ray is gradually bent back towards the normal as it rises through air of increasing density and refractive index.

There is a hazy region on the ground between the object and the observer where the surface seems shiny or reflective and a hot dry road may appear to be wet.

Figure 2.7 *Internal reflection and critical angle*

a) Angle of incidence *i* less than the critical angle *c*

b) When the angle of refraction $r = 90°$, the angle of incidence i = the critical angle c

c) When the angle of incidence *i* is greater than the critical angle *c*, total internal reflection occurs

Figure 2.6 The mirage phenomenon
(Source: Avison, 2014, p27)

Total internal reflection is seen when *light passes* through air of different density; it is of two kinds – inferior and superior. The actual item in the inferior mirage is the sky or distant object in a similar direction. These types of mirage are unstable, as hot air increases and cold air emerges, resulting in mixing. "*One of the most commonly seen optical illusions is the highway mirage in which shimmering pools of water seem to cover the roadway far ahead*" (Orman, 2010, n.d.) as shown in Figure 2.7 below. Due to the temperature difference in air, the refractive index of the air changes, causing a blurred shiny surface on the road. However, a superior mirage appears when the air under the line of eyesight is colder than the air above it.

Figure 2.7 The highway mirage
(Source: Serway and Vuille, 2016, p763)

For this current study, it is important to understand what light is and how it reacts and behaves within different environments to fully comprehend the way light and the holographic optical phenomenon work. Passing through a prism disperses the range of colours of light. Understanding the nature of light and the way it behaves in different particular stimulated environments such as the atmosphere and, in the case of this research (initially), mist environments, it will be possible to investigate the possibility of a mist display system. Holograms can be projected using a mist display system, which suggests that the eye interconnects the spiritual essence of light and proposes that the lens of the eye focuses the image on the retina (Lindberg, 1986). Also, and importantly, museums could be an ideal atmosphere and environment to display artefact holograms.

2.11.2 The concepts of light

The behaviour of light fascinates and encourages the study of its behaviour to understand its properties. The properties of light can be revealed once we answer the following questions: What is light? What is it made up of? How it is generated? How fast does it travel? How does it propagate across empty space? How does it interact with matter? It is necessary to become familiar with the definition of some of the terms used in the science of optics. Snelling (1849, p15) defined the scientifically used terms on optics as:

> ***Opaque*** *bodies permit light to pass through them, but reflect light.*
> ***Luminous*** *bodies are of two kinds; those which shine by their own light, and those which shine by reflected light.*

__Transparent__ bodies are such as permit rays of light to pass through them.
__A ray__ is a line of light.
__A beam__ is a collection of parallel rays.
__A pencil__ is a collection of converging, or diverging rays.
__A medium__ is any space through which light passes.
__Incident__ rays are those which fall upon the surface of a body.
__Reflected__ rays are those which are thrown off from the body.
__Parallel__ rays are such as proceed equally distant from each other through their whole course.

To understand exactly what is meant by light, it is helpful to first explore how people in the past considered and defined light.

During the fourth century BC Aristotle thought that the nature of light was a wave as it formed through disturbance in the element air, one of his four "*elements*" that composed matter (Stites, 2017). Aristotle also pointed out that light needs time to transmit from one place to another (Sabra, 1981). According to Weiner and Nunes (2017, p1):

> *Democritus (460–370 BC) … elaborated the atomistic construct of the universe, attributing natural phenomena to the motion atoms items and the diversity of material object to their shape and interlocking structures.*

Both these thoughts portray light as rays that travel in straight lines. According to O'Connor and Robertson (2002) Euclid:

> *... made a mathematical study of light. He wrote Optica in about 300 BC in which he studied the properties of light which he postulated travelled in straight lines. He described the laws of reflection and studied them mathematically.*

Euclid hypothesised visual rays to be straight lines, and he defined the apparent size of an object in terms of the angle formed by the rays drawn from the top and the bottom of the object to the observer's eye. He then proved that those objects seen within a larger angle appear larger and if seen within a small angle they appear smaller, and that objects seen within a number of angles appear clearly (Suppes, 2013, p26).

2.11.3 The science of light and optics

a) Geometric Optics

The Greeks spotted the rectilinear propagation of light. When light is reflected from a surface of a mirror the angle of incidence is always equal to the angle of reflection. This was indicated by Euclid (300 BC) in his book *Catoptrics* (Verma, 2006, p2). Verma pointed out that in "*the thirteenth century Francis Bacon … suggested the idea of using lenses to improve eyesight*" (Verma, 2006, p2) and in 1280 AD lenses for eyeglasses were used "*to correct faulty vision*" (Verma, 2006, p2). He added that "*Fermat (1601–1655) discovered the concept of least time*" (Verma, 2006, p2). As per this principle, light always follows a path that takes it to its destination in the shortest time. Verma (2006, p2) states that "*in 1675 Isaac Newton put forward the 'corpuscular theory'*". According to this theory, a luminous body emits streams of extremely minute particles in all directions, called *corpuscles*. These are supposed to travel through a medium with a tremendous but finite velocity in straight-line paths. "*Newton also predicted that light should travel faster in a denser medium than in a rarer medium*" (Verma, 2006, p3). However, the phenomenon of diffraction and Newton's rings could not be explained based on corpuscular theory (Verma, 2006, p2).

b) Wave Optics

In 1678 Huygens projected the light wave theory. According to Verma (2006, p3) the theory states that "*light energy … is transferred from one point to another in the form of waves*". In 1803, Thomas Young proved the interference of light beams and "*explained Newton's rings and the colours of thin films based on interference*" (Verma, 2006, p3). Murrell (2004, p21) explains Newton's theory as: "*Now I maintain that similar effects take place whenever two portions of light are thus mixed; and this I call the general law of the interference of light*".

c) The Nature of Light

Faraday established the connection between electricity and magnetism by showing that a varying magnetic field induces an electromotive force and that the polarisation of light is affected by a strong magnetic field (Verma, 2006). "*Faraday showed in 1845 … by … observation that when polarised light was passed through a magnetic field the plane of polarization was rotated*" (Murrell, 2004, p21). Furthermore, Maxwell showed that the speed of electromagnetic waves was equal to that of the speed of light (Verma, 2006).

d) Development of Quantum Optics

Verma (2006, p2) suggests that "*the first coherent source of light, namely laser was built in 1960*". Light Amplification Stimulated Emission of Radiation (laser) light source is an important asset to holography, which reached its fullest potential only after the invention of the laser. The quantum optics theory claims that light energy consists of tiny packets called photons, which have energy E=*hυ*, where *h* is Planck's constant and *υ* is the frequency of the light wave. This type of light source is extremely monochromatic and coherent (light waves are in phase to one another).

2.12 Arab contributions

The *Oxford Dictionary of Scientists 1999* confirms that "*Abu Ali Al-Hassan Ibn Al-Haytham (C. 965 to 1038)*" was "*Born in Basra*" and adds that "*Alhazen was one of the Most Original scientists of his time*" (p7), (in Arabic: Al Hasan Ibn Al-Haytham, الحسن، بن الهيثم and known as Alhazen in the West) (Salam et al., 1994). Steffens (2007) considers Ibn Al-Haytham to be a pioneer in several scientific and mathematical fields, including physics, optics, astronomy, and analytical geometry. Gross (1981) regards Ibn Al-Haytham as "*the major figure in the study of optics and vision in the Middle Ages and his influence was pervasive for over 500 years*". Likewise, O'Connor and Robertson (2002) consider that:

> *The biggest breakthrough in ancient times was made by al-Haytham around 1000 AD. He argued that sight is due only to light entering the eye from an outside source and there is no beam from the eye itself.*

And they added that Al-Haytham:

> *... gave a number of arguments to support this claim, the most persuasive being the camera obscura, or pinhole camera ... light passes through a pinhole shining on a screen where an inverted image is observed.*

Ibn Al-Haytham's experiments on how light is refracted by the atmosphere were later developed by Isaac Newton, who formulated the first law of motion.

Ibn Al-Haytham wrote a famous book called *Almanzir* (in Arabic: كتاب المناظر), "*Book of Optics*", which describes optical theory. "*Indeed, Ibn Haitham studied the anatomy and physiology of the eye in great detail, giving many eye parts their present-day names, such* *as the cornea, the lens and the retina*" (Salih et al., 2005, p3). Ibn Al-Haytham studied light and the nature of vision by looking at the eye and its functions. Regarding light Stites (2017) points out that:

> *Alhazen developed a theory that all objects radiate their own light. Alhazen's theory was contrary to earlier theories proposing that we could see because our eyes emitted light to illuminate the objects around us.*

Zghal et al. (2007, p4) confirm that:

> *Where do the names of the optical components of the eye come from? They are indeed Ibn-Haytham's appellations: cornea* (القرنية)*, retina* (الشبكية)*, Vitreous Humor (*السائل الزجاجي)*, Aqueous Humor* (السائل المائي)*, etc.*

Ibn Al-Haytham developed theories of light that related to the rainbow, the sun, the density and height of the atmosphere, lunar eclipses and sunset (Krebs, 2004, p20). One of his experiments, which contributed to science, was the invention of the pinhole camera, also called the camera obscura, which Salih et al. (2005, p2) describe as being "*the principle behind all photography from the earliest to modern-day digital cameras*". Ibn Al-Haytham's pinhole camera consisted simply of a tiny hole that led to a dark room. By placing several lamps outside the room, Ibn Al-Haytham observed that an identical number of light spots appeared inside the room on the opposite wall. By obscuring one of the lamps, he observed that one of the light spots disappeared and as he removed the obscuring obstacle, the light spot reappeared.

> *Crucially, he observed that each lamp and its corresponding light spot were always aligned perfectly in a straight line passing through the hole. Thus, using the pinhole camera, Ibn Haitham proved that light travels in straight lines* (Salih et al., p2).

Ibn Al-Haytham's research and experiments led him to prove that light travels in straight lines based on the perspective of the particle. His book on optics was published in 1038 AD and became the historical reference in the evolution of optics. The Polish scholar Witelo translated Ibn Al-Haytham's book *Kitab Al-Manazir* on optics into Latin in 1270 (Gorini, 2003). Alhazen's book *Kitab-al Manzir* [Opticae Thesaurus] was influential in the work of Leonardo da Vinci, Johannes Kepler and Isaac Newton (Krebs, 2004, p21). The website Famous Inventors also confirms that *Kitab al-Manazir* "*... was translated into Latin in the 13th century. Roger Bacon read Alhazen's works and summarized it in his own book called* "*Opus Majus*"*, or* "*Greater Work*" (Famous Inventors, 2017).

2.13 Renaissance thought

During the high Renaissance there were a number of methods mastered, such as "*linear perspective and vanishing points, foreshortening, illusionistic devices, ... and ... shading*" (Encyclopedia of Art, 2017a). Leonardo da Vinci (1452–1519) further perfected lighting, atmospheric perspective and linear perspective, which had preoccupied artists of the Early Renaissance (Calter, 1998). Leonardo da Vinci was influenced by Ibn Al-Haytham's book *Kitab-al Manzir* and experimented with the *camera obscura* (Salih et al., p2). Da Vinci confirmed that light travels in straight lines, and that the image is inverted when travelling through a small hole. He suggested that the pupil of the human eye worked in an equivalent way. The rectilinear propagation of light rays also states that light travels in a straight line, in accordance with Da Vinci's thought (British Library Online Gallery, 2016).

The eye converts incident light into electrical signals and sends them to the brain for processing; thus an image is formed. We understand the world around us with the help of information gathered via our biological sensors – eyes, ears, nose, tongue and skin. Most significantly:

> *Most of the information we get about the world around us comes into our brain through our eyes. Vision provides more than ten times as much information as hearing, principally because light waves can carry enormously more "bits" of information than sound waves* (Bova, 2002, p5).

Da Vinci depicted light and its effects on the landscape and objects more naturally, and with greater dramatic effect, as he demonstrated with the *Mona Lisa* (Encyclopedia of Art, 2017b). It was believed that "*this portrait was doubtless started in Florence around 1503*" (Louvre, 2017). The portrayal of *Mona Lisa* is "*known to Italians as* La Gioconda*, the French call her* La Joconde" (Encyclopedia of Art, 2017b). Her sensitive smile in the portrait "*seems so real that many writers have tried to explain the thoughts behind her* *smile*" (Italy: Birthplace of the Renaissance, n.d., p475). Scailliérez (2010) asserts of the *Mona Lisa* that "*the spatial coherence, the atmospheric illusionism, the monumentality, and the sheer equilibrium of the work were all new*". Figure 2.8 illustrates Da Vinci's luminous modulation of light and shade, which are two elements of the painting.

Figure 2.8 Mona Lisa – Portrait of Lisa Gheradini, wife of Francesco del Giocando (musée du Louvre) / Michel Urtado
(Source: Louvre)

The visual impact of the painting is conveyed via the relationships within its dimensions that allow it "*to include the arms and hands without them touching the frame. The portrait is painted to a realistic scale in the highly-structured space where it has the fullness of volume of a sculpture in the round*" (Scailliérez, 2010). This uniqueness in Da Vinci's painting is evident in more than words; it communicates through the emotions expressed in the painting. An article by Pizzanelli in the handbook about this world-famous painting mentions the differences between the Louvre version and the Prado copy (see Figure 2.9 below). Superficially both paintings look the same, but close observation of the fine detail reveals that the Prado copy displays less, and less corresponds with the original. The Prado version does not correspond very well with the Louvre version as, for instance, the road does not snake round the hill very well. This is a practical example of how the originality of a masterpiece is lost when copies are made (Pizzanelli, 2016, pp52–53). In the Louvre version "*the background behind the Mona Lisa's head is filled with retinal rivalry that cannot be used stereoscopically*" (Pizzanelli, 2016, p53).

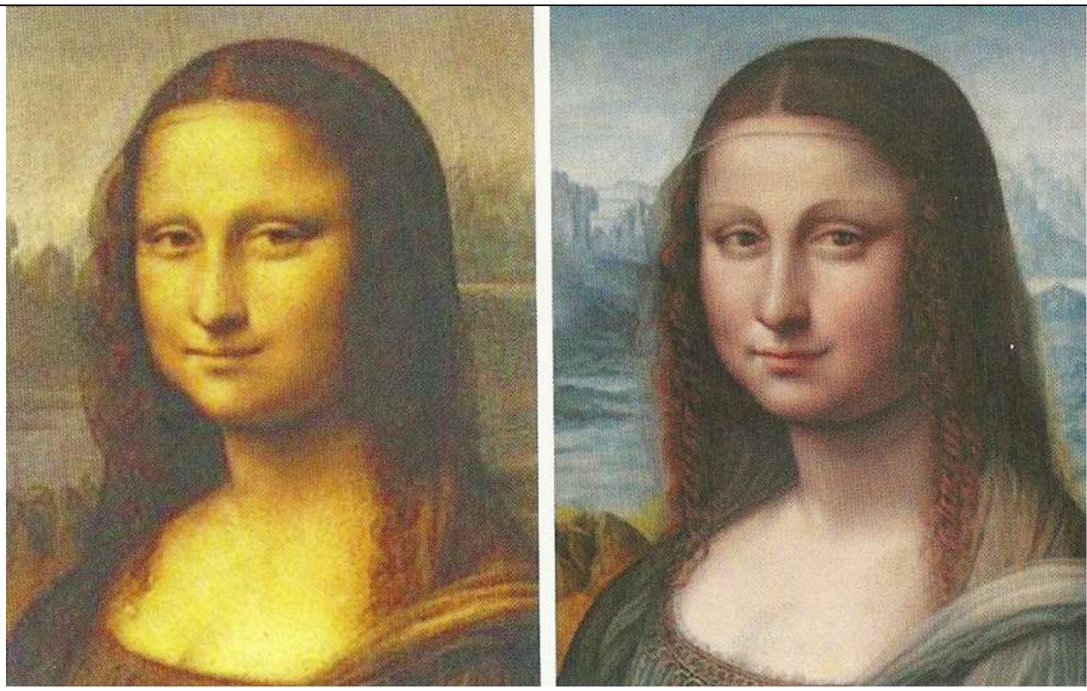


Figure 2.9 The Louvre Mona Lisa (left) and the restored Prado Mona Lisa (Source: Pizzanelli, 2016, p52)

2.14 Imaging

2.14.1 Photography

The purpose of writing about photography is that photography and holography have a similar principle. The principle behind photography dates back to ancient China when the Chinese philosopher Mo Di developed the concept of optics (Campbell, 2005). However, it was Ibn Al-Haytham (965–1040), the Arab physicist who invented the *pinhole camera* (Krebs, 2004). Underwood (2007, p3) states that "*Ibn Al-Haytham is the inventor of the pinhole camera, but the idea was later credited to Delia Porta for redescribing how the camera works*". In 1800, the first experiment to capture an image through an instrument was made by Thomas Wedgwood, using leather treated with silver nitrate. While in 1827 the French inventor Nicéphore Niépce succeeded in capturing the first photograph, "*View from the Window at Le Gras*". Underwood (2007) notes that Niépce combined photosensitive material with a camera obscura in 1816.

The difference in technique between photography and holography is that photography shows the viewer a 2D image, while holography shows the viewer a three-dimensional image on a flat sheet. Also, photographs can be captured using any type of light source such as sunlight or room light and they are more easily achievable than holographic images. Photography is a more affordable technique and uses more convenient devices, such as cameras, with very good resolution, in smart phones that fit easily in our hands. On the other hand, to capture a holographic image, a laser is the only light source that can be used and holographic viewers see 3D images.

2.14.2 Lenticulars (auto-stereoscopic)

The next medium of display that the researcher considered for displaying artefacts is lenticular imaging. The lenticular image is a three-dimensional image on a flat plastic sheet, which is produced by lenticular software that prints out on a lenticular lens sheet. "*The lens is a unique [type of] plastic that is made up of individual cylindrical lenses (lenticules) that must be perfectly aligned with the interlaced image underneath it, for the effect to work*" (The Color Detective, 2012, p4).

Rosenthal (1975), who holds a US patent in lenticular optical systems, confirms that:

> *A lenticular optical system is described in which a composite image is viewable through a lens sheet from a first angle and an object or image placed at a preselected distance beneath the composite image is viewable from a second angle.*

The production of lenticular software is the outcome of numerous video frames that are aligned in a regular periodic fashion, which is then printed out on paper located behind the lenticular lens (see Figure 2.10 below). There is a variety of lenses that show one image as seen by the right eye and a second image as seen by the left eye to create disparity that will be picked up by the brain as three-dimensional. Based on the viewer's angle "*each cylindrical lens acts as a magnifying glass to enlarge and display the portion of the image*" (The Color Detective, 2012, p4). Figure 2.11 below shows how the two eyes perceive different images formed within the lenticular lens (Timby, 2015, p44). The left and right eye images interfere in space, resulting in the creation of a three-dimensional illusion for the viewer. This is called a stereoscopic effect.

Lenticular array is not ideal for documenting artefacts as by its nature it produces an obscured image. Although lenticulars produce a three-dimensional effect, the resulting image is not good quality. The obscured image is due to the interference of the stereoscopic images formed at the junction of the two-lens column. However, for documenting, cataloguing and accessioning a very high-resolution image is needed, especially in a museum environment with, ideally, a three-dimensional feature.

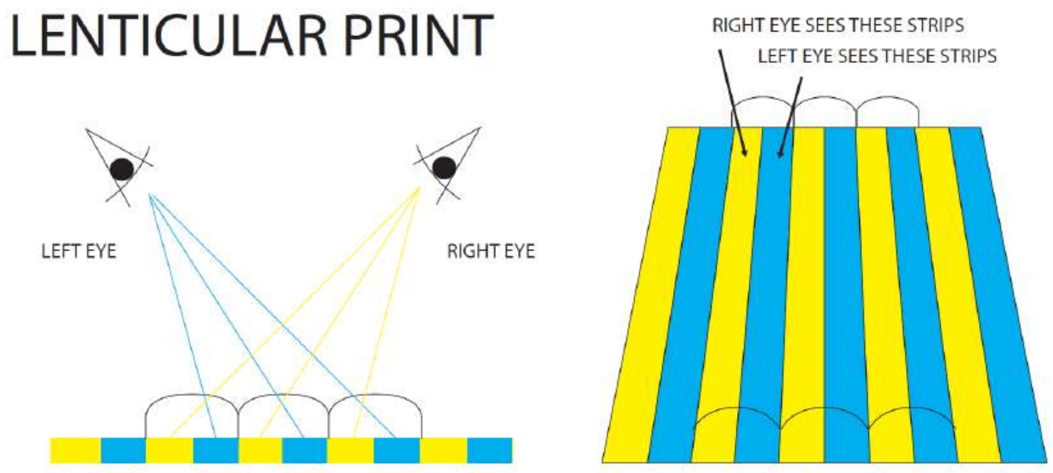


Figure 2.10 Lenticular print
(Source: Author)

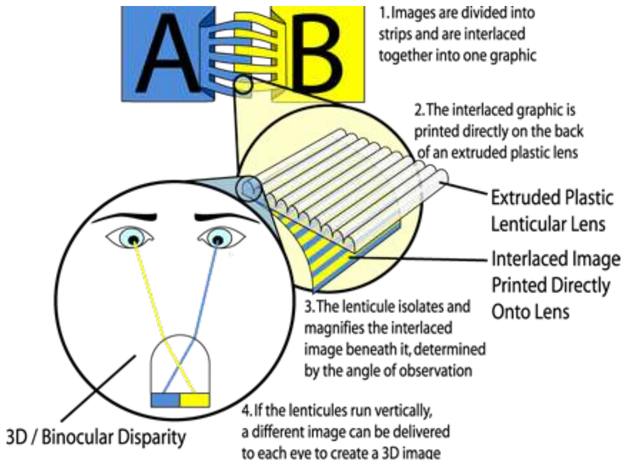


Figure 2.11 Lenticular
(Source: Lenstar Lenticular, 2017)

2.14.3 Anaglyph

"*The Anaglyph 3D method of stereoscopic visualization is both cost effective and compatible with all full-color displays*" (Woods and Harris, 2010, p1).

In 1830, the scientist Charles Wheatstone designed the first anaglyph device, which was called the "*reflecting mirrors Stereoscope*" (Zone, 2014, p5). The viewer looks at two images separately, with both eyes at the same time, through a pair of 3D glasses; however with the use of mirrors, the subject will appear as one (see Figure 2.12).

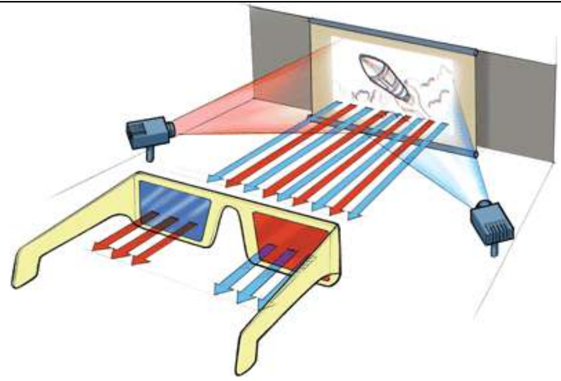


Figure 2.12 The red and blue lenses filter the two projected images allowing only one image to enter each eye.
(Source: Brain, 2003)

This is a type of three-dimensional "stereoscopic" image, formed from two photographs taken approximately 2.5 inches apart, which is the "*human interpupillary distance between eyes*" (Matsuura and Fujisawa, 2008). In fact, anaglyphs are probably the best-known "*methods for viewing stereo images*" (Matsuura and Fujisawa, 2010); however, they cannot be seen by the nakedeye (Dobbert, 2012) and 3D glasses, with a red filter over the left eye and a cyan filter or green over the right eye, are required to view the 3D effect of the anaglyph. The 3D effect only works in the horizontal plane. According to Woods and Harris (2010, p1):

> *The Anaglyph 3D method of stereoscopic visualization is both cost effective and compatible with all full-color displays, however this method often suffers from poor 3D image quality due to poor color quality and ghosting (whereby each eye sees a small portion of the perspective image intended for the other eye.*

FUJIFILM produced a 3D camera (see Figure 2.13) that can successfully capture 3D images of anaglyph and video in 3D.

> *You have two eyes, your camera should have two lenses. The Fuji W3 3D camera captures one image for each eye, recording the world just as you see it, with depth and realism. Using a camera with only one lens is like seeing with one eye closed. Use both eyes and see the Future of Imaging!* (cyclopital3d.com, n.d.)

However, the researcher did experiments attempting to capture 3D anaglyph images (but did not use a Fuji 3D camera).

Figure 2.13 Fuji FinePix Real 3D W3
(Source: cyclopital3d.com, n.d.)

When attempting to capture an anaglyph, if the focus on the picture does not take perfectly, noises can be seen and that could affect the viewer's eyesight, which could lead to headaches. Hainich and Bimber (2016, p40) explain why this happens: "*Most 3D systems cause headache because the apparent stereoscopic distance seen, does not match the required eye focus adaption*." Moreover, Omeltshenko (2010, p108) emphasises that a long period of using anaglyph glasses creates for the observer "*at some time decreased color sensitivity and a feeling of discomfort from the usual perception of the world*". As a result of this issue a number of experts, such as Surman et al. (2004), have been working on developing improved 3D screens. De Montfort University (DMU) was developing a 3D display system targeted specifically at domestic television applications. "*The design of the backlighting facilitates many other display regimes beyond the "standard" 3DTV mode in which each viewer sees the same image-pair*" (Surman et al., 2004, p208). Furthermore, Ozaktas and Onural (2007) suggest that "*3DTV will require the integration of a diversity of key technologies from computing to graphics, imaging to display, and signal processing to communications*".

In this research (i.e., the anaglyph experiment, see section 4.19 Anaglyph). The researcher used the type of 3D method anaglyph glass shown in Figure 2.12, as a demonstration of the anaglyph 3D technique, as this kind of anaglyph glass can achieve the 3D effect. However, in modern technology the use of polarised full colour 3D glasses (see Figure

2.14) gives a much better result for museum display, where it is more practical to obtain full colour. Woods and Harris emphasis that:

> *Although there are a range of other stereoscopic display technologies available that produce much better 3D image quality than the anaglyph 3D method (e.g. polarized, shutter glasses, and Infitec), the anaglyph 3d method remains widely used because of its simplicity, low cost, and compatibility with all full-color displays and prints* (2010, p12).

Figure 2.14 Polarised full colour 3D glasses
(Source: 3D Projector Buying Guide, 2014))

2.14.4 Photogram

A photogram is a technique to produce an image without having to use a camera, film or a negative. The first photogram was made by photographic pioneers William Henry Fox Talbot and Anna Atkins in the mid-1800s (Burrough and Mandiberg, 2009, p109). A photogram is a shadow image, that works directly with light and photographic paper by allowing the object to cast its shadow directly onto the photographic paper. All that is required is a light source such as an enlarger device, black and white photographic paper (sensitive material) and an object to place on the photographic paper to create the image. By exposing the sensitive paper to light, a standard black and white photograph can be created in the darkroom. This sensitive paper is processed using standard black and white paper chemicals. According to Burrough and Mandiberg (2009, p109):

> *Photograms are made by placing objects on sensitized paper, exposing the objects and paper to light, and then processing the paper to reveal the print. A camera is not necessary for the production of this type of graphic image.*

The Victoria and Albert Museum website explains the photogram principle:

> *Photograms are made by placing an object in contact with a photosensitive surface in the dark, and exposing both to light. Where the object blocks the light, either partially or fully, its shadow is recorded on the paper* (Victoria and Albert Museum, 2010-2011).

To create a photogram requires having solid, transparent objects that block all or some of the light. Depending on the opacity of the object, the negative shadow that results has a variation of tone. The results of the way light passes through objects such as the crystals, which are a kind of transparent glass made originally of sand, is fascinating to see. Objects that allow light to pass through show stunning results of light reflection (see Figure 2.15).

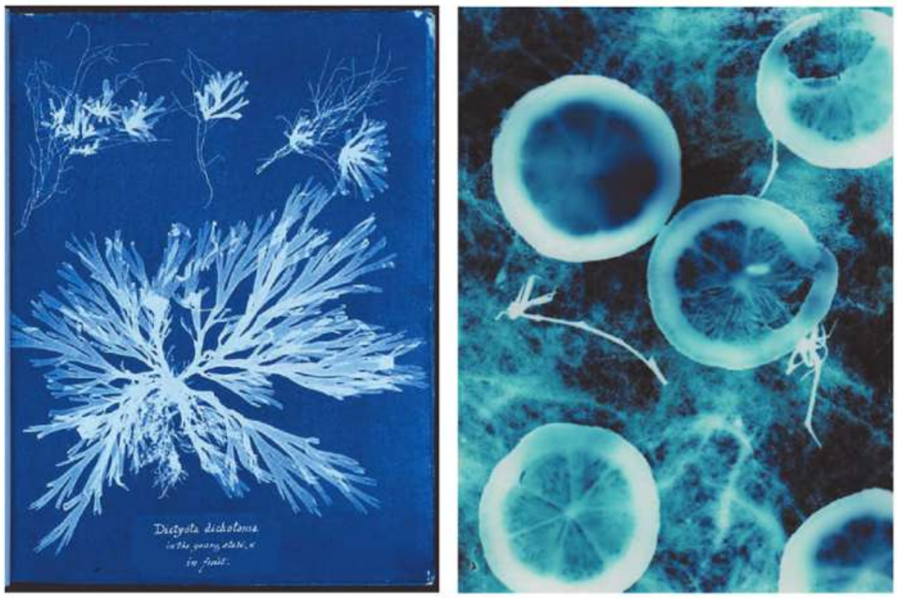


Figure 2.15 Photograms by Anna Atkins
(Source: Burrough and Mandiberg, 2009, p110)

A number of artists have used photogram art, including Richardson (2012); Figure 2.16 below is an example.

Figure 2.16 Bloom, photogram by M. Richardson, 1983, 30 × 40cm
(Source: Richardson, 2012, p34)

The researcher believes that there is popular confusion regarding the difference between a holographic image and what is known as Pepper's Ghost illusion. This confusion should be cleared by raising the reader's awareness about the differences between the two techniques. These differences are explained in the following sections.

2.14.5 Pepper's Ghost

Kriger (2012, pii) explains that "[*t*]*he ghost illusion jointly developed by Henry Dircks and John Henry Pepper in 1862*" came to be known as Pepper's Ghost, a name popularised in the 1800s (Kerzner, 2017, p607). Pepper demonstrated this technique by using it to overlay visual elements (the object) onto a physical set or stage. According to Kriger (2012, p24), the effect was first displayed at the Royal Polytechnic just before Christmas of 1862. The idea of Pepper's Ghost technique was used in theatrical performances. This kind of display system uses illusion as a key to display the object in a three-dimensional method. “*The original Pepper’s Ghost optical illusion involves placing a large piece of glass at an angle between a brightly lit* ‘*stage*’ *room into which viewers look straight ahead and a hidden room*” (Costa, 2016). It creates a virtual image using a semi-transparent mirror rotated around its vertical axis at 45 degrees. However, this technique has some limitations, such as the fixed field of view, which is illustrated in Figure 2.17 below. This means the audience can only view the three-dimensional object that is created thanks to the illusion from a fixed field of view. The view outside this area is not clear.

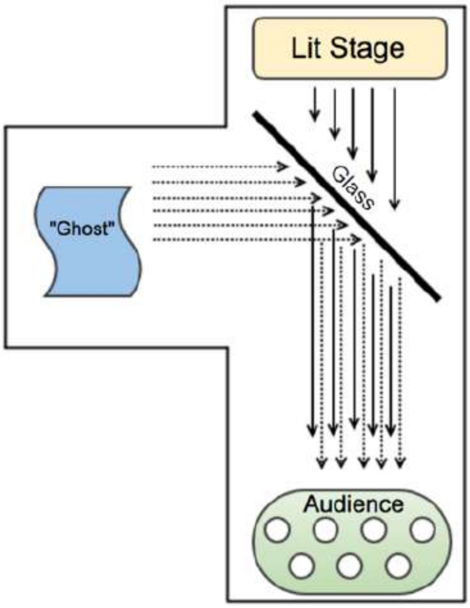


Figure 2.17 A photo describes Pepper’s Ghost technique
(Source: Costa, 2016)

Seppala (2014) explains the principle of Pepper’s Ghost as:

> *The concept requires two rooms, some specifically placed glass and carefully controlled lighting. A room adjacent to the viewing area (or stage) is set up as a mirror-image of the area the audience sees; if there’s a chair on the right of the stage, it’s on the left in the other room. The key difference is that other room is either painted black or entirely unlit, so as not to cast any unwanted reflections that would break the suspension of disbelief. That room is where the performer resides. The stage area must be brightly lit at first for the whole thing to work. Then, the stage’s lights are dimmed slightly and the lights are raised in the mirror-image room, which causes the not-physical performer to appear.*

2.14.5.1 The confusion between the concepts of hologram and Pepper's Ghost techniques

The Swedish Hologram Media website maintains that "*holography should not be confused with lenticular autostereoscopic images based on conventional lens imaging. Stage illusions such as Pepper's Ghost are also often incorrectly called holograms*" (Hologram Media, 2016). Consequently, audiences became confused about what they are seeing. This argument is considered controversial in the holographic community. Unfortunately, someone who is not aware of what a hologram is can become confused between these completely different methods. One reason is that there are many commercial companies that produce products and call them holograms. In fact, they display Pepper's Ghost technique illusions as a holographic technique and when searched for, online websites display the Pepper's Ghost technique as the holographic technique, "*Companies are paying for advert of* "*hologram and holography*" *at Googles. But app. 70%* "*hologram adverts*" *at Google are NOT Holograms!*" (Hologram Media, 2016). In fact, the process of producing a hologram and displaying it is entirely different to that of the Pepper's Ghost illusion. Hologram Media add that "*LED displays, cubes with projected pictures, shows of dead or alive persons, produce own with iphones and so on, are PROJECTION TECHNIQUES – NOT HOLOGRAMS NOR HOLOGRAPHY*" (2016).

Popular culture makes use of the Pepper's Ghost principle in mass entertainment, such as the Billboard Music Awards with Michael Jackson's performance from beyond the grave or the Coachella festival, which resurrected Tupac onstage with real-life Snoop Dogg. This technique is not only used in popular culture but also to reach and attract vast populations, such as through India's Prime Minister Modi's holographic stump speeches.

The use of the wrong terminology about the technology might be the cause of creating misunderstanding among consumers. For example, Harrison (2016, p87) also explains an illusion, which proves this point:

> *What the audience saw was an image, an extraordinarily lifelike reaction by a company called Digital Domain Media Group Inc. It was, of course, says its creator and visual effects expert, Ed Ulbrich, an illusion. It was called a hologram by the media, which was not an entirely accurate description of the technology*

> *involved. It was a blend of new digital and hologram creation with a classic stage illusion known as Pepper's Ghost.*

To create a hologram, a coherent light source (laser) is fundamental. As a hologram is a result of interference of light waves produced by the laser source, the resulting image formed is purely wavefront reconstruction of the object that carries the three-dimensional detail. However, Pepper's Ghost is a process considered to be an illusion to trick audiences. This technique projects an image that needs different materials such as film, projector, mirror and transparent glass. It does not need a laser beam or a holographic laboratory or dark room to develop the film with chemicals.

2.14.6 Modern holography and the use of light

Light plays an important role in the holographic technique as a recording process. In this section different types of three-dimensional images will be explained in detail covering process, equipment, material and its literature (results), with examples.

The term hologram originates from the Greek word *hólos* which means *whole* and *gramma* which means *message*. Holography is a specific scientific process that results in holograms. A hologram is a three-dimensional image created on a two-dimensional flat sheet of glass or film. Basically, the sensitive plate is a normal glass substrate chemically treated with a layer of gelatin, silver halide and under a process of illumination by the interference of coherent laser light beams, records and creates a 3D image. The University of Southampton's report of the city's first hologram exhibition by Pearl John describes a hologram as being an object that "*hold*[*s*] *memories and stories … the holographic images make the invisible visible*" (University of Southampton', 2014). Işik (2014) states that a "*… 3D hologram is used to display a shiny, transparent, three-dimensional hologram which is visible from every point and which you can go around them*". He points out that a "*3D hologram is used to define holographic recorded surface and the dimensions of this surface. The 3D identification here refers to the paralaxe property of holograms*" (Işik, 2014). Dawson (1999, p13) adds that "*… holographic art undermines the modernist project of 'seeing' by deluding the viewer with a predigested spectacle*".

In 1948, Dennis Gabor, the Hungarian born British physicist, discovered the holographic principle (*Oxford Dictionary of Scientists*, 1999, p198). In 1971, Gabor received a Nobel Prize for his invention of holography, a system of lensless, three-dimensional photography that has many applications (Nobelprize.org, 1971). Gabor developed a system of stereoscopic cinematography and in 1948 he carried out basic experiments in holography, at that time called "*wavefront reconstruction*". His original objective was to develop an improved electron microscope, capable of resolving atomic lattices and seeing single atoms (Nobelprize.org, 1971). Gabor was the first person to use the coherent light of a mercury vapour lamp (Saxby, 2010) . However, according to Saxby and Zacharovas, "*… in 1962, Yuri Denisyuk from the Soviet Union; and Emmett Leith and Juris Upatnieks from the University of Michigan, made the first successful holographic image*" (2010, p20). Gabor believed that his own work had been 20 years too early, as:

> *Only in recent years have certain auxiliary techniques developed to the point when electron holography could become a success. On the other hand, optical holography has become a world success after the invention and introduction of the laser, and acoustical holography has now also made a promising start* (Nobelprize.org, 1971).

Johnston (2015, p66) recounts Leith and Upatnieks description of their experimental solution:

> *Leith's and Upatnieks' first conference presentations and journal papers, describing their experimental solution to Dennis Gabor's flawed techniques and a theoretical explanation in terms of communication theory, passed with little notice. But in late 1963, they had their first taste of celebrity, at least among their peers. The American Institute of Physics (AIP), newly conscious of the publicity value of scientific research, picked up on an angle that Dennis Gabor had tried to exploit in 1948. Gabor had impressed his postwar audiences with the ability to scramble a photographic image, and then to 'reconstruct' a recognizable image from the confused hologram. By the summer of 1963, Leith and Upatnieks could improve this conjuring trick dramatically: their holograms could reveal a sharp image ….*

Yuri Denisyuk discovered a new method of making reflection holograms in 1962 called "*single-beam reflection holograms*" (Saxby, 1980), and in 1963 Denisyuk combined art with holograms from which the "*holographic techniques developed rapidl*y" (Saxby, 2010, p11) .

> *Actually the technique of recording such ultra-realistic images can be traced back to the Russian Scientist Professor Yuri Denisyuk who invented in 1963 a technique for storing images as an interference pattern in a super-fine grain recording material with the help of a laser* (Bjelkhagen et al., 2015, p6).

Using the principle of holography display, holograms were recorded showing realistic features clearly. This stimulated artists to create art in the form of holography. The type of hologram of interest to this research is Denisyuk's type of reflection hologram, whereby the view of the three-dimensional image can be seen clearly when a laser beam illuminates the front of the recorded plate. The sensitive plate is then developed in the darkroom, to show the image of the hologram (plate) emerging from a two-dimensional flat sensitive plate. An LED or a halogen light source is needed for illumination, and there is no special viewing equipment required.

However, the transmission hologram process is different from that of the reflection hologram. The equipment is the same; however, the difference in the recording process is that in the holographic laboratory the laser beam is directed at the sensitive plate position. The transmission hologram is recorded using a laser beam directed, using mirrors, from behind the sensitive plate. The image is then transmitted to the observer's side, when it is illuminated by a laser beam only. Furthermore, this type of hologram must be only viewed under laser light to view the three-dimensional image (i.e., it should be viewed by pointing the laser through the back of the plate). Saxby (1980) verifies that "[*t*]*he object beam is reflected from the object rather than transmitted through it*". Consequently, reflection holograms are more suitable for this project's experiments, due to their ease of viewing by the viewer.

Yamaguchi (2014, p1) clarifies the principle of holography as "*holographic 3D displays … based on wave optics … produc*[*ing*] *high-resolution images even when the image is located at a significant distance from the display plane*". If we consider that holography is a technique that continues to develop, it is possible to say that it will bring changes to the diversities of holograms that are used in art. Dawson (1999) points out that:

> *There is a lack of comprehensive analysis of the holographic representational system within art related theoretical and critical writing and a tendency to analyse*

individual works only in terms of generalities which apply to the concepts surrounding the holographic medium. While these form an important background for art image production, in some cases corresponding to artists' works, the existing written material on the subject is inadequate as a model from which to draw the important chronological conclusions.

Işik (2014) identified holographic terms and types of hologram used in holographic art, as shown in Table 2.2.

Table 2.2 Holographic terms and types of hologram used in holographic art

analog	- using analog recording devices - direct laser light systems (CW or Pulse) - photochemical methods, developing phase, bleaching
Digital	- a mathematical approximation of analog - using digital recording devices - dot-matrix hologram, printing digital hologram - digital screen, computer, CCD array, SLM, scaning etc.
optic and electronic elements	HOE (lenses, mirrors, filters, prisms etc.) HEE (electrons, crystal displays, cameras, computers etc.)
holographic object	- animate or inanimate - material or immaterial - immobile or mobile - sound frequency, microscopic organisms, electrons micro, nano, subatomic particles, human, animal, plant, hologram, film sequences or computergenerated 2D or 3D images
reference and object beams	- single beam, double beam etc. - off-axis or on-axis
copy and multiplication	- analog or digital - broken/cut hologram - hologram's hologram
Laser	- red, blue, green laser - continuous wave laser (to stabile holographic object) - pulse laser (to live and moving holographic object)
color	achromatic, true color, pseudo color, multi color
construction stage	- recording and reconstruction - one-step, two-step, - master, copy, multiplication - hybrid techniques - H1, H2, H3, H4...
dimensions	- thin or thick holograms - small or large-scale holograms - 1D, 2D, 2D/3D, 3D, 3D/4D
parallax	vertical parallax, horizontal parallax, full parallax
axis	- x, y, z (z: holographic depth of field)
angle	360^0, 180^0, 120^0, 45^0 etc.
directions	up ↔ down left ↔ right front ↔ back
holographic images	- real image, virtual image - pseudoscopic image, orthoscopic image - final image
illumination	- laser light, halogen lamp, led light, ordinary bulb, daylight etc.
holographic depth of field	z axis - real image (space in front of the holographic image recording material, max. 3 m) - virtual image (space in behind the plate, max. 10 m)
types of hologram used in holographic art	- reflection hologram - transmission hologram - denisyuk hologram - white light transmission hologram-WLT - rainbow hologram - pulse laser hologram - multi channel hologram - 360° hologram - holographic stereogram - computer-generated hologram-CGH - digital hologram - dot-matrix hologram
ready-made holographic materials	holographic panel, paper, foil, textile etc. holographic print

Source: (Işik, 2016, p1405)

2.15 Principles of holography

There are numerous properties of light; however, in this thesis the author will focus only on two, diffraction and interference, as these are relevant to the technique of holography. Dawson's 1999 doctoral study about holograms examines:

> *... the concrete holographic image in great detail on its own terms, firstly through theories of the basic image forming phenomena of interference and diffraction and secondly through the techniques of production as they have been adapted for the making of my art work.*

a) Diffraction

Diffraction is the bending of light waves around an obstacle or aperture. Thomas Young demonstrated this with his double slit experiment. In holography, it is relevant because the object beam is a diffracted beam, as this is a modification to its original nature that carries information about the object (Heavens and Ditchburn, 1991).

b) Interference

To understand the way a hologram converts the information about the object to be recorded, interference is a phenomenon where two different light wavefronts, from the same source, are superimposed on one another. The difference in wavefronts is that one evolves from the object and the other directly from the source itself. Therefore, during the reconstruction process only, the reference wave is required to decode the information about the object. The hologram is a three-dimensional image recording and displaying the original objects using coherent laser light. Saxby (2010, p3) defines the hologram as a:

> *record of the interaction of two mutually coherent light beams, in the form of a microscopic pattern of interference fringes. It is a photographic film or plate that has been exposed to laser light and processed so that when illuminated appropriately it produces a three-dimensional image.*

The laser beam splits into two beams, one beam illuminates the object and the other is used as a reference.

Holography is an extension of early photography. Photography is a record of an object in two-dimensional features, whereas holography is a record in three-dimensional recording. In other words, holography can be described as a photographic recording of an optical interference pattern. Gabor, who first coined the term holography, made his first holograms using a mercury arc lamp with a very narrow band green filter (Saxby, 2004). There are two major types of holograms:

(i) transmission hologram (see Figure 2.18)
(ii) reflection hologram (see Figure 2.19)

In the transmission case the reference and object wave originate from the same side (see Figure 2.20), whereas in the reflection case reference and object waves are opposite each other (see Figure 2.21).

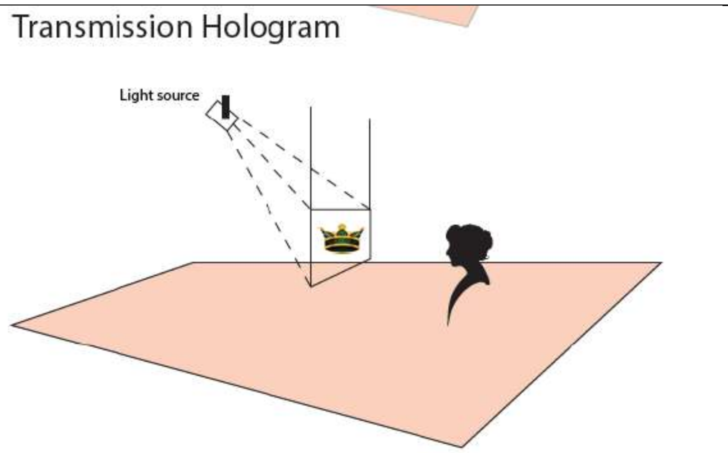


Figure 2.18 Transmission Hologram
(Source: Author)

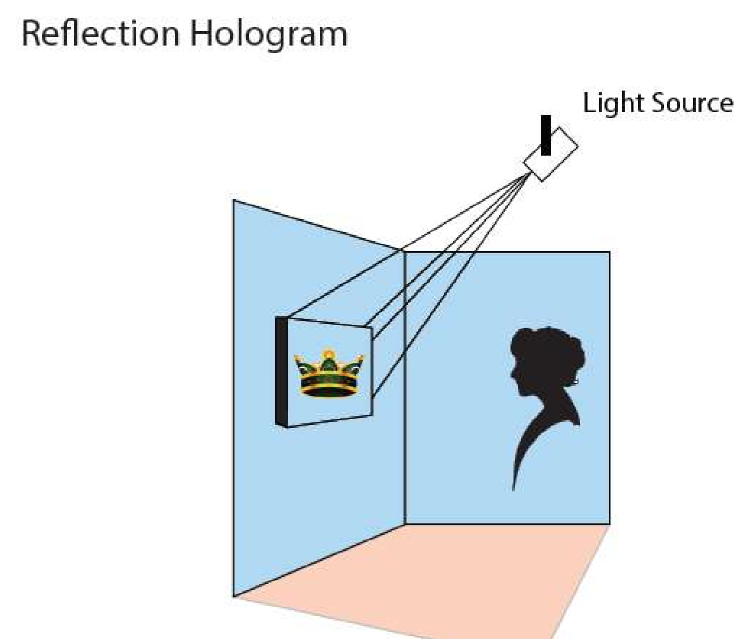
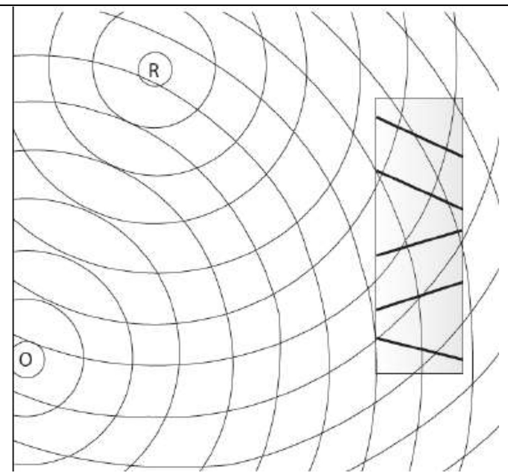


Figure 2.19 Reflection Hologram
(Source: Author)



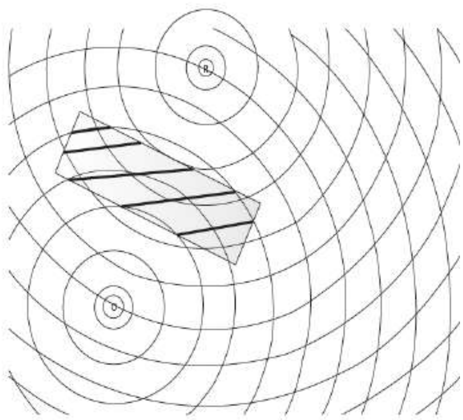


Figure 2.20 Transmission (interference waves)	**Figure 2.21 Reflection (interference waves)**

(Source: Author)

2.15.1 Reflection hologram

Reflection holograms were the first type of holograms produced, and Bjelkhagen refers to full colour *True Color* reflection holograms as "*OptoClones*" (Bjelkhagen et al., 2015, p1). In 1995 Bjelkhagen and Vukičević received a patent for producing true-colour holograms by mixing three colours of laser: red, green and blue (RGB) (Bjelkhagen and Vukičević, 1995).

Dawson (1999) highlights that:

> *To date the critical reception of holograms has made no mention of acuity, the size of the viewing frustum, the depth of the image and scant mention of interference phenomena, which are the intrinsic factors, which I believe precipitate temporal illusions.*

This current research project mainly focuses on reflection holograms, as they are white light viewable and ideal for museum display. Bjelkhagen and Cook (2010, p88) confirm that "[*t*]*he advantages of reflection holography for museum displays are that the holograms are easier to record in colour and can be displayed using ordinary 'white light' sources*". The resolution (image quality) of a reflection hologram is about 100 tera-pixels (Lakes, n.d.). Ideally, to record a reflection hologram the object wave (light wave that illuminates the object) and the reference wave (light wave that is incident directly from the source) are on opposite sides of the recording plate. Denisyuk invented a method that made it simple to record reflection holograms. Here, the object lies beneath the recording medium and a single beam is used to expose the object. This technique reproduces the reflection recording case as shown in Figure 4.16. The wave from the laser source that passes through the recording plate illuminates the object. During this process, until it reaches the recording plate the wave behaves as the reference source; the object wave is formed by this same wave that is diffracted from the object and returns to the recording plate in the reverse direction.

OptoClones™ are a full colour Denisyuk reflection hologram. Using this technique museum display holograms such as the Fabergé egg have already been made. This type of hologram is preferred in a museum environment as it offers depth of information on a very high-resolution scale (see Figure 2.22).

Figure 2.22 OptoClones™
(Source: Bjelkhagen et al., 2015, p7)

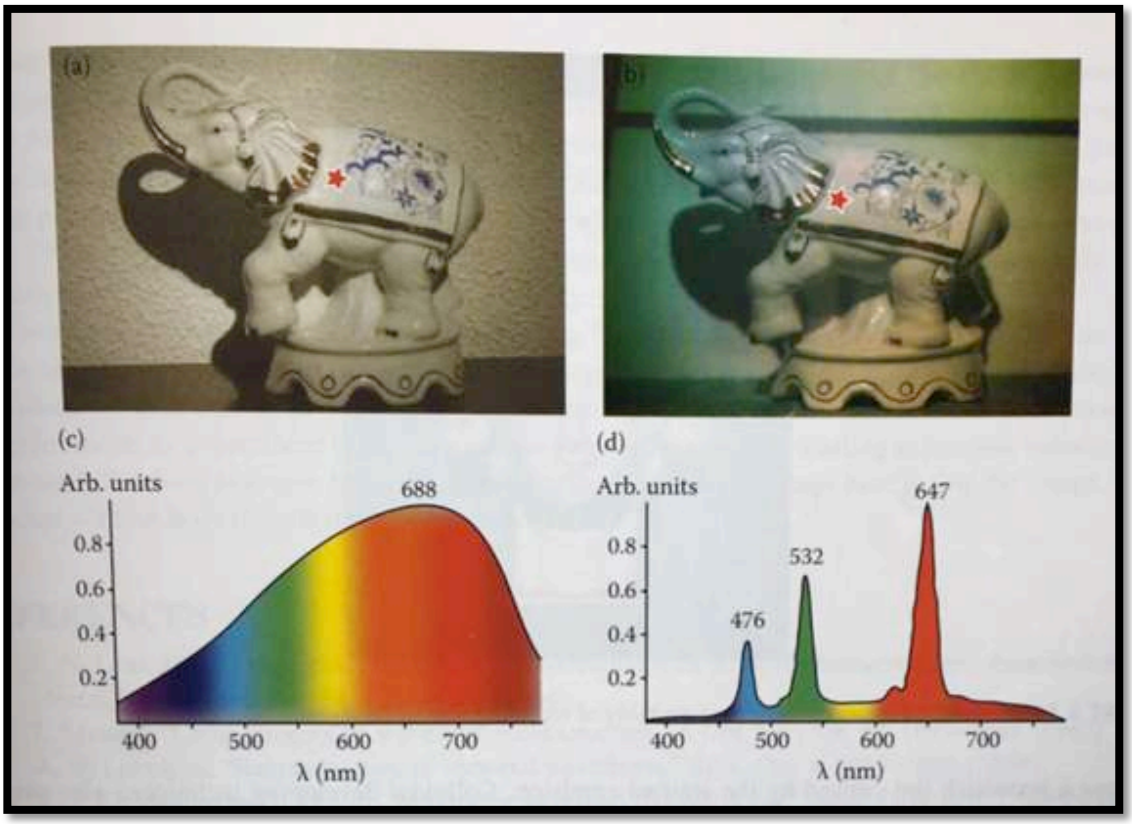


Figure 2.23 Analogue Colour Holography of White Elephant
(Source: Bjelkhagen and Brotherton-Ratcliffe, 2012, p151)

2.16 Practical application of the holographic technique for museums

The importance of a mobile or portable camera is to capture holographic images of valuable and expensive objects to be recorded in museums, rather than to move the objects to a laboratory to be recorded. Bjelkhagen et al. refer in their paper "Malcolm Forbes, Faberge Eggs and *OptoClones*™" to a project creating ultra-realistic images called *OptoClone*™. The Hellenic Institute of Holography (HIH) in Athens, Greece has completed its version of a camera to be used in museums universally:

> *HiH in Greece has developed equipment that can be moved to a museum for recording OptoClone™, which is absolutely necessary in order to record rare and expensive artefacts. It would be very difficult or almost impossible to move such artefacts like the Fabergé Eggs out of the museum to record them in a remote laboratory* (Bjelkhagen et al., 2015, p6).

Mobile holographic imaging technique would be useful to museums if they can create ultra-realistic images to a standard "*that people who have seen these new images can't* *believe that what they see is an image and not a real object*" (Bjelkhagen et al., 2015, p1). The remote equipment is shown in Figure 2.24 and Figure 2.25 below.

Figure 2.24

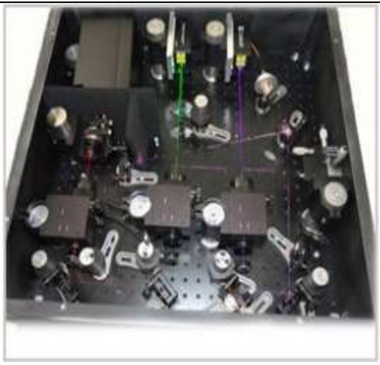


Figure 2.25

HIH transportable Camera Z3^{RGB} (Courtesy of Hellenic Institute of Holography)
(Source: Bjelkhagen and Brotherton-Ratcliffe, 2012, p621)

Figure 2.26 and Figure 2.27 show a diagrammatic view of the HIH transportable camera Z3^{RGB} in operation.

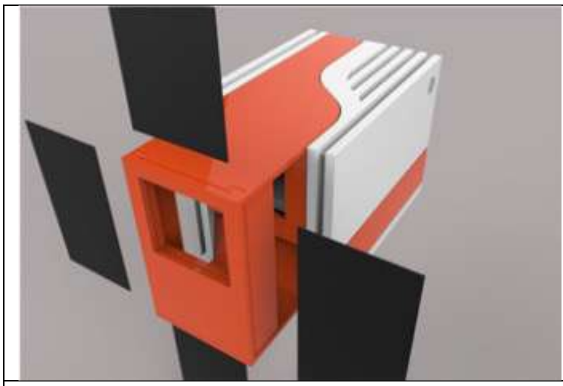


Figure 2.26

Figure 2.27

RGB HIH
(Source: Bjelkhagen and Brotherton-Ratcliffe, 2012, p622)

Significantly, in this research a recording mobile system is considered an ideal solution and its use is described in Chapter 4, section 4.10 . It is a useful method of saving priceless historical items and recording them in museums without taking the risk of moving them out of the museum.

In Saudi Arabia there are a number of items and jewellery items that hold immense importance and need to be documented. This project addresses the importance and significance of volume reflection holograms. In Chapter 3, section, 3.4 Jewellery collection recorded in this research, more details and descriptions of each item of jewellery of Arabian heritage objects, recorded using the holographic medium, are presented.

Holography and "*its ability to reconstitute … information of a scene, allows the observer to perceive the light as it would have been scattered by the real object itself*" (Blanche et al., 2010). It is this ability of holography that is perfect for experimentation with display systems, and the technique of projecting images is distributed within the chosen display apparatus. Also, and vitally, displaying artefacts using the hologram technique in museums could create an atmosphere and environment that attracts visitors and tourists as it can offer diversity in display. An example of this atmosphere is created in the Fabergé egg), mentioned earlier (see Figure 2.28 below).

> *To publicize the OptoClone technology, Bjelkhagen's team decided to record several of the famous Faberge Imperial Easter Eggs in the Faberge Museum (St. Petersburg, Russia). The new OptoClones were on display at the International Symposium of Display Holography 2015 (ISDH2015) in St. Petersburg in July 2015 ... The team used a red laser emitting at 638 nm with an output power of 90 mW ... a green laser emitting at 532 nm with an output power of 100 mW…, and a blue laser emitting at 457 nm with an output power 50 mW ... All recordings were done with mobile recording equipment in the museum itself* (Wallace, 2016).

Figure 2.28 The Recorded Coronation Easter Egg
(Source: Bjelkhagen et al., 2015, p9)

In relation to this study, a paper published under the title "*Analysing Cultural Heritage and its Representation in Video Games*" outlines research concerned with strengthening the understanding of the representation of cultural artefacts in video games. The paper describes steps towards "*utilising a framework using dimensions of cultural heritage as reference points for games analysis*" (Balela and Mundy, 2015, p1).

> *Video games can allow players to explore environments, which are representative of, or contain elements of physical world cultures, for example, allowing a player to explore ancient Egypt ...*

Artefacts can be contextualised by understanding the designer's attitudes towards the inclusion of these items and their cultural meanings and the designer's perspectives on the importance of these cultural representations within video games. Appreciation of cultural artefacts through modern technology can be broadened through various means, including video games and holographic representations within museums. This current study and Balela's study (2016) both approach appreciation of cultural heritage albeit through different presentational technologies.

2.17 Digital holography

The digital hologram technique is also known as a stereogram. Digital holography is a modern method in the presentation of valuable ancient artefacts, providing a practical solution to transporting three-dimensional images around the world and allowing inspection of the original objects. Moreover, digital holography will display a virtual three-dimensional representation of the original object including movement, texture, size and shape. Richardson (2014, p160) defines digital holography as "*a method of forming the holographic interference image itself by digital means*". Işik (2014, p9) addresses the digital method as a "*... technique consisting of taking and combining the images from different angles through camera and computer, combines photography, cinematography and holography*". This section provides a review of recent improvements and applications in the holographic recording of images of ancient cultural items in museums.

The 3D holographic recording process is made possible "... *by the interference of the object's optical field and the reference optical field, and therefore requires coherence between the two*" (Kim, 2013, p1). A photograph records a two-dimensional image of an object, whereas holography records sufficient information to be able to "*... create the three-dimensional optical field emanating from an object, including both the amplitude and phase of the optical field*" (Kim, 2013, p1). The examples clearly demonstrate the feasibility of full colour natural light holographic 3D imaging.

> *Zebra Imaging's holographic technology represents a leap forward in three-dimensional imaging. Our 3D holographic prints help your audiences connect, collaborate and comprehend as never. You'll not only see information from every angle — you'll experience it. From architectural design concepts, to understanding complex medical information, understanding and comprehension in 3D is a proven methodology* (Zebra Inc Imaging, 2015).

Zebra Inc Imaging (2015) produce high quality resolution digital holograms and describe them as "*... an entirely new medium – it appears as if the model/object is really there, just made of light!*" The hologram is produced from a model object created by software then printed onto a thin plastic sheet of film, which allows the image to float above the film. The print consists of a thin sheet of plastic film, which is placed on a horizontal surface and illuminated with an appropriate light source and reveals a three-dimensional, full-parallax, colour or monochromatic (green) image that appears to float above the surface (Zebra Inc Imaging, 2015). Thus, "*holographic technology is a fundamental innovation that could be used to archive antique objects for the public domain in museums and educational establishments*" (Althagafi, Richardson and Azevedo, 2015, p2). Lord and Blankenberg (2015, p12) highlight that "[*m*]*useums needed to be broadly educational and attract the full diversity of the public – whether or not these visitors had prior subject-matter expertise*". This is what is needed to improve and develop museums' display systems and techniques for the benefit of their visitors and researchers. Although digital holograms are successful in displaying three-dimensional images they are not as efficient as the Denisyuk holograms. At present the resolution of a digital hologram lags far behind the Denisyuk type hologram in reality.

2.18 Comparison between digital holography and analogue methods

In this section the analogue method and digital holography will be explained in detail, to leave the reader with a good understanding of the two different techniques.

The analogue method can capture, in very high resolution, an image of the jewellery that appears clearly to the viewer from different angles. Additionally, analogue holograms offer full parallax fields of view, i.e., both vertical and horizontal. With digital holograms it is often very difficult to obtain full parallax, and the resolution is limited. Moreover, the analogue method provides sufficient depth indications for viewers to perceive the image as a true three-dimensional object, as reported by the BBC News (2010). In this broadcast, Bjelkhagan stated that: "*In the museum, they have put an axe and the hologram next to it and people can't tell which is the real image.*" This is an outstanding result that demonstrates the response the viewer gains while looking at a hologram plate image.

> *Anybody who has seen a hologram will agree that holography is one of the most interesting revolutionary techniques for creating three-dimensional images and its capacity to fascinate is unquestionable* (Beléndez, 2015).

In comparison between analogue (reflection type) and digital holographic methods, pulse laser technology can be used during exposure to the human eye and skin, under strict safety conditions. "*It provides a flash of coherent light of within the maximum permissible* *amount of energy insuring that this is enough to expose a holographic plate during 5 nanoseconds*" (Richardson, 2014, pp158–60). In the researcher's opinion, the technique of digital holography is more practical, because of its portability and the ease of setting up the equipment, and it is without the risk of laser exposure to human beings. However, while the analogue technique provides the depth and high quality of image resolution (focus), the digital hologram method does not deliver the best resolution results.

2.19 Conclusion

This chapter started with Syria's ruins and the advantages of holography in this situation. My focus is Arabic heritage jewellery, which is much smaller but still as important, as it is part of the region's cultural heritage. Bringing all the points in this literature review together explains how the literature has informed my research. The chapter has also discussed the function and focus of museums, their strategies for involving visitors and technology's potential in this aspect.

The chapter has highlighted existing methods and techniques to document museum artefacts. Moreover, each technique has its own advantages and disadvantages; for example, digital holograms are quicker and less sensitive to vibrations during the process of production but lack resolution. The analogue technique is much better in terms of resolution.

The subsequent chapters deal with how experiments were conducted to record museum objects using Denisyuk's reflection holograms to produce high quality and high-resolution holograms. The next chapter focuses on the methodology adopted during this research and identifies the research design the study is situated in, in order to address the specific research objectives and answer the research question.

Chapter 3

CHAPTER 3
Methodology Selection of Objects

The best approach to research always depends on the question you are trying to answer
(Killam, 2013, p10)

3.1 Introduction

This chapter will discuss the fundamental factors upon which this research is established and the different methodological techniques that have been selected to gather appropriate and relevant data in order to achieve the objectives of the research. It will further highlight the methodology and methods undertaken to meet the research objectives to answer the research question:

> *Can the holographic medium be applied as a method for documenting and displaying Saudi cultural heritage artefacts?*

An overview of the wide-ranging processes and diverse phases of the research will be proposed. Description and clarification of the methodology will be presented and also the rationale for the chosen methodological approach. A mixed methods approach was employed to investigate the potential method for documenting the cultural heritage jewellery for museum application in the KSA. Also presented are the analysis processes, which include descriptive analysis for both the survey questionnaire and the interview data. Finally, ethical procedures and validity and reliability issues are discussed.

3.2 Research philosophy

The research philosophy is mainly concerned with the researcher's perceptions of the topic and the basis upon which a research problem is to be solved. The researcher observes the topic and also the related fields that might influence the research in one or more ways. Many steps in the research, including data collection and data analysis are influenced by the research philosophy. Positivist and phenomenological paradigms are the two main elements of the methodology domain (Easterby-Smith et al., 1991; Hussey and Hussey, 1997). The positivist approach is a scientific approach and is based on quantitative matters, while the phenomenological approach is based on a qualitative matter. Furthermore, the researcher's preferences, aims and objectives influence the choice of approach to be taken (Oates, 2005). Both approaches obtain results; however, there are a number of advantages and disadvantages to both.

The philosophical basis of research depends upon ontology, epistemology, human nature and the method by which reality is determined. Relationships regarding such matters are widely accepted and valued by researchers (Healy and Perry, 2000). Ontology depends on the external and objective reality, while epistemology states that observers are independent. The researcher's ontological position originates from her background as an artist and the wish to do something to record a small part of her Saudi cultural heritage – in this study, the jewellery of the Arabian Peninsula, referred to as traditional jewellery. Before these items disappear forever, I decided to utilise the latest state-of-the-art technology to record the beauty and precision of my ancestors' creations for future generations. To develop my knowledge of the processes required to document heritage artefacts and gather reactions to the outcomes of these processes, I adopted the qualitative approach. This approach enabled me to realise their experience of holograms being displayed in museums from the point of view of the museum staff involved, in order to determine their views.

3.2.1 The quantitative approach

Elements that are part of the society in which a certain phenomenon occurs are studied by the research in the quantitative study for the purpose of defining and predicting the relationships and their relevant processes as part of that society (Burrell and Morgan, 1979). The main objective of such a study is "*to formulate fruitful facts concerned with the society that are later analysed in a statistical and numeric way to have a deep understanding of the processes in which the world as a society functions*" (Gilbert, 2008, p32).

Amaratunga et al. (2002) explain that the positivist approach may have an inflexible method of collecting data but nevertheless covers a wide range of data, is completed in comparatively less time and seems more economical. The positivist approach revolves around the numerical way of collecting data, in order to develop an understanding of human behaviour. Objective values are used to reflect the attitudes and behaviours of humans through this approach. The positivist approach has relations with statistical analysis and objective reality with the help of theories, hypotheses and variables to find the facts and causes of human behaviours or attitudes that exist in society (Hussey and Hussey 1997).

3.2.2 The qualitative approach

The qualitative research approach, also termed phenomenological, subjective or non-positivist approach is concerned with the collection and analysis of descriptive data. Qualitative research can be used to determine values, beliefs and understanding of people in a deeper and richer manner (Cavana et al., 2001). This researcher considers that this approach will provide a link between objective reality and the phenomenon of holography and museum display. Human actions and behaviours are described by such research and the outcomes of the research are also managed in a descriptive way (Sarantakos, 1993). The data collection for a qualitative approach is natural and the results drawn from this approach are easy to understand. However, it is more time consuming; the analysis might require more effort as the data to be interpreted is more complex (Amaratunga et al., 2002).

3.3 Jewellery in the Arabian Peninsula

Countries record and maintain their monuments, ancient buildings and archaeology and palaeontology sites. Scientists study them to know more about the ancient world in order to understand the development of human culture. Jewellery has always been part of human culture, from the times when humans first started using clothes and tools. Jewellery was produced from a number of materials that were available – stones, animal skins, feathers, plants, bones, shells, wood and semi-precious materials such as obsidian. As the time went on, advancing technology enabled artisans to start taming metals and valuable gems into works of art, which influenced entire cultures and many modern jewellery styles. The researcher considers that an advantage of using the holographic medium, to record rare pieces, would improve display systems as well as allow museums to exhibit holograms of pieces in different places, while at the same time keeping the originals safe from exposure to harmful elements that might damage these precious, priceless pieces. The following figures, Figure 3.1 to Figure 3.8, show collections of jewellery and related apparel displayed in museums in the KSA. These are representative of the cultural heritage being considered in this study.

Figure 3.1 Jewellery Collection in the National Museum in Riyadh, KSA
(المتحف الوطني، الرياض)
(Captured by: Author)

Figure 3.2 Jewellery Collection in Alhamad Private Museum in in Alzulfi, KSA.
(متحف الحمد، الزلفي)
(Source: Saudi Commision for Tourism and National Heritage, 2017)

Figure 3.3 Jewellery Collection in Annayef Historical Palace Museum in Jubbah city, KSA. (Private museum)

(متحف قصر النايف الأثري، حائل)

(Source: Saudi Commision for Tourism and National Heritage, 2017)

Figure 3.4 Jewellery Collection in Okaz Private Museum in Altaef, KSA.

(متحف عكاظ، الطائف)

(Source: Saudi Commision for Tourism and National Heritage, 2017)

Figure 3.5 Jewellery Collection in Alkhalifh Private Museum in Alihsa'a KSA
(متحف الخليفة، الإحساء)
(Source: Saudi Commision of Tourism and National Heritage, 2017)

Figure 3.6 Jewellery Collection in Human Heritage Private Museum in Makkah KSA
(متحف التراث الإنساني، مكة المكرمة)
(Source: Saudi Commision for Tourism and National Heritage, 2017)

Figure 3.7 Abdulraouf Khalil Museum
(متحف عبد الروؤف خليل، جدة)
(Source: YouTube. Abdulraouf Khalil Museum)

Figure 3.8 Abdulraouf Khalil Museum
(متحف عبد الروؤف خليل، جدة)
(Source: YouTube. Abdulraouf Khalil Museum)

In order to display and at the same time preserve precious artefacts, the researcher decided to experiment with different techniques in order to record heritage, utilising twenty-first century techniques to provide access to a wide range of people through functioning technology.

3.4 Jewellery collection recorded in this research

The ancient jewellery items, shown in Figure 3.9 to Figure 3.20 inclusive, were used in this research. This collection of items was chosen for a number of reasons:

- *portability* – the size of most of the jewellery items meant they were portable, so they were easy to transport in luggage between the KSA and the UK. These items were of low monetary value (in museum terms) and did not require to be accompanied by a museum curator. No specific insurance was required;
- *accessibility* – in the experiments to record the jewellery the researcher did not choose priceless items that are difficult to obtain or that needed to be secured due to their history and value;
- *complex composition* – the selected items provided good models for recording purposes due to their complexity of detail, delicate designs and richness of minutiae;
- *culturally recognisable* – the items were considered as widely culturally recognisable as part of Saudi cultural heritage, and represented national identity;
- *potential visitor engagement* – the items were chosen on the basis of their ability to engage viewers/museum visitors from the KSA;
- *exposure to laser recording* – the items were selected for their capability to survive exposure to laser recording without damaging effects. The metals that the jewellery items were made of would not be affected by the laser beam in the recording process.

One of the features of a hologram is that the size is considered one-to-one, which means that the size of the hologram of the item is equal to the actual size of the original item. Photographs of the original items of Arabian Peninsula jewellery (Figure 3.9 to Figure 3.20) were captured by the researcher, and all the items' measurements taken by the researcher. The information about each item was taken from two books - AL-Qahtani (2000) and Bin Jeniadel (2003).

Jewellery	Description	Figure
Name: Lubbah or Iqd with beads. **English Name: Necklace.**	**Region:** South of Saudi Arabia, early twentieth century. **Material:** silver **Description:** Three amulet cases, hirz, hanging on a multi-row with intercalated rectangular and triangular plates. The set, filigreed decor and granulation, and it is mounted on braided hemp. **Measurement:** Length: 50 cm; Width: 18 cm; Weight: 790 g **References:** Al-Qahtani (2000) and Bin Jeniadel (2003).	 **(Source: Author)**

Figure 3.9 Lubbah / Necklace

Jewellery	Description	Figure
Name: Lubbah. **English Name: Necklace.**	**Region:** South of Saudi Arabia **Material:** silver **Description:** Five amulet cases, hirz, hanging on a multi-row with intercalated long plates. The set, filigreed decor and granulation. **Measurement:** Length: 35 cm; Width: 15 cm; Weight: 300 g **Reference:** Al-Qahtani (2000).	 **(Source: Author)**

Figure 3.10 Lubbah / Necklace

Jewellery	Description	Figure
Name: Mea'dhad. **English Name: Bracelet.**	**Region:** South of Saudi Arabia. Early twentieth century. **Material:** Mix of silver and metal. **Description:** Circular, enhanced with small circles surrounding the main large flat circle in the top and middle of the item. Enhanced with a large circle in the core of the flat circle, enclosed with engraving similar to a leaf. **Measurement:** Radius: 4 cm; Weight: 610 g **Reference:** Al-Qahtani (2000).	 **(Source: Author)**

Figure 3.11 Mea'dhad / Bracelet

Jewellery	Description	Figure
Name: Khurose. **English Name: Pendant.**	**Region:** South of Saudi Arabia **Material:** silver and gemstone **Description:** Rectangular plate, provided with three red gems, enhanced with line of tiny circles around the shape, provided with six chains with bells hanging from the bottom. **Measurement:** Length: 6 cm; Width: 7 cm; Weight: 50 g **References:** Al-Qahtani (2000) and Bin Jeniadel (2003).	 **(Source: Author)**

Figure 3.12 Khurose / Pendant

Jewellery	Description	Figure
Name: Alaga or Thuqul. **English Name: Pendant.**	**Region:** South of Saudi Arabia **Material:** silver and gemstone **Purpose:** women's ornament to be hung on her veil. **Description:** A triangular plate, embellished with cabochons of a gem, coral, and ended with long chains with bells and small amulets enhanced with a line of tiny circles hanging from the base of the triangle. **Measurement:** Length: 23 cm; Width: 9 cm; Weight:190 g **Reference:** Al-Qahtani (2000).	 **(Source: Author)**

Figure 3.13 Alaga / Pendant

Jewellery	Description	Figure
Name: Osbah. **English Name: Headband.**	**Region:** South of Saudi Arabia **Material:** silver **Purpose:** women's ornament for forehead or hair. **Measurement:** **Length:** 30 cm; Width: 5 cm; **Weight**: 145 g **References:** Al-Qahtani (2000) and Bin Jeniadel (2003).	 **(Source: Author)**

Figure 3.14 Osbah / Headband

Jewellery	Description	Figure
Name: **Hezam.** **English Name:** **Waistband or Belt.**	**Region:** South of Saudi Arabia **Material:** silver **Description:** Made of 17 panels interconnected with handmade links and a two part clasp (hook and eye) combined with 12 bells hanging from side of the clasp. **Measurement:** Length: 95 cm; Width: 4 cm; Weight: 450 g **Reference:** Al-Qahtani (2000).	 **(Source: Author)**

Figure 3.15 Hezam / Belt

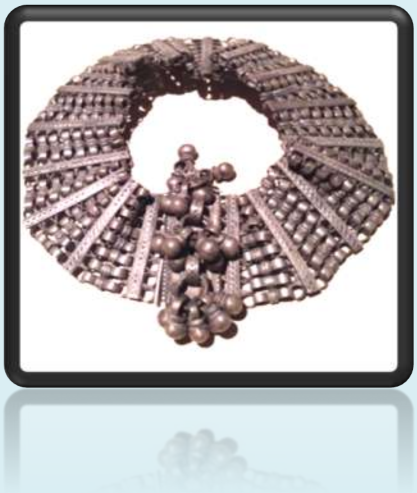
Jewellery	Description	Figure
Name: **Khulkhal.** **English Name:** **Anklet.**	**Region:** South of Saudi Arabia **Material:** silver **Description:** Made of 17 panels interconnected with handmade links and clasp rings combined with 12 bells hanging from side of the clasp. **Measurement:** Length: 32 cm; Width: 3.5 cm; Weight: 150 g **References:** Al-Qahtani (2000) and Bin Jeniadel (2003).	 **(Source: Author)**

Figure 3.16 Khulkhal / Anklet

Jewellery	Description	Figure
Public Name: Khurose. **English Name: Pendant.**	**Region:** South of Saudi Arabia **Material:** silver **Purpose:** women's pendant to be hung on the veil both side or on headband. **Description:** A long pendant enhanced with circular shape, provided with long chains hanging from the middle. **Measurement:** Length: 15 cm; Width: 7 cm; Weight: 40 g **Reference:** Al-Qahtani (2000).	 **(Source: Author)**

Figure 3.17 Khurose / Pendant

Jewellery	Description	Figure
Name: Khurose. **English Name: Pendant.**	**Region:** South of Saudi Arabia **Material:** silver **Purpose:** women's ornament to be hung on the veil or on the headband. **Description:** A long pendant, with a circular core, enhanced with different length size of chains hanging from the side of the top and the bottom. **Measurement:** Length: 15 cm; Width: 7 cm; Weight: 40 g **Reference:** Al-Qahtani (2000).	 **(Source: Author)**

Figure 3.18 Khurose / Pendant

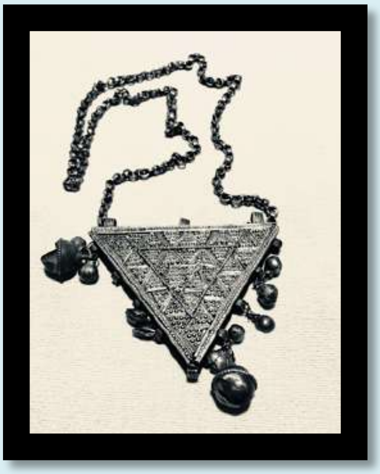
Jewellery	Description	Figure
Name: **Ta'aleegah.** **English Name:** **Necklace.**	**Region:** South of Saudi Arabia **Material:** silver **Description:** A triangular plate, embellished with engraved triangles and with a long chain. Enhanced with small and large bells around the triangle. **Measurement:** Length: 39 cm; Width: 8 cm; Weight: 120 g **Reference:** Bin Jeniadel (2003).	 **(Source: Author)**

Figure 3.19 Ta'aleegah / Necklace

Jewellery	Description	Figure
Name: Taj **English Name:** **Headband.**	**Region:** South of Saudi Arabia **Material:** silver with gems **Description:** Circular head band fixed on leather, decorated with orange gems with chains hanging from the bottom. **Measurement:** Radius: 25 cm; Width: 9 cm; Weight: 850 g **Reference:** Bin Jeniadel (2003).	 **(Source: Author)**

Figure 3.20 Taj / Headband

3.5 The research investigation

The research process followed a number of steps, each of which is described in the following sections.

3.5.1 The investigation

The aim of the investigation stage was to gather opinions about the value of 3D images for recording and displaying historical items (traditional heritage jewellery), using the holographic technique. The researcher employed a mixed methods approach to obtain the primary data, with assistance from the secondary data (literature review). Steps were taken to measure a cross-section of potential museum visitors. A survey questionnaire was used to establish the opinions of museum visitors about the quality of the displayed 3D images against those of the original items. Furthermore, museum directors, hall curators and a museum owner were interviewed to obtain their opinions, as they were considered to have knowledge and experience of museum's systems and methods of display.

3.6 Mixed methods approach

The specific research objectives were leading features in choosing a suitable research approach. This research study sought to "*develop a detailed view of the meaning of a phenomenon or concept for individuals*" (Creswell, 2009, p18). "*The knowledge claims, the strategies, and the method all contribute to a research approach that tends to be quantitative or qualitative or mixed methods*" (Creswell, 1998).

In this research a mixed methods approach was used and was reliant on both quantitative and qualitative data. Therefore, to provide the best understanding of the phenomenon the strengths of both quantitative and qualitative research (and their data) were considered most appropriate to provide the best understanding (Creswell, 2009). A quantitative approach "[...] *employs strategies of inquiry such as experiments and surveys, and collects data on predetermined instruments that yield statistics data*" (Creswell, 1998). Whereas, Leedy and Ormord (2010, p135) point out that all qualitative approaches have two things in common: *"First, they focus on phenomena that occur in natural settings – that is in the real world. And second, they involve studying of those phenomena in all their complexity.*"

This research used two methods of data collection: quantitative survey questionnaire and qualitative semi-structured interview, positioning it in the mixed methods approach, which allowed the researcher to gain essential rich data. Table 3.1 below shows the application of the mixed methods approach in this study.

Table 3.1 Mixed methods

Type of data ⇨	**Quantitative**	**Qualitative**
Questionnaire ⇨	241 participants	Cross-section of public
Interview ⇨		9 participants (staff, hall curators and a museum owner)

3.7 The quantitative research process in this study

Fowler et al. (1990, p12) point out that "[t]*he goal of a survey is to produce accurate statistics*". The quantitative data from the survey questionnaire related to demographics and practical design methods produced quantifiable data. The use of a survey questionnaire was to determine whether a problem exists and if it can be solved by the technique of displaying holograms in museums.

> *The type descriptive quantitative research, involves either identifying the characteristics of an observed phenomenon or exploring possible correlations among two or more phenomena. In every case, descriptive research examines a situation as it is. It does not involve changing or modifying the situation under investigation, nor is it intended to detect cause–effect relationships* (Leedy and Ormord, 2010, p183).

The survey is becoming one of the more useful research instruments to understand visitors' opinions and judgments about the type of technology used for displaying holographic images in museums. Ambrose and Paine (2012, p37) identify that "[*r*]*egular use of survey questionnaires can also help to identify changing trends in your museum audience, and help to explain the reasons why people do not come to the museum!*" This research looked at the impact of 3D images with the intention of informing and improving museum display systems in the KSA. Therefore, asking the opinion of a cross-section of museum visitors was fundamental to enhancing the aim of this research. A quantitative survey was conducted to ascertain the validity of the holographic medium for recording heritage and improving display systems. For this goal, the researcher chose to distribute a questionnaire to a random sample of the Saudi community to examine and measure the situation and investigate visitors' opinions about the holographic technique, and to see if it could make differences in attracting them and inspiring them to visit museums and help them to gain and learn from their museum experience.

3.7.1 Questionnaire

The survey method enabled the researcher to capture the results of the effectiveness of three-dimensional images as a technique to engage the visiting public. The survey questionnaire was designed to be distributed to a cross-section of public museum visitors to gain demographic and quantitative information on their opinions and descriptive knowledge that would reveal their behaviour towards and thoughts about the holographic medium as a technique for recording traditional and ancient heritage items of the Arabian Peninsula and displaying them in museums. Several steps were taken to measure what people thought of the use of holographic images as a method to display artefacts as opposed to the traditional method of displaying the actual items.

In this research four variables were investigated:

1. Technology and recording heritage.
2. Original item and hologram comparison.
3. Photograph and hologram comparison.
4. Hologram preference reasons.

3.7.2 Survey questionnaire design

The questionnaire included closed-end questions and was distributed to a cross-section of the public as potential museum visitors, to ascertain the validity of the holographic medium for documenting heritage. The images tested visitors' reactions (opinions), with the use of a survey to establish their opinions on the quality and appropriateness of the displayed 3D images beside the original item.

The questionnaire started with the thesis title, definition of a hologram, and ended by thanking the participants for their participation (see questionnaire form in Appendix A). The survey questionnaire consisted of two sections, Section A contained the main survey of 18 items while Section B covered participants' background and demographic details, which included gender, age group, education level, position and whether the participant had seen holograms before.

The researcher used a Likert five points measurement scale, which ranged from:

- Strongly agree – 5
- Agree – 4
- Neutral – 3
- Disagree – 2
- Strongly disagree – 1

> *Likert scales were developed in 1932 as the familiar five-point bipolar response …These scales range from a group of categories-least to most-asking people to indicate how much they agree or disagree, approve or disapprove ... There's really no wrong way to build a Likert scale. The most important consideration is to include at least five response categories* (Allen and Seaman, 2007, p64).

The choice of this type of scale was to obtain participants' opinions regarding their levels of agreement or disagreement to each survey questionnaire item. Section A was constructed to identify participants' views in order to establish whether the holographic medium can be considered as an appropriate method for documenting heritage and display in museums.

The Likert scale was used to gather data that delivered direct and reliable assessment of the participants' attitudes (Allen and Seaman, 2007). The Likert scale used employed close-ended specific statements (Reja et al., 2003). To achieve the object of the research, which is "*to evaluate museum visitors' reactions, engagement and experiences of project*", gaining percentages of participants' responses was important as this would provide a quantifiable value.

Allen and Seaman (2007, p64) describe data groups thus:

> *Statisticians have generally grouped data collected from these surveys into a hierarchy of four levels of measurement: 1. nominal data, 2. ordinal data, 3. interval data, and 4. ratio data.*

The data collected by the survey questionnaires were ordinal data, which Allen and Seaman (2007, p64) consider to be "[*d*]*ata in which an ordering or ranking of responses is possible but no measure of distance is possible*". Therefore, parametric techniques could not be used in the research data analysis as the gathered data were ordinal data, and descriptive analysis was employed to reveal the results of the participants' responses and also to understand the measurements of the results simply and easily, in a way that might help the reader understand the aim and objectives of this research. Allen and Seaman state that:

> *As a general rule, mean and standard deviation are invalid parameters for descriptive statistics whenever data are on ordinal scales, as are any parametric analyses based on the normal distribution* (2007, p64).

Whereas Leedy and Ormord (2010, p26) confirm that ordinal scales measure the data so that "[*w*]*e can use a percentile rank to identify the relative position of any item or individual in a group*". This research engaged colleagues in the field in a pilot study in order to evaluate the questionnaire design prior to its actual use (see section 3.10.1 The pilot study).

3.7.3 Questionnaire participant sample

Ambrose and Paine (2012, p38) suggest that:

> *The minimum size of sample should be somewhere between 200 and 300 visitors. There are different approaches to sampling, with the goal of achieving a balanced and representative sample of the population. A random sampling approach may need to be balanced by a degree of selection.*

Random sampling was used for the distribution of the questionnaires. The participants in this research were a cross-section of potential museum visitors in the KSA, the UK, and the USA. Four hundred questionnaires were distributed to Saudi and non-Saudi public museum visitors. The potential participants were informed that they would not be identified; this approach increased the chances that they would answer questions without being influenced or intimidated by the presence of the researcher.

3.7.4 Questionnaire distribution process

The survey was conducted in a number of countries and in the KSA to ascertain the accuracy of the holographic medium for documenting and displaying heritage in museums. This took the form of a questionnaire designed for distribution to a cross-section of public museum visitors. The questionnaire was distributed in different areas where it was possible for the researcher to collect data. It was distributed at the Saudi student conference in London, UK and the SPIE conference in San Francisco, USA, as well as in the cities of Riyadh and Makkah in Saudi Arabia (see Table 3.2).

Table 3.2 Questionnaire distribution details

Place	Date	Time
▪ **Saudi Conference, London.**	31st January 2015.	Between 1:00 – 7:00 pm.
▪ **SPIE Conference, San Francisco, USA.**	7th February 2015.	Between 12:00 – 2:00 pm.
▪ **Saudi Career Fair, London.**	21st March 2015.	Between 12:00 – 7:00 pm.
▪ **Design Faculty, Umm-Al-Qura University, Makkah.**	12th May 2016.	Between 10:00 am – 3:30 pm.
▪ **Main campus, Umm-Al-Qura University, Makkah.**	16th May 2016	Between 09:00 am – 2:00 pm.
▪ **National Museum in Riyadh.**	31st May 2016.	Between 10:00 am – 1:00 pm.

Every participant in the questionnaire (and the interview sample) was shown the same specific hologram plate beside the original item (illustrated in Figure 3.21 and Figure 3.22) to ensure fair results. They were all given a hard copy of the research ethics (consent) form and questionnaire, with a brief description of the research. A research title, brief of the hologram concept and process and enough reasonable time was given to each participant to complete the questionnaire and return the research ethics form and questionnaire, no participant was influenced to take part in the survey. The question of whether or not the holographic medium can be considered an appropriate method to record heritage for museum application in the KSA was presented to the survey participants. To avoid differences of understanding among the potential participants, the researcher showed them the original item alongside the hologram plate and then distributed the questionnaire. The researcher was available to explain any questions to the participants.

The researcher could not use online questionnaire to reach a large number of participants because it is not easy to capture a recorded hologram plate adequately, and more significantly due to the lack of participants' knowledge of what a hologram actually is. In this research it was necessary to show the original hologram plate to the sample in order that the potential museum visitor questionnaire participants perceived depth control methods, as discussed in Chapter 4, section, 4.5.2 Denisyuk reflection hologram.

Figure 3.21 Photograph of original jewellery item shown to the participants
(Source: Author)

Figure 3.22 The hologram plate shown to the participants
(Photographed by Author)

The researcher intended that the questions asked would mean the same to all the respondents as they did to the researcher. To achieve this (to a major extent) the researcher conducted a pilot study prior to conducting the real survey. The pilot study conducted for this research is explained in section 3.10.1 The pilot study.

3.7.5 Questionnaire analysis

> *It is not a question of right and wrong ways to analyze data from Likert-type items the question is more directed to answering the research questions meaningfully. Some techniques answer meaningful questions completely, others ignore aspects of the problem* (Clason and Dormody, 1994, p31).

In this research a five-points Likert scale was used to measure response variations and percentages were employed.

> *Measurement is the attempt to discover real numerical relations (ratios) between things (magnitudes of attributes), and not the attempt to construct conventional numerical relations where they do not otherwise exist* (Michell, 1999, p17).

The Oxford Dictionary defines ratio as "[*t*]*he quantitative relation between two amounts showing the number of times one value contains or is contained within the other*" (Oxford Dictionary, 2017b). In this investigation the results were analysed by percentage (ratio); the researcher calculated manually the number of responses (frequency) to every item from the forms (see Figure 3.23 and Figure 3.24 for the frequency of responses). Next, an Excel worksheet was created for all the data from the questionnaire forms returned. A percentage formula was applied in the Excel worksheet to calculate the percentages of the participants' responses to display the values of the questionnaire data.

Figure 3.23 Questionnaires' manual frequency counting P.1

Figure 3.24 Questionnaires' manual frequency counting P.2

The counting of the frequency of numbers was done manually, as the researcher received a number of the survey forms from the participants via email (after they had already seen the hologram beside the original item).

Therefore, in this case the researcher calculated the participants' responses to the Likert scale items by total responses to the value of agreement, etc. The percentages were analysed descriptively – the method chosen to interpret the data. Adding the value of every item portrayed descriptively shows the reader the value of every single item (responses). This was then demonstrated visually in graph form (pie chart, etc.) so as to present the data straightforwardly and simply to the reader.

3.8 The qualitative research process in this study

3.8.1 Interview objectives

Museum specialists were interviewed in order to gather data about museums in the KSA, including methods of documenting and display systems. Museum curators were interviewed to gauge their opinions about recording, heritage and display methods in museums. Hall curators were included in the research to capture their expert opinions in relation to the documenting methodology currently implemented in museums across Saudi Arabia. Their experience in recording artefacts is fundamental, as ultimately this research is arguing the point that the holographic method would be an ideal method to augment heritage content in Saudi museums in the future and provide the Saudi museum community with the opportunity to develop a route for documenting and display techniques. The interviews conducted in the KSA with hall curators and museum staff aimed to gain a deep understanding of the contemporary methods used in recording heritage items in Saudi museums. Due to the semi-structured interview's ability and flexibility to gain more information from the interviewees, sub-questions were chosen to allow exploration of conflicts between questions and to gain deep understanding covering the issues of this research.

3.8.2 Contacting museums and arranging interviews

There are a number of museums in the KSA, as explained in Chapter 2 section, 2.7 Museums in Saudi Arabia. To arrange the interviews, the researcher undertook a number of steps. First contact was made by e-mailing the Saudi Commission for Tourism Saudi and National Heritage (SCTH) in Riyadh to get their support and acceptance to interview hall curators of museums and museum staff. The Commission showed a sound understanding of the research issues and deep interest to participate in this study. The researcher received an encouraging offer from them when they replied that they were happy to participate in this research, and welcomed the idea. They were very excited to see the holograms and know about the concept of holograms. The researcher endeavoured to educate them and to ensure understanding of what a hologram is and awareness of the difference between holographic technique and Pepper's Ghost technique (see section, 2.14.5.1 The confusion between the concept of hologram and Pepper's Ghost technique). Characteristics of holograms and Pepper's Ghost, as had already been explained to the SCTH (see letter in Appendix D). The researcher also contacted the director of museums in the Jeddah governorate, but he apologised for not being able to offer the same facilities as the National Museum in Riyadh, due to refurbishment of the largest museum in Jeddah. However, an interview was conducted in Jeddah with a painter, who is also an owner of a private museum.

3.8.3 Interview sample (community)

Quantitative and qualitative inquiry differs in terms of the study sample size. Quantitative research inquiries, such as questionnaires, use large random sampling, while qualitative research inquiries, such as interviews, utilise small non-random sampling (Patton, 1990). The qualitative research in this study, which involved interviews, adopted non-random sampling. This research employed purposive sampling, which refers to selecting information-rich participants (Patton, 1990). This type of sample has three classifications: accidental, quota and purposive (Walliman, 2017). Thus, this researcher selected participants who have knowledge of museums and expertise in the heritage of Saudi Arabia.

3.8.4 Interview participants

In order to understand the context in which curators in Saudi museums work today, information on the workings of museums in Saudi Arabia was investigated. Interviews were conducted with members of the museum community to capture their opinions about museum documenting and display systems in the KSA. The interview participants were Saudi professionals in museology and were targeted for their association with and knowledge of museums in Saudi Arabia. As such, nine museum staff, hall curators and a museum owner were interviewed. The interviews were semi-structured face-to-face interviews where possible.

3.8.5 Interview process

Semi-structured interview questions were prepared, and the interviews were held in locations convenient to the interviewees. Collecting the interview data required travel arrangements to be made by the researcher. During the field trip in the KSA to collect data, the researcher travelled to a number of cities. The interviews were conducted in May and June 2016 in the cities of Riyadh and Jeddah in Saudi Arabia, with nine interviewees from two museums. Eight interviewees were from the National Museum of Saudi Arabia in Riyadh and one interview was conducted in June 2016 with the private owner of a museum in Jeddah. The interviews with the museum directors and hall curators were conducted in Arabic.

The interviews were either face-to-face or via mobile phone, due to some interviewees' personal preferences. All the interviewees agreed to have their interview recorded, which was done digitally by smart phone, and field notes were also taken to add increased understanding of the interviewee's opinions. Each interview lasted for approximately 45 minutes. The mobile phone interviews were conducted after face-to-face meetings, when the hologram as well as the original item was shown to interviewees.

The interviewees responded to the researcher's questions, and in addition photos and contemporary methods of the prevailing documenting methods used by the interviewees in their museums were obtained. The researcher started with a broad question before moving to more specific issues, encouraging open and easy discussion, to find out curators' opinions on the possibility of using holographic techniques in museums with the possibility of developing display systems in the KSA's museums. Afterwards, each interview each was transcribed into Arabic and then translated into English.

3.8.6 Interview analysis

The collected data were analysed descriptively to find out the directors' and hall curators' opinions regarding hologram technology and the aspects of display in Saudi museums.

During analysis of the qualitative data, in order to identify interviewees understanding and opinions about 3D images, the researcher described the data manually. The result gave the study initial insights into the emerging results. The generated key words from the interviews were hologram, technology, museum, cultural, heritage, artefacts, documenting, cataloguing, accessioning, display, items, stunning and jewellery.

3.9 Ethical procedures

This study was officially approved and research processes ethically fulfilled. In May 2014 the Ethical Commission of the Faculty of Technology at De Montfort University accepted the consent form submission to conduct the research interviews and survey questionnaires (shown in Appendix A). The survey participants were assured that their participation would be anonymous. Every survey participant was provided with a consent form ahead of completing the questionnaire. They were also informed by the researcher that all data provided by them would be used for academic purposes only. All survey forms will be kept in a locked drawer in a university office until the results appear. Also, before the distribution of the questionnaire form every participant was informed that their identity would be kept anonymous, and at no point on the form (section B) were the participants asked for their names.

With regard to the interview, all museum directors, the museum owner and hall curators volunteering to take part in the interviews were provided with a consent form prior to the recording of the one-to-one interviews. Two of the interviews were conducted over the telephone in order to accommodate the availability of the interviewees. However, these interviewees had been presented with the 'physical' holograms prior to the telephone interview, so they could comment on it in the interview itself.

3.10 Validity and reliability

3.10.1 The pilot study

"*Likert's original work assumed an attitude scale would first be pilot tested for reliability assessment of the individual items*" (Clason and Dormody, 1994, p31). Consequently, this researcher requested colleagues in the field to engage in a pilot study. The pilot study was used in order to evaluate the questions in the questionnaire prior to the actual survey taking place and being distributed to the sample.

The questionnaire and interview questions, and subsequent translation into Arabic, were found to be reliable and valid by the researcher's first supervisor, as well as the researcher's colleagues from the Faculty of Technology (Imaging & Research Group) at DMU, Faculty of Design and the Faculty of Art & Design at Umm Al-Qura University. Thus, native speakers of both languages, English and Arabic, assessed the questions used in the questionnaire and found these reliable and valid for the purpose of this research. The researcher gave an overview and explanation of the holographic technique to both samples (interviewees and survey participants) because it was the first time that a hologram had been viewed by almost all of the two samples' participants. The questionnaires were physically distributed by the researcher. An online delivery method was not used as viewing the actual hologram alongside the original item was a fundamental objective of the survey.

3.11 Conclusion

This chapter has defined the methodology employed in the investigative part of this research study. The research approach has been clarified together with justification for the choice of methodology, methods and instruments. Descriptions of the quantitative and qualitative approaches have been presented and each data source explained. Finally, the analysis techniques have been described in order to highlight how they were employed for both qualitatively and quantitatively collected data in this research.

Chapter 4

Chapter 4
Experiments

4.1 Introduction

This chapter explains the various experiments undertaken in this investigation to achieve the aim and adjectives of the study. This process was achieved by selecting the best method of creating 3D images to display museum artefacts. It also describes why holographic is preferred above all other methods to present artefacts for museum display purposes.

4.2 The road leading to holography

The initial idea was designed to investigate how to project a 3D image of an artefact in a museum display. This central part of the investigation was to establish the possibilities for projecting reflection holograms and installing them in museums, and what would be required to establish a display technique that could project a 3D image. Explanations and descriptions of the process are presented in Chapter 2, Literature Review, Reflection hologram. The diagram of recording a reflection hologram is shown in Figure 4.15. The first step was to experiment with a mist maker unit, and this was followed by a number of experiments using reflection holograms. All these experiments are explained next.

4.3 Mist display experiment 1

A mist maker device (shown in Figure 4.1) is basically a device that converts water into dense mist. It contains a high frequency ceramic membrane that vibrates water into mist [Maplin mist maker description]. The level of water covering the mist maker is important here. Two experiments were undertaken to design, develop and test a mist screen. The aim of this investigation was to produce a mist screen on which laser transmission holograms could be projected.

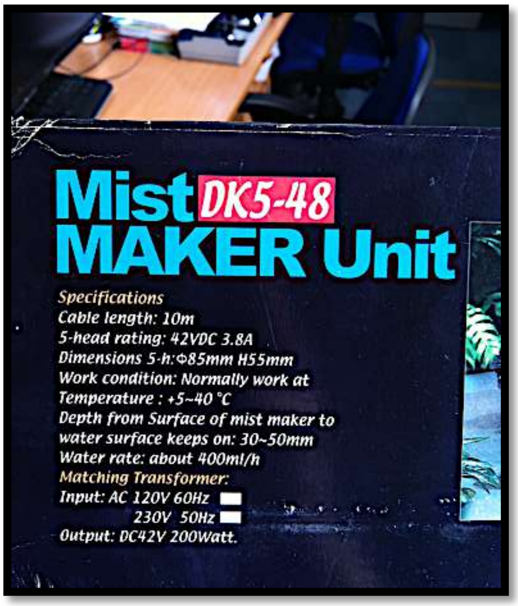


Figure 4.1 Photo of "mist maker" device
(Photographed by Author)

The mist maker device was set up in the laboratory to project a 3D image into mist. There were no fire hazards involved as this experiment only increased the humidity of the room. The power of the laser beam, being too high for safety, could possibly have damaging effects on a person's eyes, so the experiment was performed in a laser designated area. The mist maker device was placed in a large plastic bowl and covered with water at room temperature. A pre-made film of transmission hologram was used for testing purposes, shown in in Figure 4.2.

Figure 4.2 A photo of pre-made transmission hologram
(Source: Professor. Richardson)

A green diode laser of wavelength 532nm (nanometres) with power rating 150mW was used to point at the hologram containing the image. The Bragg angle, about 32 degrees, yielded a bright image [Bragg reflection condition] (Saxby, 2010). To record the experiment, a mist spray was used to make the laser beam path visible and the image was captured by a Canon 600 SLR camera. A rough sketch of the experimental set-up can be found in in Figure 4.3.

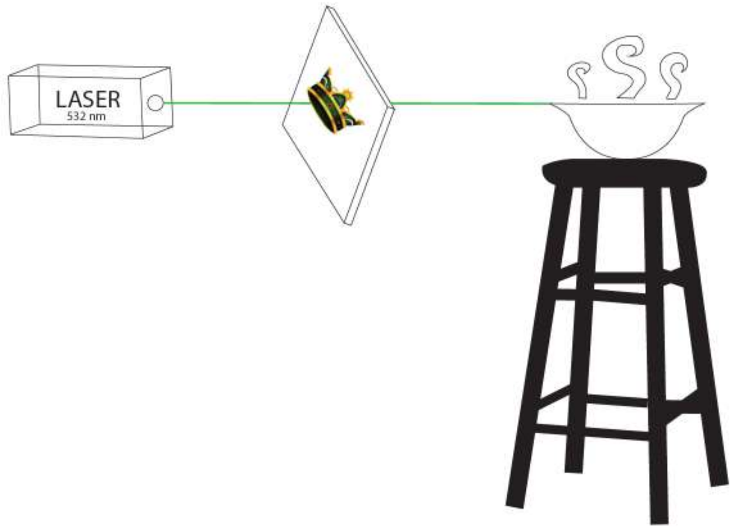


Figure 4.3 Mist experiment set-up
(Source: Author)

4.3.1 Analysis of the mist display experiment 1

One of the main points identified was that the mist was too weak to display the hologram successfully. It was evident that not only was the mist too weak, i.e. the concentration level too low, but also that the image of the transmission hologram was not captured sufficiently well for a suitable display, due to the concentration of the mist. Moreover, only once a suitable capturing system was being used would it be possible to determine the level of the mist concentration needed to establish a successful mist screen. The distribution of the mist over an area in space was very limited and was affected by airflow in the room; as a result, controlling the mist accurately to display a holographic image was difficult. However, in the above experiment, the mist disappeared too soon and it was not possible to establish a stable flow rate. Furthermore, the mist did not rise above the bowl in a concentration sufficient for the beam to be directed into. Instead, as it was directed into the bowl the ray was redirected (by the edge of the bowl) onto the floor with an unexpected outcome. As a result of the reflection of the laser with the water, the laser projected a visual image onto the floor, which lead to the appearance of a random pattern, as seen below in in Figure 4.4. This pattern is formed because of light being diffracted through the hologram and trying to form an image.

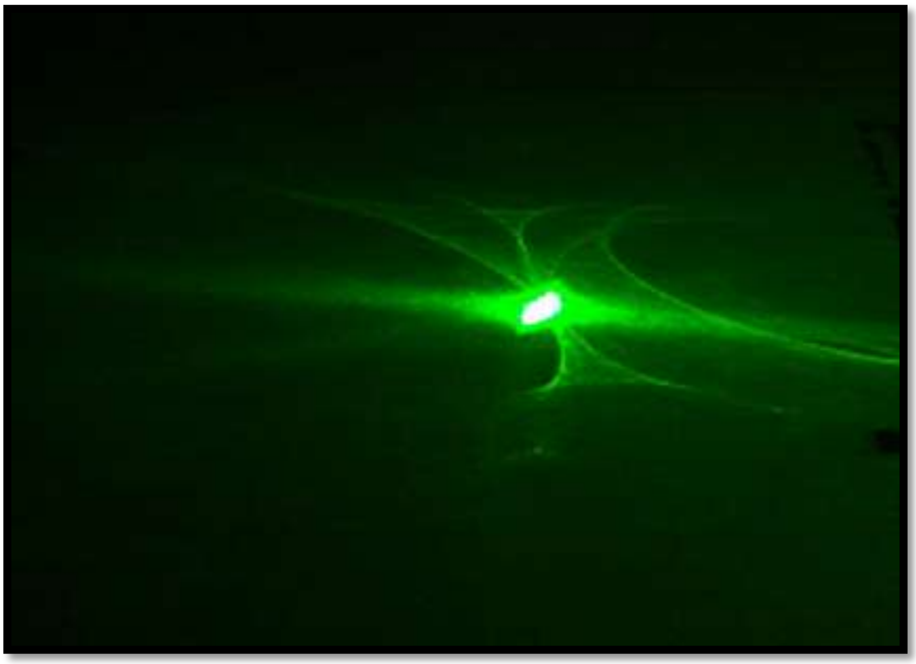


Figure 4.4 The pattern on the floor as a result of a laser reflection
(Source: Author)

A further test was carried out as a result, where a mist sprayer was used to see the interaction between the mist spray and the mist with the green laser beam. It became very bright and glowing, almost blazing, as seen in Figure 4.5 and Figure 4.6 below. Additionally, the transmission hologram did eventually appear clearly on the table once the plate was moved within the laser beam. However, the mist curtain needed to be stable. This indicates that there is certainly a design aspect to the display system that needs to be researched further, as does the improvement of the delivery system, i.e. better flow and better concentration of the mist. The following points have therefore been identified for further research and development:

- mist flow volume.
- component of the mist.
- hologram projection.
- mist spray effect.

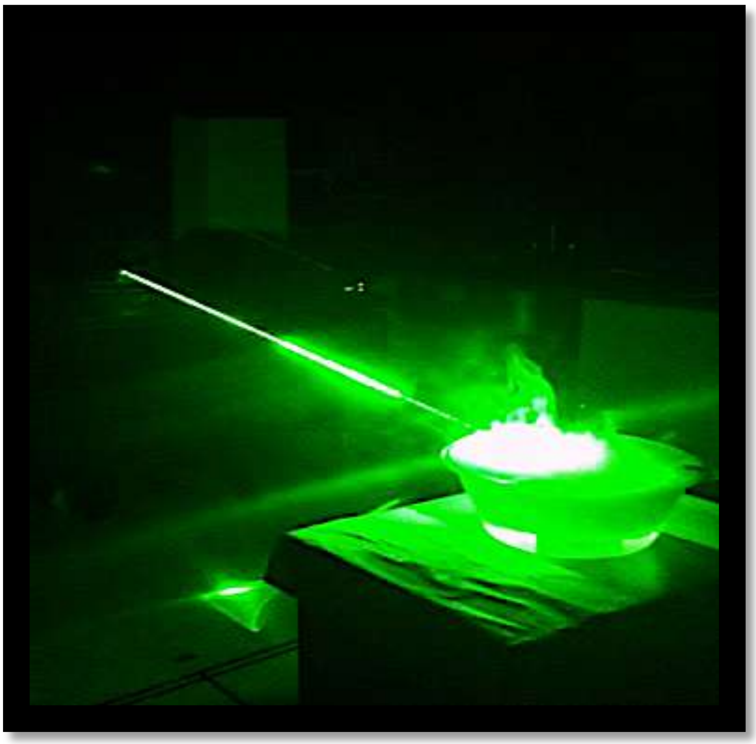


Figure 4.5 Mist spray interaction with a laser beam
(Source: Author)

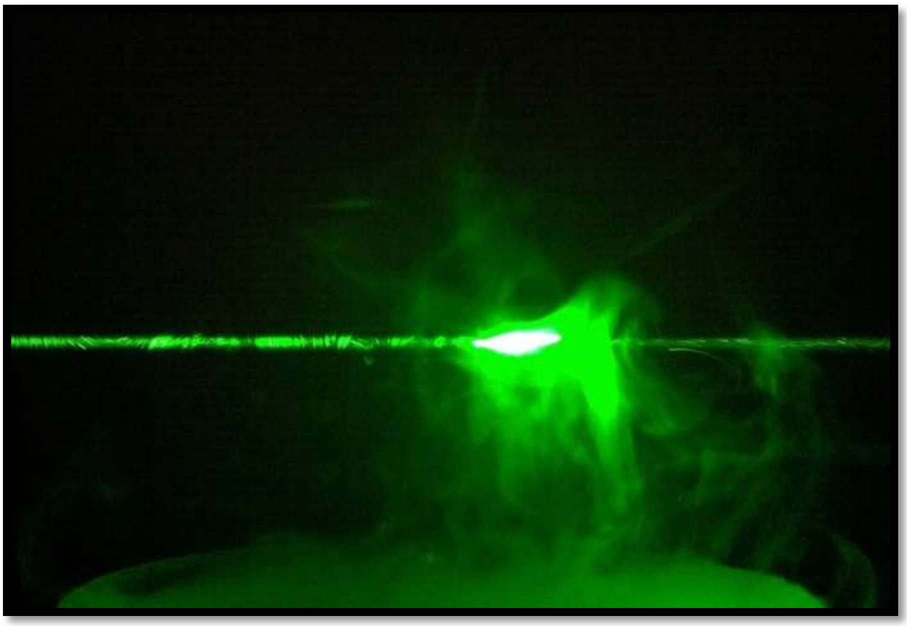


Figure 4.6 Laser beam interaction with weak mist rising from bowl
(Source: Author)

4.3.2 Conclusion of the mist display experiment 1

Although the mist created in the experiment was concentrated within the depth of the bowl, the issue was that it stayed within the bowl. It was therefore essential to create a method by which the flow of the mist could be directed into a larger area in a stable way so that the laser projected image could be displayed within the mist. This meant that any future experiment would have to improve the system by which the mist is directed and delivered. Moreover, it would also need to address the issue of how to then capture the mist in a stable and controlled technique to create a ‘curtain’ of mist. This became very clear from the experiment described in “A Novel Walk-through 3D Display” (DiVerdi et al., 2006, pp428–37), where the flow and capture of the mist is discussed and where DiVerdi et al. used airflow to control and contain the mist. Subsequently, the next experiment in this project lead to improvements in the concept of airflow control and the building of a delivery system like the one used in the experiment by DiVerdi et al. Although, the aim of their work was to demonstrate an illusion of a 3D image within a fog screen system, this project aimed to create and project *real* 3D images into a mist screen. However, the airflow control system used in their work was considered to be potentially suitable for the next step in this experiment design. To that end, a new mist display was built by the researcher to be tested in a new experiment (see in Figure 4.7).

4.4 Mist display experiment 2

This experiment was performed to strengthen the idea of projecting a hologram extending from the mist screen experiment. An attempt was made to create a system by which the mist would be delivered in the screen, with air blown by fans (as seen in in Figure 4.8 to in Figure 4.12). This device was made by the researcher to improve the airflow around the mist curtain.

Figure 4.7 Straws controlling the air delivery
(Source: Author)

4.4.1 Construction details

The components used were as follows:

1. Sheets of wood (15 × 75cm) glued together to create a rectangular box.
2. Five 6V computer cooling unit fans. The air fans were mounted on top of the rectangular frame on the basic area of the wooden box, to blow air to produce a stable mist in an attempt to create a curtain of mist.
3. Hundreds of plastic straws were stuck together, on both sides of the box, aiming to achieve a laminar flow of air. Laminar flow refers to a uniform flow of air or water in a medium whereas a turbulent flow refers to the opposite, which is a non-uniform flow.
4. A PVC (poly-vinyl chloride) pipe of length 90cm and a diameter of 6cm was inserted across the wooden box right below the air flow fans. 1.5cm holes, facing down, were drilled periodically so that they formed a passage for the mist to escape.
5. Finally, two sheets of wood were glued within the inner side of the box angled away from each other. This formed a passage for the mist to escape.

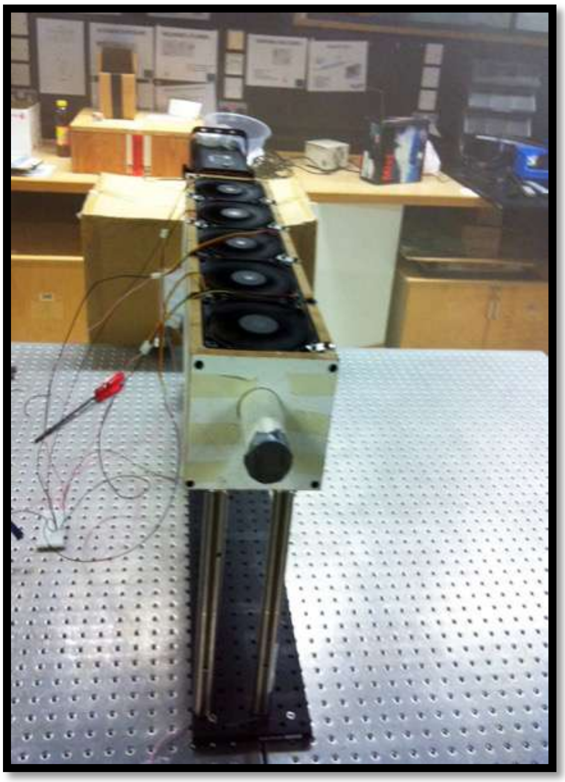


Figure 4.8 Mist construction system
(Source: Author)

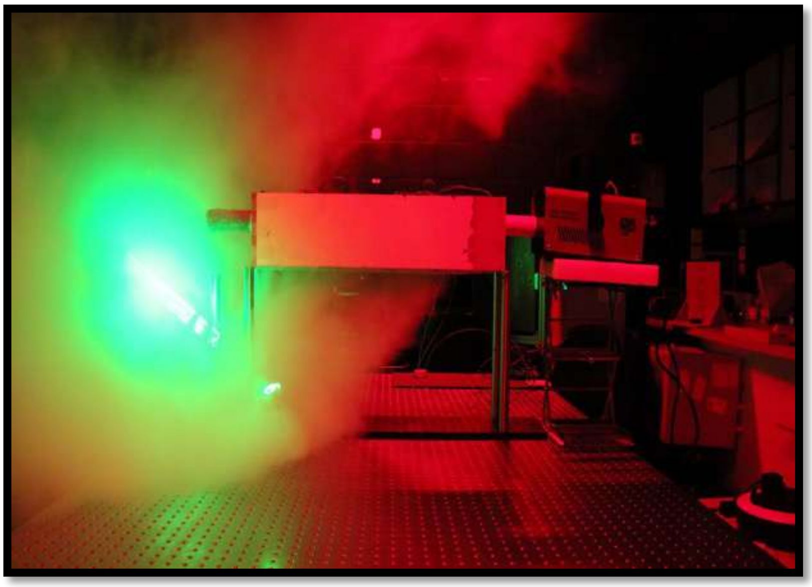


Figure 4.9 Mist device blowing the air in the lab
(Source: Author)

Figure 4.10 Mist device
(Source: ebay.co.uk)

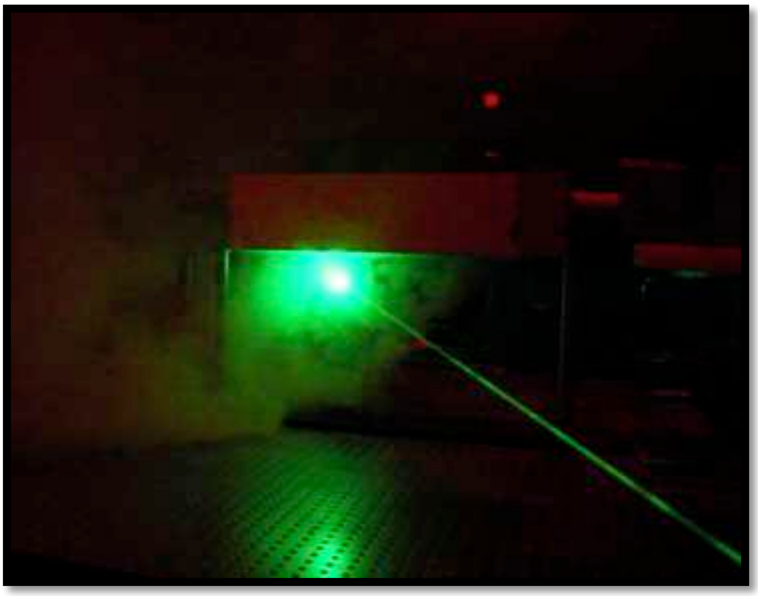


Figure 4.11 A laser beam projected into mist
(Source: Author)

Figure 4.12 The new mist screen
(Source: Author)

4.4.2 Limitation of mist display experiment 2

1. **Viewing reason**

   To view transmission holograms, a laser beam should point at the plate or film at 45 degrees from the rear of the plate or film, which is not a practical solution in museum display. Typically, museum space is limited and should be organised to take advantage of every available space. However, hologram displays need large spaces and dark areas in which to be displayed, so the researcher decided to discontinue conducting and improving this type of display system due its inadequacy within a museum context.

2. **Space**

   The transmission hologram and mist screen display system took up too much space for a museum environment in which display space is at a premium.

3. **Mist flow thickness**

   Several more steps were needed to improve the thickness of the mist, including creating a mist curtain and holding on to its flow and surroundings to facilitate this experiment, in terms of air flow.

4.4.3 Conclusion from mist display experiment 2

It became evident from the two mist display experiments undertaken that they did not match expectations. Projecting a hologram onto mist is complex and impractical, especially within a museum. To conclude, maintaining the mist flow rate to project a hologram is difficult even within a laboratory; therefore it was considered that it would even more complex to project a hologram in a museum environment. These unsuccessful results lead the researcher to change the technique and approach of this research in order to find another method that would be more successful.

4.5 Denisyuk's reflection hologram – single-beam reflection

4.5.1 Equipment required

To record a Denisyuk reflection hologram in a laboratory, the process requires sequential, concatenated, organized steps. Therefore, specific optical equipment, materials and tools, show in Table 4.1, were needed.

Table 4.1 Holographic process equipment and its function

Tool	Usage and role
1. A laser source - green and red 532nm	This is the most important tool to illuminate the scene and activate the photographic emulsion to form an image.
2. A shutter	To control the length of exposure light time of the emulsion (in these experiments a control shutter was used).
3. Sensitive plates	Sensitive red and green, full colour plates – in this project red and green sensitive were chosen, manufactured by Colour Holographic™.
4. Safe light	Ranging between different colour degrees: red, green, blue and white. These kinds of safe light allow the plates to be taken out of boxes as they do not damage the sensitive plates, as a normal light would do. So, it is possible to move, arrange and locate all tools safely while the lab is completely dark, except for the safe light. Green and red safe lights were used.
5. A heavy anti-vibration isolated table (bench)	To arrange the recording hologram equipment on, and to run the process of recording the hologram. To gain a clear and successful result the table needed to be heavy enough, with rubber underneath, in order to prevent any outside vibration.
6. Lenses	This is a fundamental tool that was used to adjust (optimise) the laser beam to be very clear, clean, shiny and directed to the middle of the mirror on the tripod, which was reflected (scattered) into the object throughout the process of recording the hologram.
7. Mirrors	These were used to direct and reflect the lasers throughout the process preparation.
8. Aluminum tripod	This was used to adjust the degree of the angle as required.

4.5.2 Denisyuk reflection hologram

Elements of the Denisyuk type reflection hologram recording process are shown in Figure 4.13.

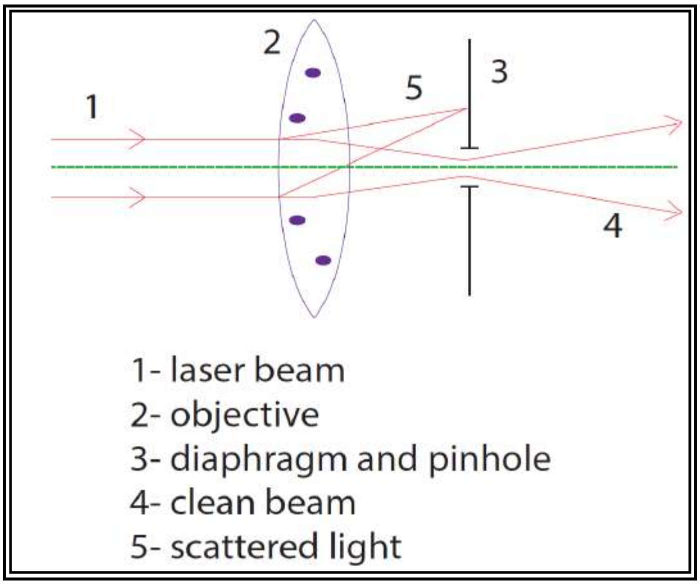


Figure 4.13 Denisyuk's reflection hologram
(Source: Author)

The laser light source used here was a helium-neon gas laser whose wavelength of emitted light is 632.8nm with the power of 75mW, manufactured by Melles Griot. The beam was reflected by using a mirror and directed to a beam expander with a magnification of X20 and the pinhole used was 25 microns. The beam expander is basically a lens arrangement through which the diameter of the input beam is enlarged. The raw expanded beam is not suitable to be used for recording purposes because it contains Newton's Rings diffracted, due to the dust particles in the air. If this beam is used then Newton's Rings appear (see in Figure 4.14 below) on the recorded hologram, consequently reducing the clarity of the image. To overcome this problem the expander beam is spatially filtered using a pinhole. The beam output from the objective lens converges at a point where the pinhole is placed; the beam that comes out through the pinhole is clean and free of Newton's Rings and is now suitable for recording. Figure 4.14 represents the beam path between the objective lens and the pinhole.

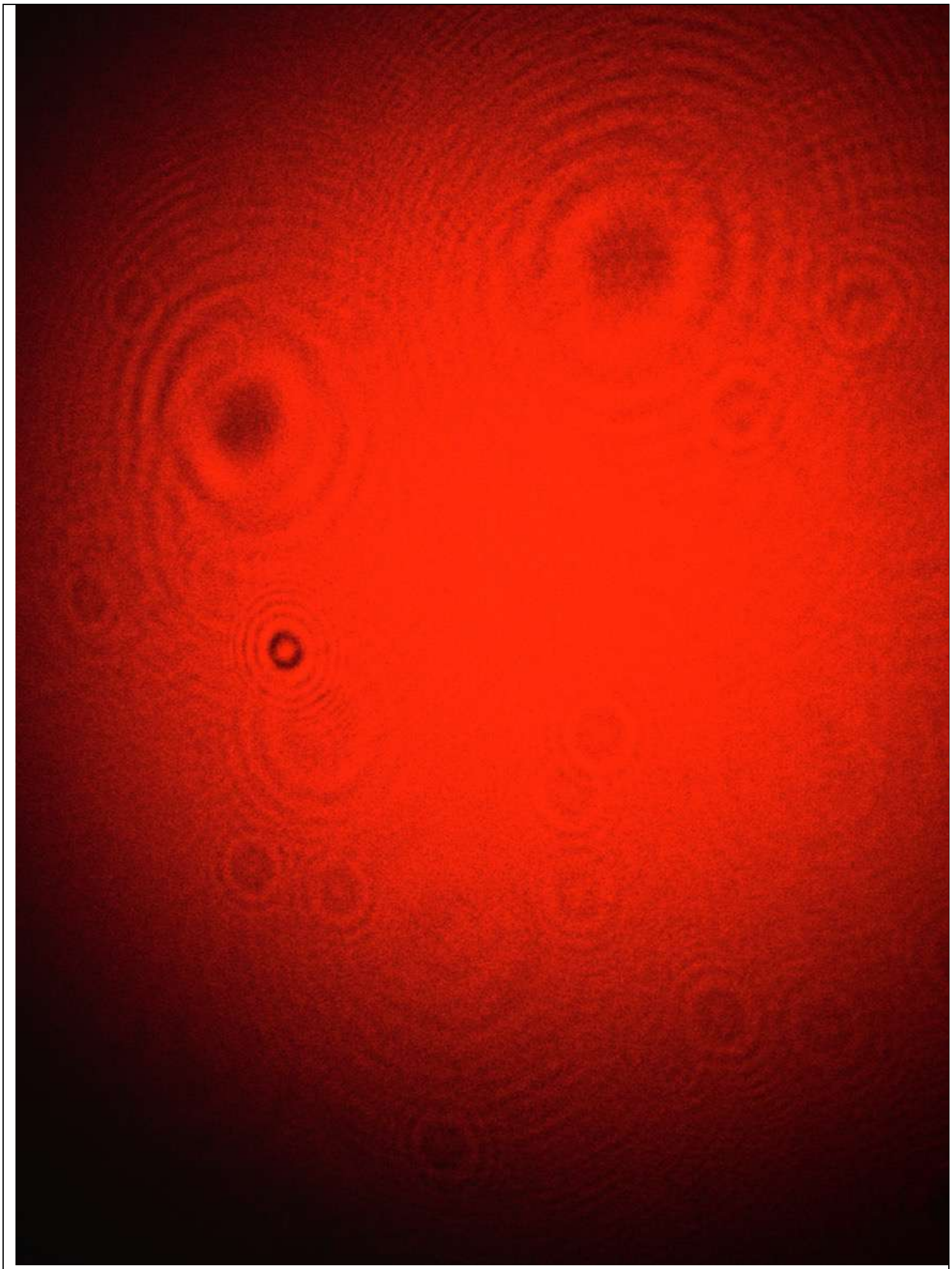


Figure 4.14 Newton's Rings
(Source: Professor. Richardson)

The filtered expanded beam is reflected onto a mirror at an angle of 32 degrees and is directed to illuminate the object as shown in the mobile recording process (Figure 4.15).

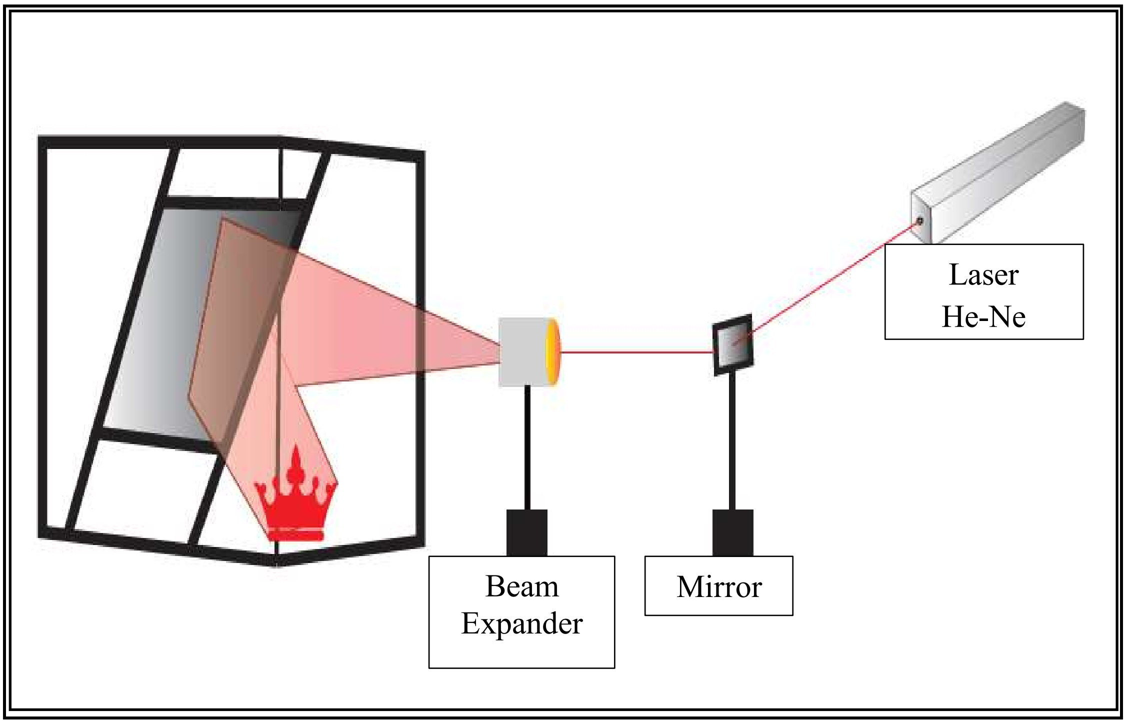


Figure 4.15 Diagram of reflection: Denisyuk's hologram mobile recording process (Source: Author)

A recording plate is placed over the object, emulsion side facing the object, and it is then in a position ready for exposure to the laser beam, as shown in Figure 4.16.

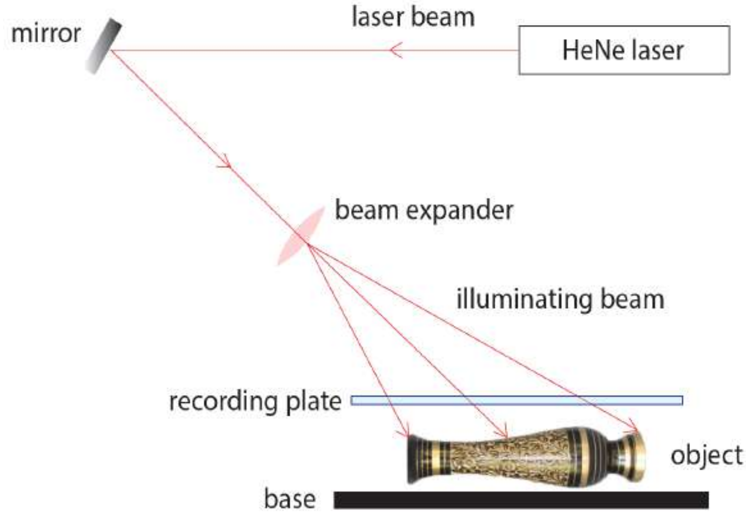


Figure 4.16 Denisyuk reflection hologram mobile recording process
(Source: Author)

In recording holograms, the source of light is fundamental to illuminate the scene and to activate the photographic emulsion. In this experiment a helium neon (He-Ne) laser was used to reconstruct the hologram with 633nm, as shown in Figure 4.17. A shutter was needed to control the length of time of exposure for the emulsion in these experiments (a custom-built electronic shutter was used). Due to diverse experiments, exposure times ranged between 6 to 22 seconds of laser light dispersion.

The glass-sensitive plates used in these experiments were 8in. × 10in. (20cm width × 25cm length) and recorded between 3mm thickness or on 1.5mm. A plate size of 3in. × 5in. (7.62cm width × 12.7cm length) was used in the first experiment beside the portable recording system. Different variants of chemical formulae were used to develop and bleach the recorded sensitive plates in order to discover which would be most appropriate to develop the best quality 3D images. Sand from Saudi Arabia was used as a background for the items before the recording process in order to construct a correlation with the original item's environment.

When viewing such a hologram in the same monochromatic light as the recording one the hologram image looks amazingly shiny and clear, and most importantly, the viewer can see the depth of the 3D image. If the hologram is recorded by red laser, a red light source or LED should be pointed onto a red sensitive holographic plate, otherwise the viewer will probably not see the hologram. Alternatively, a green sensitive plate should be illuminated by a green LED torch or light to be seen clearly.

The preparation in the laboratory started by turning the laser device on to warm it up for about 30 minutes, see Figure 4.17. Then, the chemicals were mixed in the darkroom while the laser warmed up. The holographic sensitive plate was set up in the dark over the lens, which controls the laser beam around the object. The plate was placed 2–3mm in front of the object (i.e., between the object and the laser). Finally, the plate was expose for about 12–22 seconds, depending upon reflectivity.

Figure 4.17 The isolation table in the holographic laboratory with the portable holographic camera
(Source: Author)

4.5.3 Developing the holographic plate process

The entire process of developing a holographic plate is must be done in a darkroom laboratory with just a safe light turned on. In sequential order, firstly the recorded plate that had already been exposed to a laser beam was taken from a box and placed into a tray of room temperature water, then it was immersed in a developer tray for around two minutes. Afterwards the plate was washed in a tray of room temperature water for around three minutes (see Figure 4.18). Then, the holographic plate was soaked in a tray of bleach until it become clear (particles, black stains removed). Subsequently, it was washed again in tap water and squeegeed dry on the glass side surface and by tissue on the emulsion side, then dried using a hair dryer for approximately one minute.

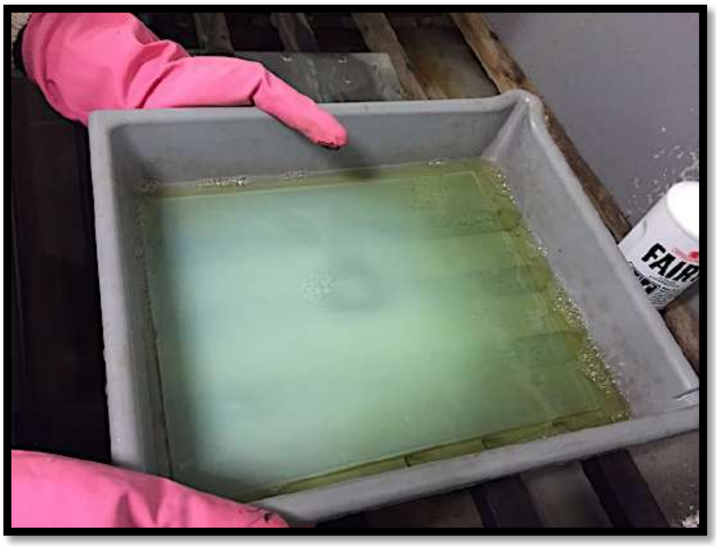


Figure 4.18 Plate in the developing tray
(Photographed by: Vivian Amos)

4.5.4 Developer chemicals

The formulation of the developer and bleach were:

a) Developer

- 2g EDTA – acid (Ethylenediaminetetraacetic acid)
- 2,5g Metol
- 45g Sodium Carbonate
- 50g Ascorbic Acid
- 1g Potassium

b) Bleach

- 75g Ferric nitrate
- 30g EDTA - Ethylenediaminetetraacetic acid
- 30g Potassium Bromide
- 30g Sulphuric Acid

The formulations used were similar, with slight modifications between one experiment and another. Based on the concept of Denisyuk's single beam reflection technique, experiments were undertaken with different original objects and these are explained as follows:

4.6 Reflection hologram experiment 1

The first analogue holography experiment of a diamond watch was done on a 5 × 5cm holographic sensitive plate. The aim of this experiment was to explore and discover the suitability of the reflection type of hologram with a laser beam on shiny diamonds in jewellery, to produce a successful reflection hologram (see Figure 4.19). To explore this, in the holographic laboratory an ILFORD HARMAN© Ltd red sensitive plate was used with a red laser, with 22 seconds of exposure time for the laser beam (see Figure 4.20).

Figure 4.19 Photograph of the diamond watch used in experiment 1
(Source: Author)

Figure 4.20 Photograph of the reflection hologram of the diamond watch used in experiment 1
(Source: Author)

As a first experiment to investigate the results of the hologram technique, it was considered to be effective.

4.7 Reflection hologram experiment 2

At the beginning of this PhD study, the researcher visited the Design Museum in London and was inspired by the crystals and the interaction between light and crystals and the shadows and the reflections of light when reflected from the crystals (see Figure 4.21 below). This inspired the researcher to discover the results of capturing glass and how the results would appear after being exposed to a laser beam, which encouraged her to try different materials. The second experiment with reflection holograms was undertaken on a sculpture made of glass (shown in Figure 4.22) from the glass workshop at De Montfort University in Leicester, UK and a ready sequins item shown in Figure 4.23 and Figure 4.24.

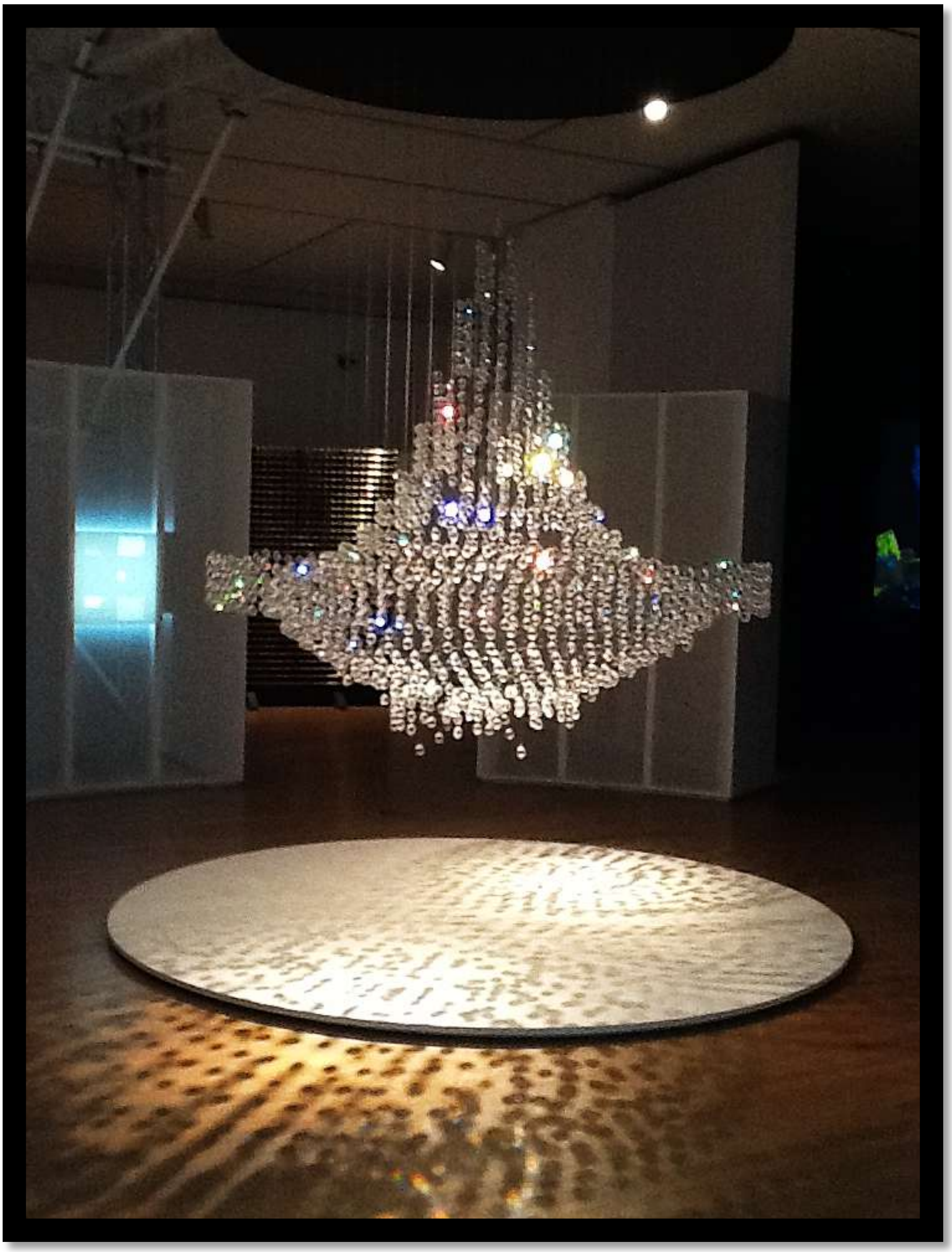


Figure 4.21 A chandelier in the Design Museum, London
(Photographed by the author, 5 November 2012)

Figure 4.22 A photograph of the reflection hologram of a glass sculpture (Size: 8in. × 10in.)
(Source: Author)

Figure 4.23 A photograph of the original sequins

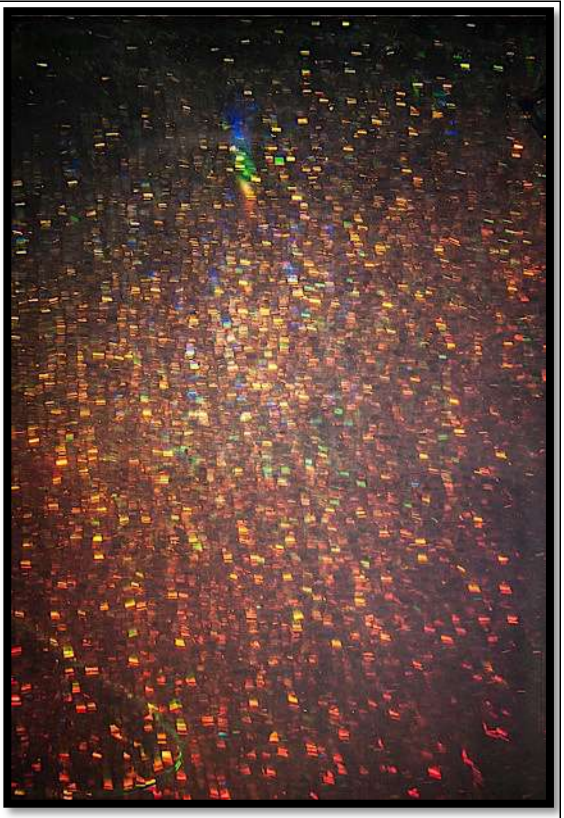


Figure 4.24 A photograph of the reflection hologram of the sequins (Size: 8in. × 10in.)

(Source: Author)

4.8 Reflection hologram experiment 3

The third experiment was an attempt to record a burqa (veil), shown in Figure 4.25. This was an amazing handmade piece; however, due to the fabric and sequins used to create it several steps had to been taken, as the holographic process requires a completely static material, such as crystal, jewellery, a vase or other heavy items. The burqa was recorded on a green sensitive plate with a green laser. Although, the burqa was left on the recording area for around half an hour in the laboratory, with the aim of increasing its stability, unfortunately the result was not successful. As can be seen in Figure 4.26 and Figure 4.27, approximately half of the plate faded and was not shiny or clear, as the details were not captured clearly, as a result of the movement of the fabric material.

Figure 4.25 Original burqa (veil) used in experiment 3
(Source: Author)

Figure 4.26 Hologram of the burqa used in experiment 3 (Size: 8in. × 10in.)
(Photographed by: Jeremy Collingwood)

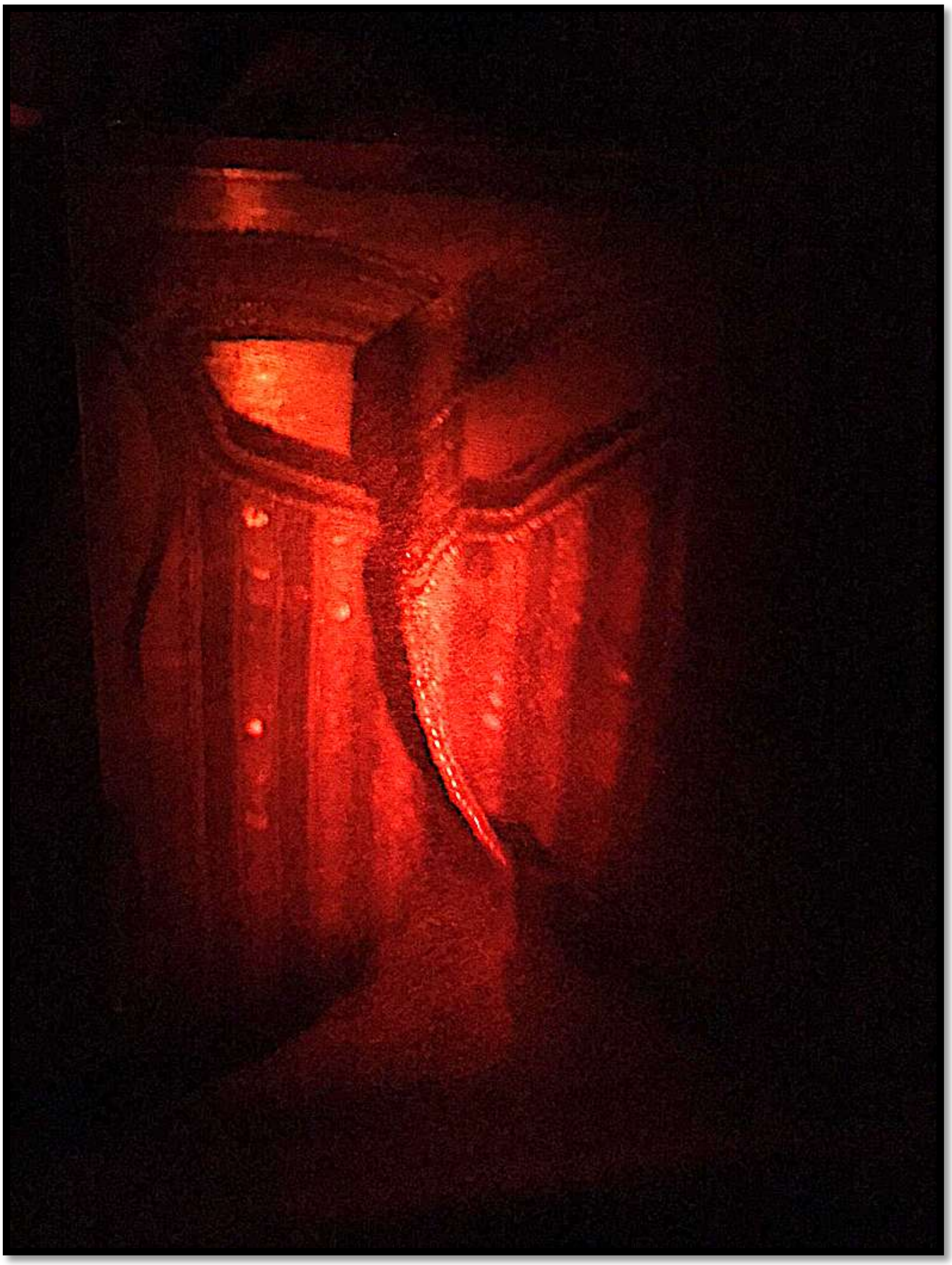


Figure 4.27 Hologram of the burqa used in experiment 3 (Size: 8in. × 10in.) (Source: Author)

The burqa experiment was a failure; however, the necklace (lubbah) (see Figure 4.28 and Figure 4.29) experiment was successful shown in (Figure 4.30 and Figure 4.31) below.

Figure 4.28 Photo of an original item (necklace, lubbah)
(Source: Author)

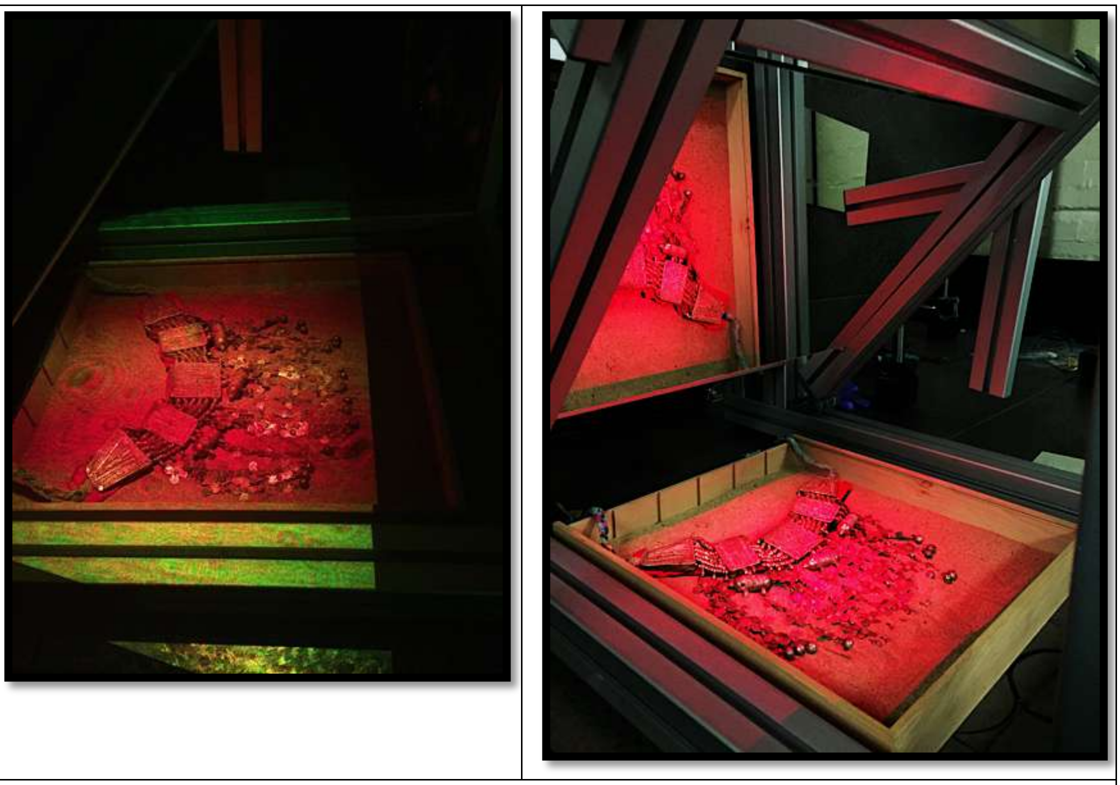


Figure 4.29 Photographs of the original necklace (lubbah) prepared in the lab to be exposed
(Source: Author)

Figure 4.30 Photo Photograph of the hologram of the necklace (lubbah)
(Size: 8in. × 10in.)
(Photographed by: Jeremy Collingwood)

Figure 4.31 Photograph of the hologram of the necklace (lubbah)
(Size: 8in. × 10in.)
(Source: Author)

4.9 Reflection hologram experiment 4

In this experiment reflection holograms of a ring, bracelet and belt were recorded on a red sensitive plate with 3mm thickness with 20 seconds of exposure time to a red laser beam. Figure 4.32 shows the original ring and bracelet and Figure 4.33 shows the hologram of the two items. Figure 4.34 shows the belt and Figure 4.35 shows the hologram of this item.

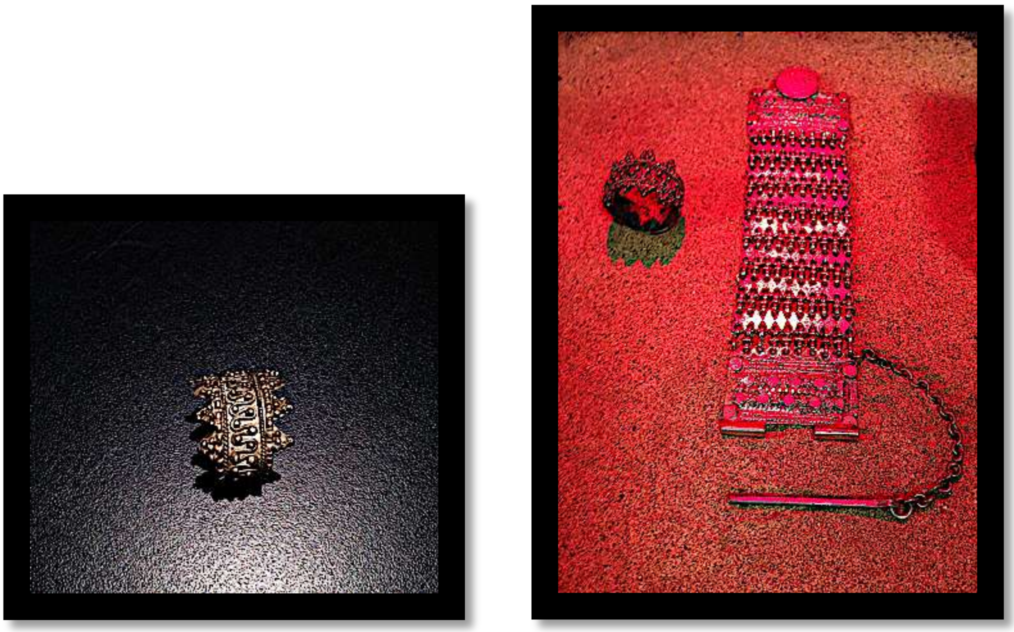


Figure 4.32 Photograph of the original ring and bracelet used in experiment 4
(Source: Author)

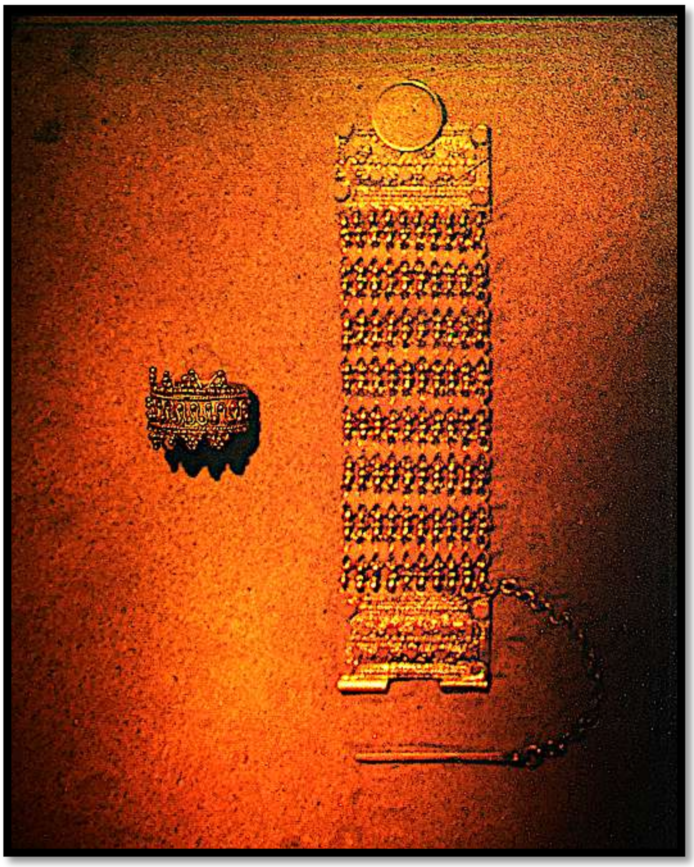


Figure 4.33 Photograph of the hologram of the ring and bracelet in experiment 4
(Size: 8in. × 10in.)
(Photographed by: Jeremy Collingwood)

Figure 4.34 Photograph of the original belt
(Source: Author)

Figure 4.35 Photograph of the hologram of the belt in experiment 4
(Size: 8in. × 10in.)
(Photographed by: Jeremy Collingwood)

4.10 Reflection hologram experiment 5 (mobile recording of holograms)

In this experiment, a mobile hologram system was tested, using small size holographic plates, using jewellery as the original items. The researcher recorded on holographic plates size 4in. × 5in. plate thickness 1.5m five items. However, the max size of recording using a mobile system is 8in. × 10in. A green diode laser device with power rating of 150mW and of wavelength 532nm was used, with the beam emitted through the lens, which pointed to a mirror. The mirror reflects the laser onto the green sensitive plate, with its emulsion side face up and the original item placed exactly underneath the plate.

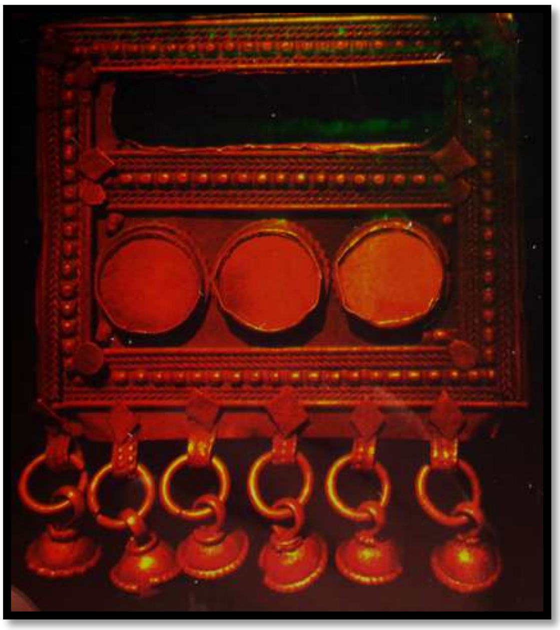
4.10.1 Reflection hologram experiment 5 conclusions

The results of this experiment of holographic recorded plates were successful as the images were clear and shiny. The researcher concluded that the size of the holographic plates was too small, due to the size limitations of the mobile system at that time, because of the creation of a mobile system and the power of the laser beam, which is 150mW. The researcher considered that this type of portable camera should be developed to allow the recording of larger sizes of plates in order to gain its maximum potential. Furthermore, the resolution of the images was as high as the resolution of the recorded images on the large bench. The original items of jewellery and hologram results are shown in Figure 4.37 to Figure 4.45 inclusive.

The quality of the mobile recording of the holograms proved that the portable camera is very useful and convenient for recording priceless and valuable cultural heritage items in museums. The portable camera is considered to be an easy and comfortable piece of equipment to be carried and moved when travelling. Its main advantage is that holographers can record holograms of priceless and valuable items on location and therefore reduce the risk of damage to or theft of these precious items.

Figure 4.36 Photograph of the original anklet
(Source: Author)

Figure 4.37 Photographs of the hologram of the anklet from different angles
(Size: 4in. × 5in.)
(Source: Author)

	
Figure 4.38 Photograph of original herz	**Figure 4.39 Photograph of the hologram of the herz (Size: 4in. × 5in.)**

(Source: Author)

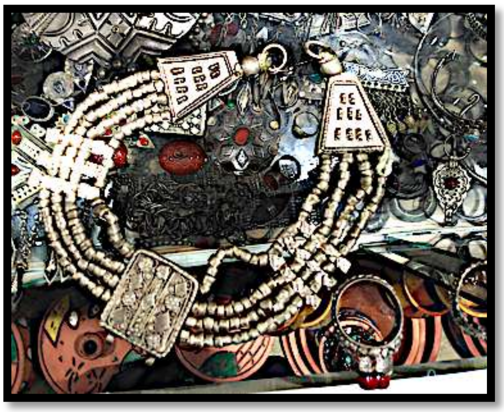
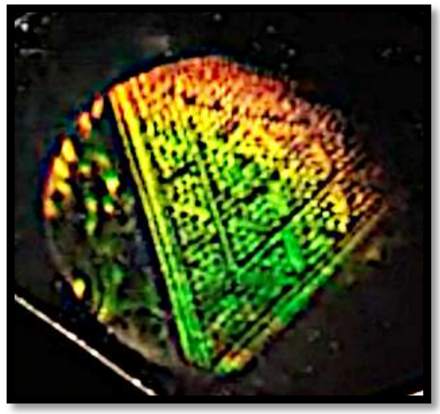
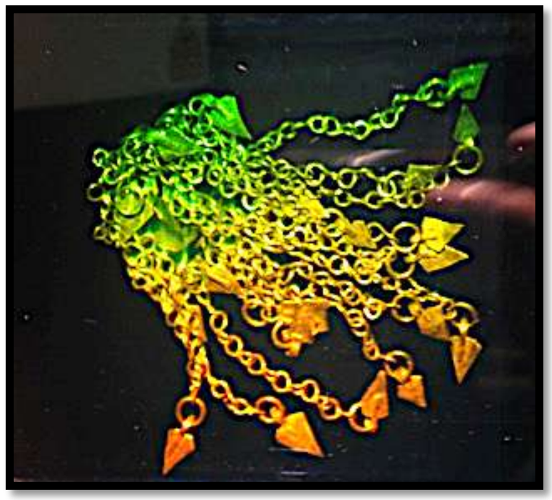


Figure 4.40 Photograph of original necklace	**Figure 4.41 Photograph of the necklace (Size: 4in. × 5in.)**

(Source: Author)

	
Figure 4.42 Photograph of original pendant	**Figure 4.43 Photograph of the hologram of the pendant (Size: 4in. × 5in.)**

(Source: Author)

	
Figure 4.44 Photograph of original pendant	**Figure 4.45 Photograph of a hologram of a pendant**

(Source: Author)

4.11 Reflection hologram experiment 6

As a result of the previous experiments, the aim of this experiment was to produce a number of successful reflection holograms testing new materials (colour holographic™ plates) and selected times of exposure. For this experiment the author applied sand (brought from Saudi Arabia) as a background under the jewellery items in the experiments. It was found that 18 seconds was the most suitable exposure time with this power laser device and these original items (see Figure 4.46 to Figure 4.54) inclusive.

	
Figure 4.46 Photograph of a traditional Arabian wristband jewellery	**Figure 4.47 Photograph of the hologram of traditional Arabian wristband jewellery (Size: 8in. × 10in.)**

(Source: Author)

Figure 4.48 Photograph of a traditional Arabian wristband jewellery
(Source: Author)

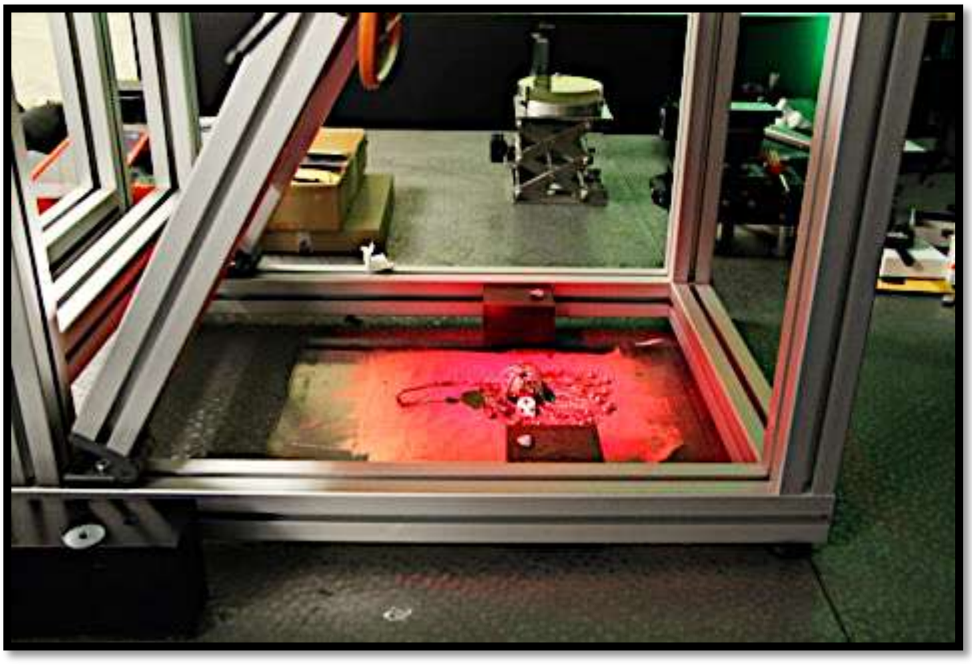


Figure 4.49 Photograph of an original pendant item being prepared for recording in the laboratory
(Source: Author)

Figure 4.50 Photograph of the hologram of the pendant (Size: 8in. × 10in.)
(Photographed by: Jeremy Collingwood)

Figure 4.51 Photograph of the original headband
(Source: Author)

Figure 4.52 Photograph of the hologram of the headband (Size: 8in. × 10in.)
(Photographed by: Jeremy Collingwood)

	
Figure 4.53 Photograph of the original pendant	**Figure 4.54 Photograph of the hologram of the pendant (Size: 8in. × 10in.)**

(Source: Author)

4.12 Reflection hologram experiment 7

These were the last experiments in this research. In these experiments colour holographic™ red sensistive plates size 8in. × 10in. were used with exposure time set at 18 seconds. Figure 4.55 shows the red laser light on and Figure 4.56 with the green safe light on. The original jewellery items are genuine and the resulting holograms were very successful in capturing high resolution and were clear and shiny with every minute detail evident (see Figure 4.57 to Figure 4.60).

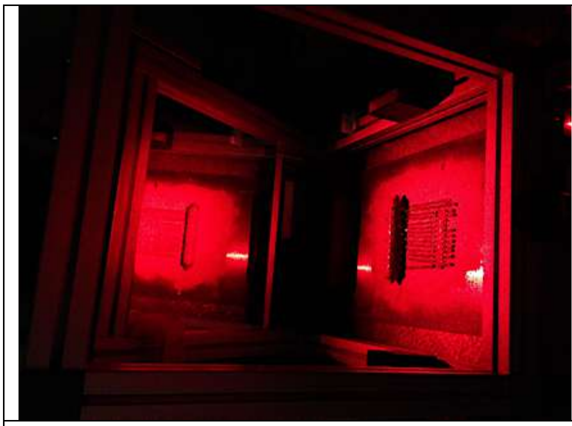


Figure 4.55 Preparation in the lab

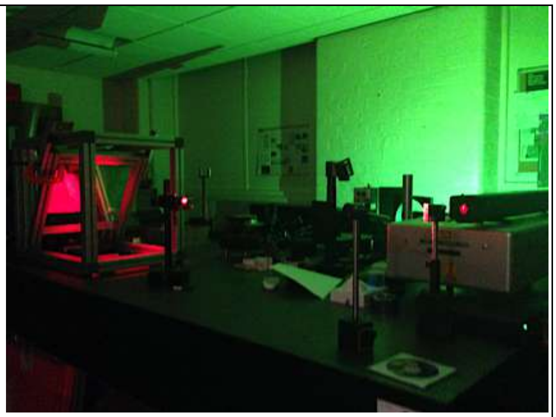


Figure 4.56 Preparation in the lab

(Source: Author)

Figure 4.57 Photograph of the original pendant

Figure 4.58 Photograph of the hologram of the pendant (Size: 8in. × 10in.)

(Source: Author)

Figure 4.59 Photograph of the original necklace prepared for exposure to laser beam (Source: Author)

Figure 4.60 Photograph of the hologram of the necklace (Size: 8in. × 10in.)
(Photographed by: Professor. Bjelkhagen, 2015)

4.13 Results and analysis

The outcome in each experiment was varied. These experiments were conducted testing different materials including:

Sensitive holographic plates (green and red): ILFORD HARMAN© Ltd then Color Holographic^{Tm} plates;

Laser devices: red laser and diode green laser;

Shelters: electronic and manual shelters;

Exposure times: ranged between 6–22 seconds;

Developer chemicals formula: (T.E.A 1% Triethanolamine) substance, which was added specifically for Color Holographic^{Tm} plates before the exposure process.

The holographic technique captured the jewellery pieces with all the engravings and minute details and gave a sensation of depth. The researcher considers that this technique captures the authenticity of the jewellery objects as well as the ancient heritage of the Arabian Peninsula. How this is achieved is explained by Hariharan (1996, p2):

> *To an observer, the reconstructed wave is indistinguishable from the original object wave, the observer sees a three-dimensional image ... all the normal effects of perspective and depth of focus that the object would exhibit if it were still there.*

4.14 Reflection hologram technique outcome

A diversity of types of holographic medium are used regularly in art, such as rainbow and white transmission holograms, which have not been recorded in this research due to the researcher's limited time and equipment offered and the cost of the material. However, Denisyuk's reflection method was chosen and experimented with because of its clarity, simplicity and equipment accessibility in the holographic laboratory.

Throughout this experimental and exploratory research, a variety of materials, methods and types of holographic experimental techniques were used. The results of Denisyuk's reflection hologram were found to be most suited to this research to achieve the aim and objectives of this investigation. The results were successful and revealed a more appropriate method to record and display holograms of artefact items in museums.

What makes a hologram a revolutionary method for presenting valuable and ancient artefacts is the fact that it offers a practical and convenient solution for portability of the artefacts around the world, rather than displaying and moving the original items. Thus, museum visitors can enjoy and appreciate the precious artefacts, which without the advantages of the holography techniques would otherwise remain unseen and lost to them.

4.15 Transmission hologram

The process of recording a transmission hologram is different from recording a reflection hologram due to the arrangement of the position of the source material. However, the equipment and material used to record and develop both types is the same. These are:

coherent light (laser device); lenses; mirror; sensitive plate (red or green); shutter; stable bench; and finally the original item. The difference in the case of recording a transmission hologram is the position of the diffraction of the laser beam onto the plate, which should be directed from the rear side of the plate not from the front emulsion side (as is the case in recording a reflection hologram). Moreover, in order to display a transmission hologram for viewing (the plate after development), a laser beam must illuminate the plate from the same angle that the laser beam was pointed at it at the time of recording. On the other hand, to view a reflection hologram an LED or spotlight can be used to view the result of the holographic plate.

4.15.1 Transmission hologram experiment

This was the only experiment conducted to record a transmission hologram, with the aim of investigating which type of hologram is more appropriate for displaying ancient jewellery in museums. In this experiment a 5cm × 8cm red sensitive plate was chosen to record a transmission hologram to be fitted in a small box, to be displayed as a jewellery box. A viewer can view a picture that is as realistic as the original item just by pressing a small button to light up the box. The inspiration for the initial idea to display a hologram in a box came from Gary Cullen, a Canadian holographer, who created the hologram illustrated in Figure 4.61 below. Cullen created this to celebrate the 50th anniversary of the laser which was created by Theodore Maiman in 1960, which Ross (2010) describes:

> *is on a 2.5" x 4.75" sheet of holographic film, mounted as a window in a small box and illuminated with a built-in diode laser, powered by a small battery. When a button is* [depressed]*, Maiman's laser appears to be inside the box, reflected by mirrors on three sides [however,] when the lid is* [removed] *there* [is nothing inside the box]. *Truly modern magic!*

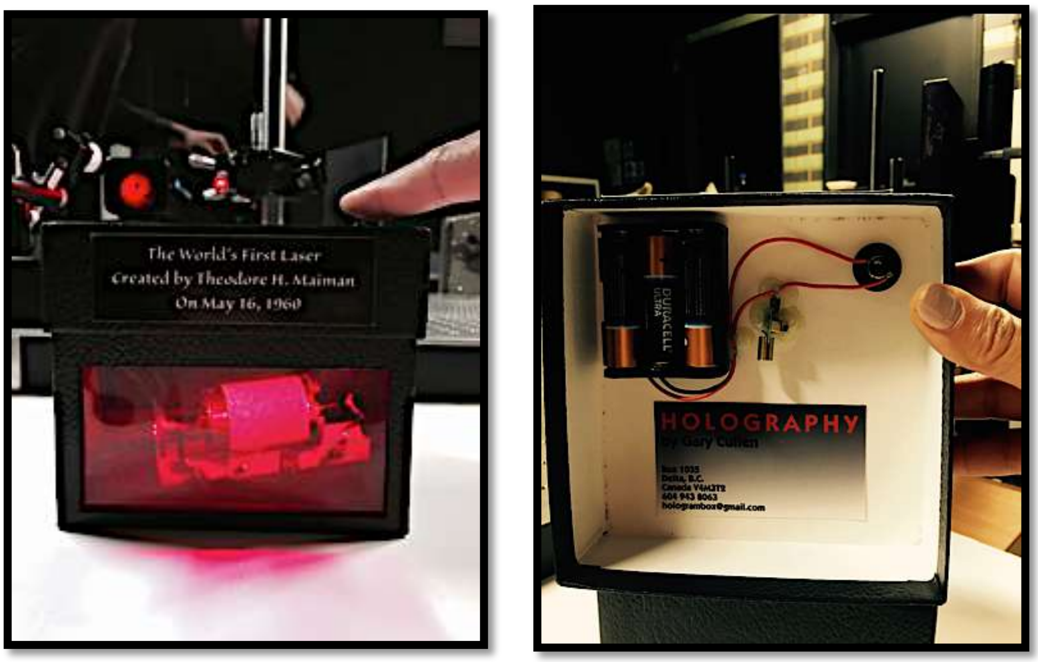


Figure 4.61 Photographs of a transmission hologram in the box
(Source: Holography by Gary Cullen, Canada)
(Photographed by the Author)

This process inspired the researcher to display heritage items using a transmission hologram. The steps taken in the processes involved in this experiment are illustrated in Figure 4.62 to Figure 4.68 inclusive.

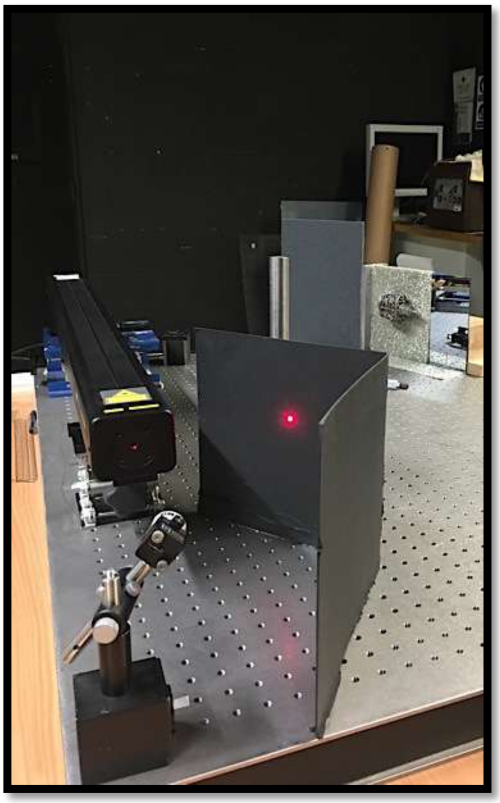


Figure 4.62 Transmission hologram set-up in the laboratory
(Source: Author)

	
Figure 4.63 Transmission hologram set-up in the laboratory	**Figure 4.64 Photograph of the object to record the transmission hologram**

(Source: Author)

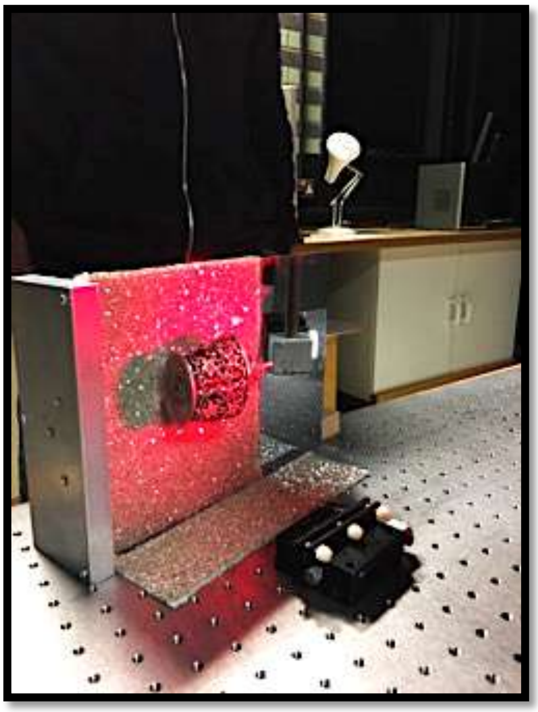


Figure 4.65 A photograph of the object to record the transmission hologram with laboratory light

Figure 4.66 Photograph of the object to record the transmission hologram with red laser beam before shooting

(Source: Author)

Figure 4.67 Photograph of the preparation to record the transmission hologram
(Source: Author)

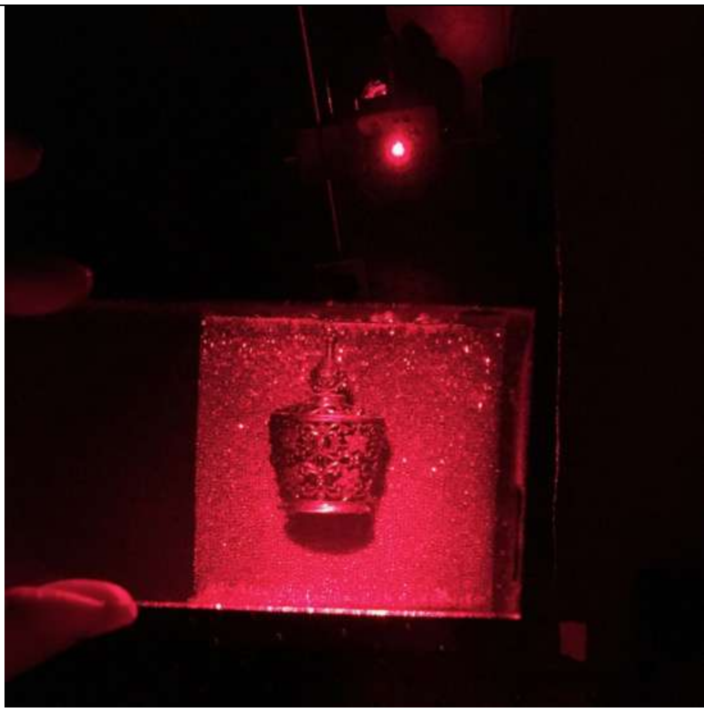


Figure 4.68 Photograph of the transmission hologram
(Source: Author)

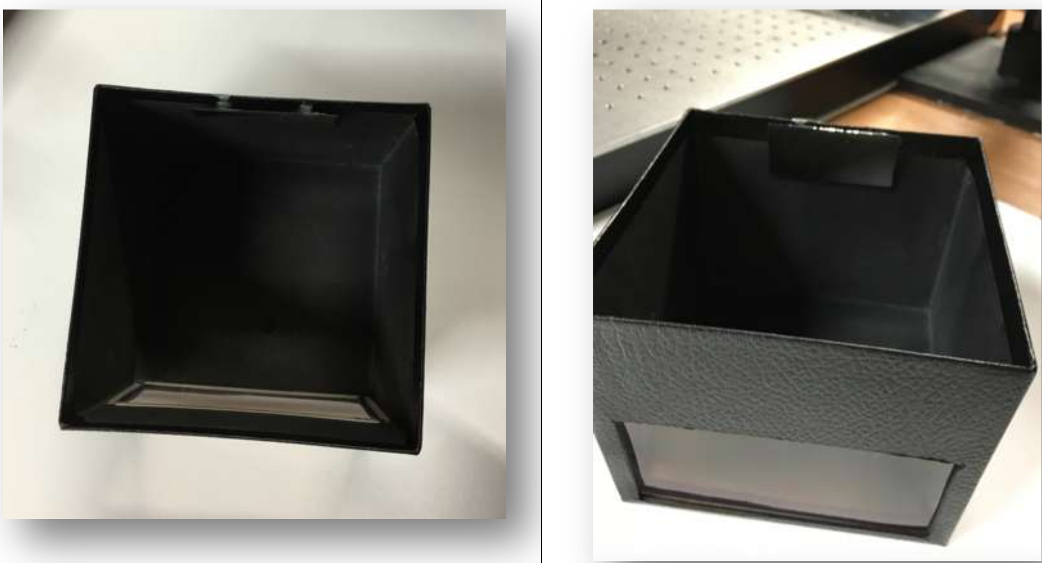


Figure 4.69 Photograph of the empty box to fit the plate of the transmission hologram into
(Source: Author)

Figure 4.70 Photograph of the box, with the transmission hologram fitted and displayed (Source: Author)

4.15.2 Conclusion of the transmission hologram experiment

The success of the transmission hologram result is shown clearly in the box (Figure 4.68 above). Figure 4.70 shows the successful fitting of the transmission hologram for displayed purposes. As a method of displaying artefacts in museums, a transmission hologram does not meet the requirements of museum display systems, as this method requires a large area for projection, with the laser light directed from the back of the plate.

4.16 Digital hologram

This specific experiment presents the use of a digital hologram, with the aim to discover the results of producing such items using a stereogram technique. This experiment investigated the suitability of producing a successful 3D image for the purpose of displaying artefacts in museums. The researcher chose to experiment with a digital hologram due to its ability to record performance and movement as well as static objects, making it suitable for use with heritage artefacts. This type of technique requires incoherent light, so it is safe to use for recording a human being without exposing them to a laser beam, which is dangerous for their eyes and skin. Furthermore, the aim of using a digital hologram in this experiment was to maintain an auto-stereoscopic 3D image to display historical artefacts in museums. The experiment was to test the possibility of using this kind technology to record distinctive items of cultural heritage in sufficient detail to contribute to maintaining their history, authenticity and aesthetic.

Conveying the films into photographic film material to produce a digital hologram was undertaken by Geola©, a specialist printing company located in Lithuania. The next procedure after recording on film was processed by Final Cut Pro and Motion software. Then it was developed by Geola©, using a special printer, to produce a digital hologram. This method is explained in detail in Chapter 2, section, 2.17 Digital holography.

4.16.1 Digital hologram experiment

In order to provide a baseline for choosing a holographic image method to document Arabian jewellery heritage, a subjective experiment was conducted and recorded in the studio, to assess the quality of this type of hologram. Figure 4.71 to Figure 4.73 show a schematic of the components of the mechanical parts of the camera holder and the movable assembly on which the camera moves along the rail to capture a stereo image of the object. Figure 4.74 is an image of the assembly in the studio.

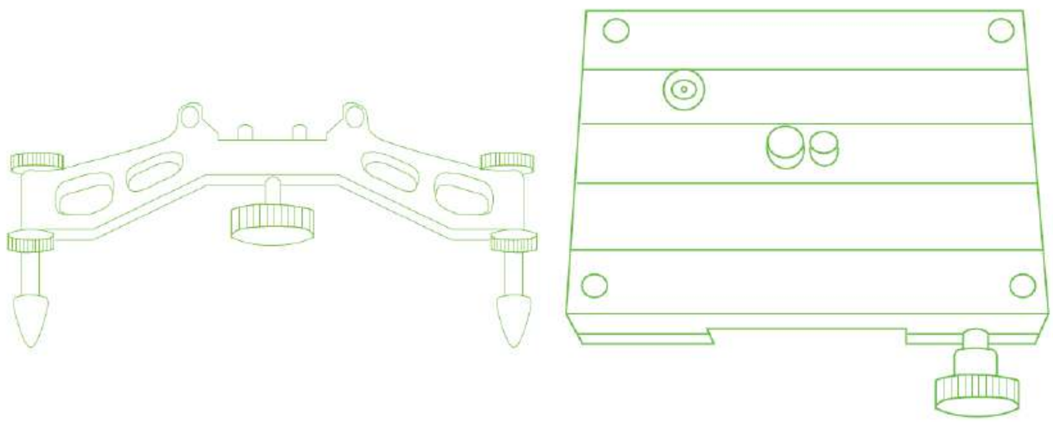


Figure 4.71 Mechanical parts of the HoloCam
(Source: Author)

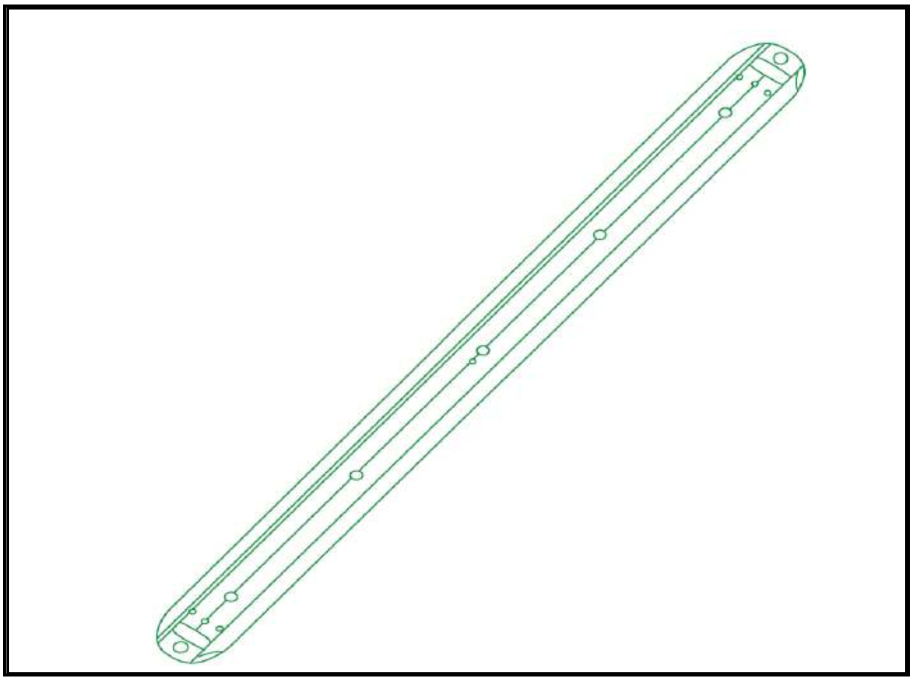


Figure 4.72 The camera rail
(Source: Author)

The full kit, along with the camera mounted on the rail, is balanced by a tripod at either end of the rail. The camera is guided by a gear system that runs along the rail to move the camera focussing on the object at different angles, as shown in Figure 4.73.

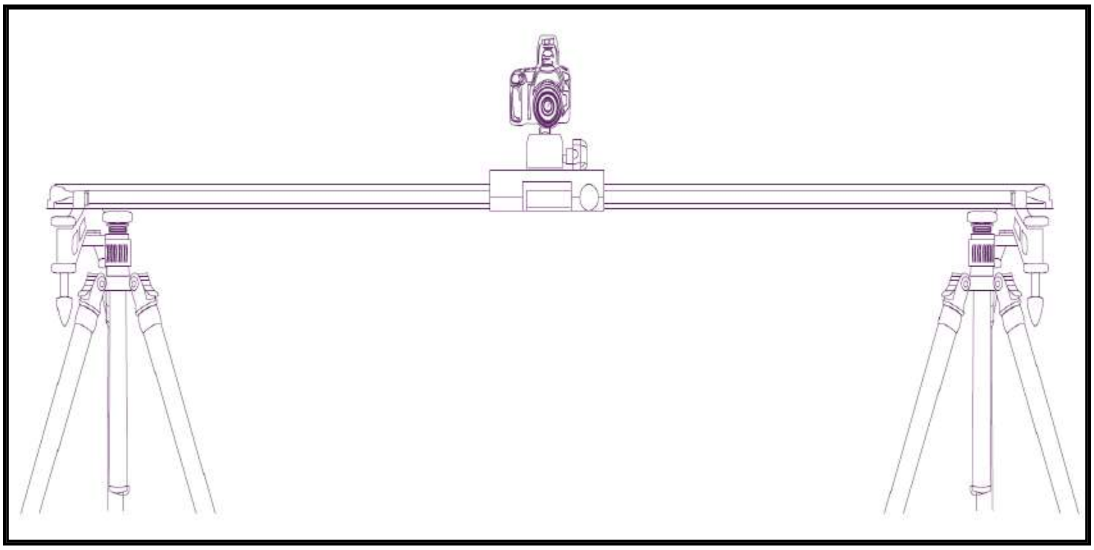


Figure 4.73 Diagram of the camera on the track
(Source: Author)

The HoloCam device tool function is simply to record objects. This system consists of a rail and a track upon which a 35mm camera films the object, while the camera is moved horizontally. This results in a horizontal parallax from the left to the right side of the model. The HoloCam controller system diagram is shown in Figure 4.73 above. The studio set up is shown in Figure 4.74 below.

Figure 4.74 HoloCam track in the studio
(Source: Author)

4.16.2 Digital experiment set-up

The digital hologram in this experiment started by recording a movie in the studio using the HoloCam (Light Portable System) from Geola©. The camera moves on its track from left to right for a distance of 1.8m. Althagafi, Richardson and Azevedo found that:

> *It takes over 7 seconds recording 24 frames per a second. So there are 168 frames in 1.8 m. If 1.8 m is divided by seven, the result is 0.26 m, thus 0.26 m is the distance that the camera travels in one second* (2015, p134).

A number of recordings were made, using a Cannon 60D digital camera to capture the images of the display pieces of jewellery. A green background was also required in the studio; in this experiment the green background helped to remove disruption. There is a two-laser beam encounter at a cross-point as a result of merging two laser beams, one from the right and one from the left side of the track. The model, wearing the items of jewellery, was located at this meeting point. A live model was used to wear the jewellery, which included a headband with leather and silver pendant, a silver necklace with chains and a pendant used to accessories garments, as shown in Figure 4.75 below. This technique does not need laser beams for capturing the image compared to holograms, moreover, it does not require a dark room to work in while recording, just a studio with suitable lighting for filming a normal movie, as shown in Figure 4.76. Two selected films were combined together and edited in Final Cut Pro and Motion software.

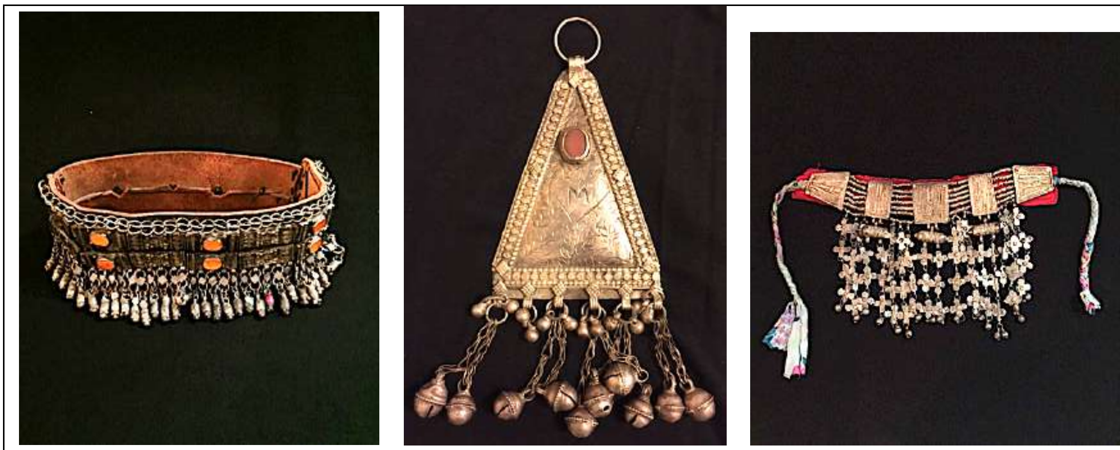


Figure 4.75 Original jewellery items used in this experiment

Figure 4.76 Frames of recorded movies
(Source: Althagafi, Richardson and Azevedo, 2015)

The combined film was printed out as a digital hologram, size: 30cm × 40cm as shown in Figure 4.77.

Figure 4.77 Photograph of a digital hologram, size: 30cm × 40cm
(Source: Author)

The Digital hologram "*should be printed in holopixels each of which being 0.8mm x 0.8mm. Hologram size 300mm x 400mm* (Stanislovas Zacharovas, 2015, by email), containing 375 × 500 holopixels. The movie was produced by Geola© in Lithuania and the resulting hologram was perceived to be a good resolution image due to the pixel average in the frames. This method was able to display the antique jewellery that would have been worn in the context of an historical era.

4.16.3 Digital hologram experiment results

The results of the digital hologram (stereogram) experiment were encouraging; it positively captured the model's movement and jewellery parts in general when videotaped. This method allowed the qualities of the artefact item, such as authenticity and history, to be recorded properly. The stereogram method accepts the capture of the features of the item and the movements of the subject. Even though it did not capture as high-quality resolution as a reflection hologram, it did facilitate the recording of multiple items simultaneously.

There are numerous advantages in conducting experiments using vintage jewellery as a theme. In the process of recording a digital hologram, a model was used to wear the jewellery and several films were produced in order to achieve the best digital result. However, the main limitation of the digital holography method was that it did not capture the delicate details of the jewellery designs in comparison to a Denisyuk reflection hologram. The resolution of the image on a Denisyuk hologram is far greater than a digital hologram.

4.16.4 Conclusion

Using the stereogram method for preserving cultural heritage and display in museums cannot be discounted. Museums have thousands of ancient items that may not be displayed as a result of not having enough space for them to be displayed or if the object is too large, such as archaeological artefacts like walls such as the Mada'in Saleh in the KSA (Figure 4.78 below).

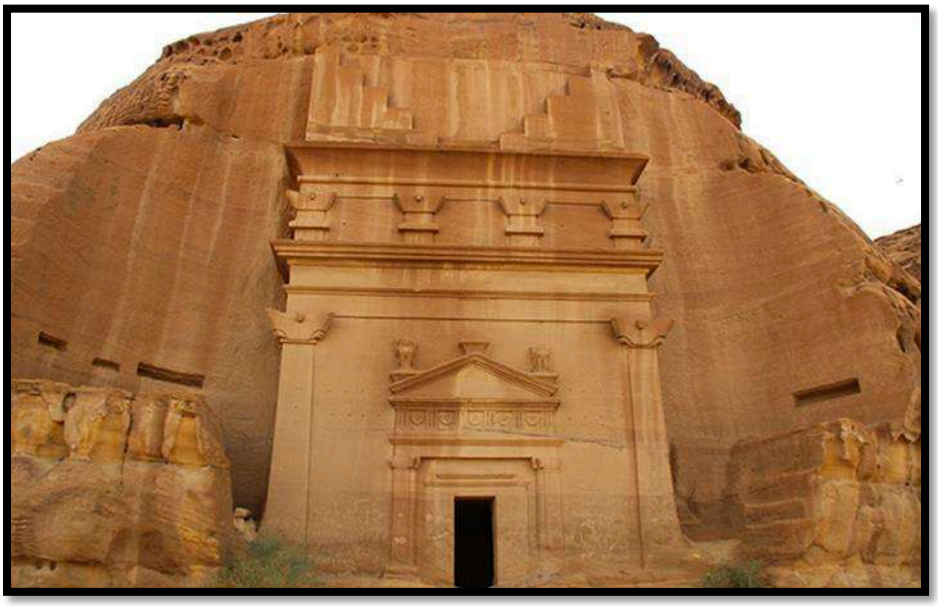


Figure 4.78 Mada'in Saleh tomb from the Nabatean era.
Photographer: Amaria Rebiai
(WECHE, J. 2015)

However, digital holography could be a solution to preserving these valuable items for display in other countries to show different heritages. Moreover, digital holograms offer a suitable solution to saving recorded items securely and displaying them in an attractive manner.

4.17 Lenticular experiment

Lenticular is a method that converts a 2D image to a 3D image, showing a 3D image on a flat plastic sheet. This method has been explained in Chapter 2, section 2.14.2 Lenticulars (auto-stereoscopic). Due to its comparatively lower cost, effort and time, the lenticular array technique was experimented with as a possible means of displaying Arabian Peninsula cultural heritage jewellery. Figure 4.80 to Figure 4.81 show the lenticular images from different angles.

Figure 4.79 A Photograph of lenticular experiment
(Source: Author)

Figure 4.80 A Photograph of lenticular experiment
(Photographed by Jeremy Collingwood)

4.17.1 Lenticular experiment set-up

Twenty-two frames of a movie were recorded in the studio (the same films that were used in the digital hologram experiment). The films were exported to Photoshop software for preparation and to interlace multiple images for positioning behind the lens. In this experiment, slices from four different images were each placed in order behind the lens. The lens then focused on each different frame as the lens or spectators move (from left to right or the opposite side). Next, the frames were exported to lenticular software. The resolution of a lenticular image is a direct (instant) result of the number of lenses per inch multiplied by the number of frames used. In this experiment the lenticular was printed at 90 LPI (lenses per inch). This number of LPI matched the number of lenses in each inch according to the printer (particular lenticular printer) used in this experiment. So, in this experiment, 22 frames were used at 90 LPI, resulting in a 1980 DPI file.

4.17.2 Result and analysis

The lenticular method is considered to be reasonable to produce as it does not consume much time and effort and is low cost. The material is reasonably priced and this technique shows a three-dimensional image that delivers reasonable results (see Figure 4.80 and Figure 4.81).

Figure 4.81 Photographs of lenticular image
(Source: Author)

4.17.3 Conclusion

To conclude, it would be instructive to produce a catalogue of ancient artefacts of jewellery and items of Arabian Peninsula cultural heritage to be displayed. Unfortunately, the researcher could not produce the catalogue due to time constraints. Due to the lenticular's reasonable cost as well as its being a convenient technique, its materials could be offered easily. Therefore, the researcher would recommend conducting a number of experiments expressly for the Saudi environment and its cultural heritage items. Transport and/or travel for this kind of artwork product (3D image) between countries could be considered easy and convenient due to its light weight and convenience in handling. However, a major drawback of lenticular array is that it produces an obscured image, which is caused by the interference of the stereoscopic images formed at the junction of the two-lens column. Although lenticulars produce a 3D effect, the resulting image is not good quality. Displaying images of museum artefacts requires high resolution with, ideally, a three-dimensional feature.

4.18 Photogram

The photogram technique is also known as camera-less. This technique captures the shadow of light on the object. The reason behind investigating the photogram method was because the principle of it is similar to that of the hologram method. In these experiments the researcher used ILFORD© Ltd Black & White monochrome photographic paper.

4.18.1 Photogram experiment

Different materials were experimented with to discover the reflection of light, for example, crystals, lace, sequins, etc. Examples of photograms can be viewed in Figure 4.82 to Figure 4.84. As noted in Figures 4.82 - 4.83, the light level in the device was the same, while in Figure 4.84 the light level was reduced to make the photogram darker. After capturing the photograms in the darkroom, they were taken into the developing room to be developed (see Figure 4.85).

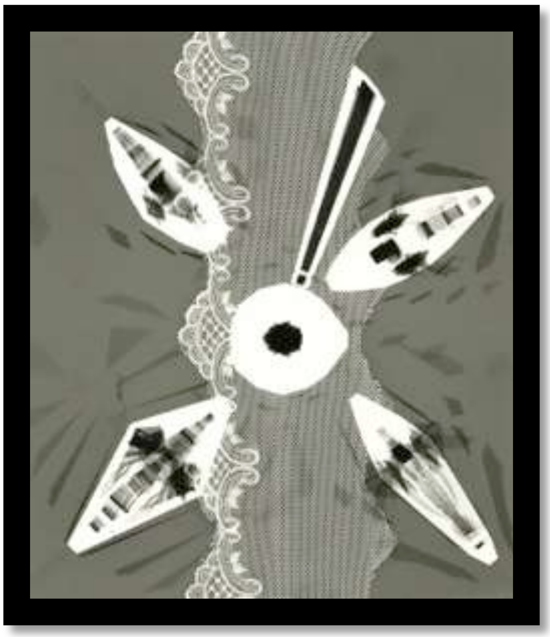


Figure 4.82 Photogram of different materials	**Figure 4.83 Photogram of crystals**

(Source: Author)

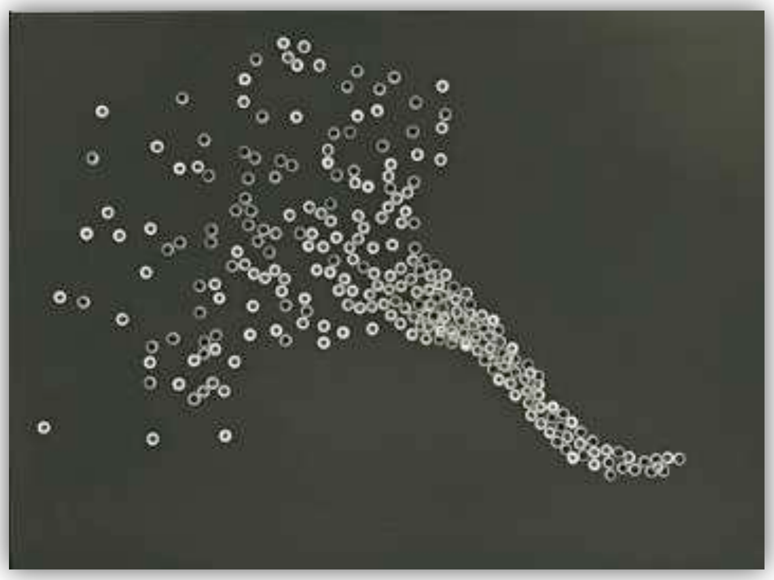


Figure 4.84 Photogram of sequins
(Source: Author)

Figure 4.85 Dark room, developing area of photogram
(Source: Author)

4.18.2 Results and analysis

It was a good experience to take photos of objects without a camera. The reflection of light could be seen through different objects and materials. The idea of a photogram is similar to the hologram technique, in that both of these techniques must be produced in a darkened room using sensitive materials (sensitive paper for the photogram; sensitive glass or film for the holograms). Both methods used similar substances at the developing stage (black and white) in the darkroom. The difference is that a laser beam is used to record holograms, while white light is used to capture the photograms.

4.18.3 Conclusion

Photogram, as a technique, shows the effect of light on a variety of materials. It shows beautiful reflections on the sensitive paper after the developing process in the darkroom. However, the photogram technique does not produce a 3D image.

4.19 Anaglyph

In this experiment the researcher captured photos of different areas of various scenes in the UK, such as a chandelier in the main entrance of Victoria and Albert Museum in London and attempted to produce an anaglyph image.

4.19.1 Anaglyph experiment set-up

The primary tool needed to produce an anaglyph image is a camera to capture two photos of a scene. Both images were exported to Adobe Photoshop and then the right and left images were imposed onto a single image in the software. Glasses with lenses of differing colours (the right lens coloured red and the left coloured cyan) must be worn to view the 3D effect of the image produced (see Figure 2.12 and Figure 2.14).

4.19.2 Anaglyph results

The result of an anaglyph must be seen by using (cyan and red) glasses. However, this research experiment could not be considered as producing successful results as the researcher could not capture two good photos with an acceptable distance between the two images. The collected images had considerable information and detail in the background of the images; the researcher could not control the focus, which resulted in noise and disruption in specific parts of the anaglyph (composed images), see Figure 4.86 to Figure 4.89. The results of the researcher's images in this experiment were unsuitable and uncomfortable when viewing the anaglyph.

Figure 4.86 Anaglyph experiment
(Source: Author)

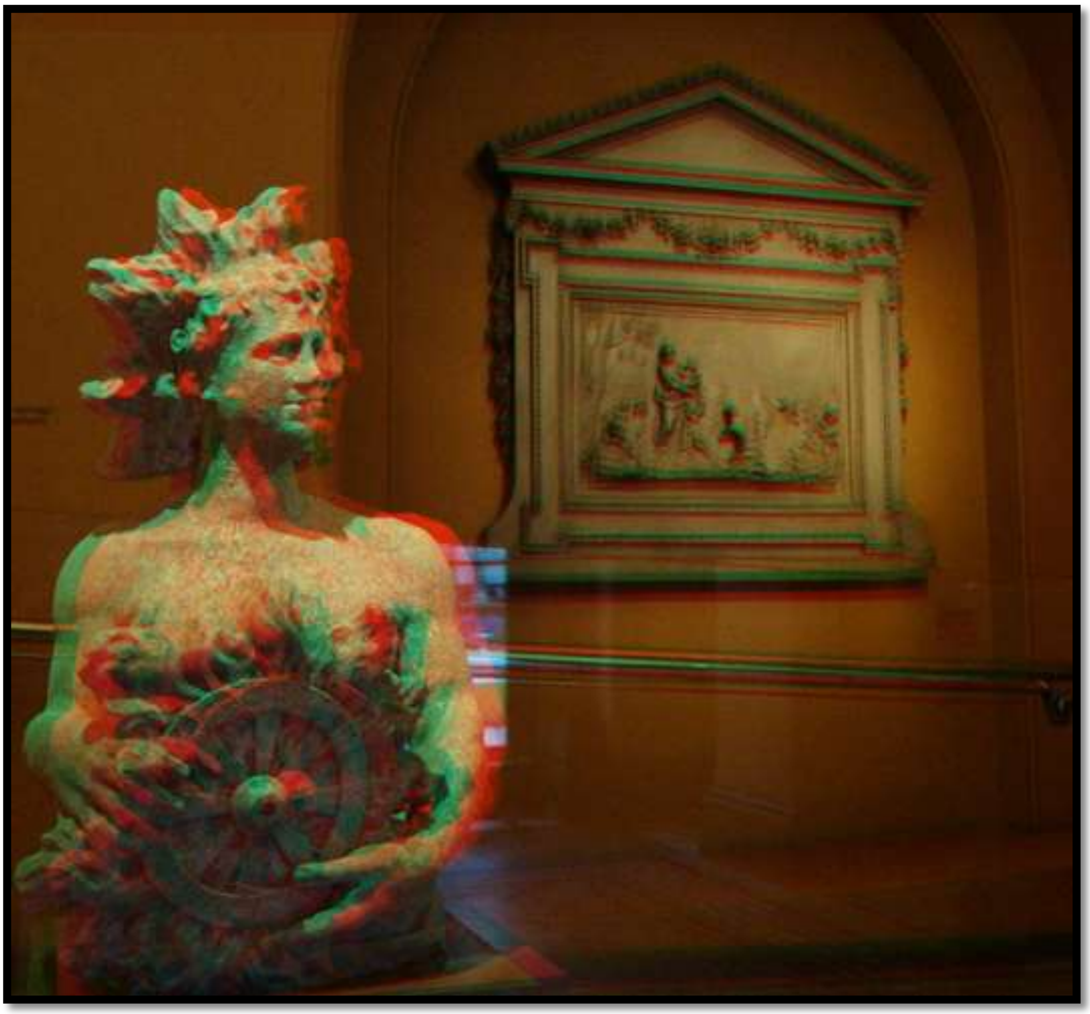


Figure 4.87 Anaglyph experiment
(Source: Author)

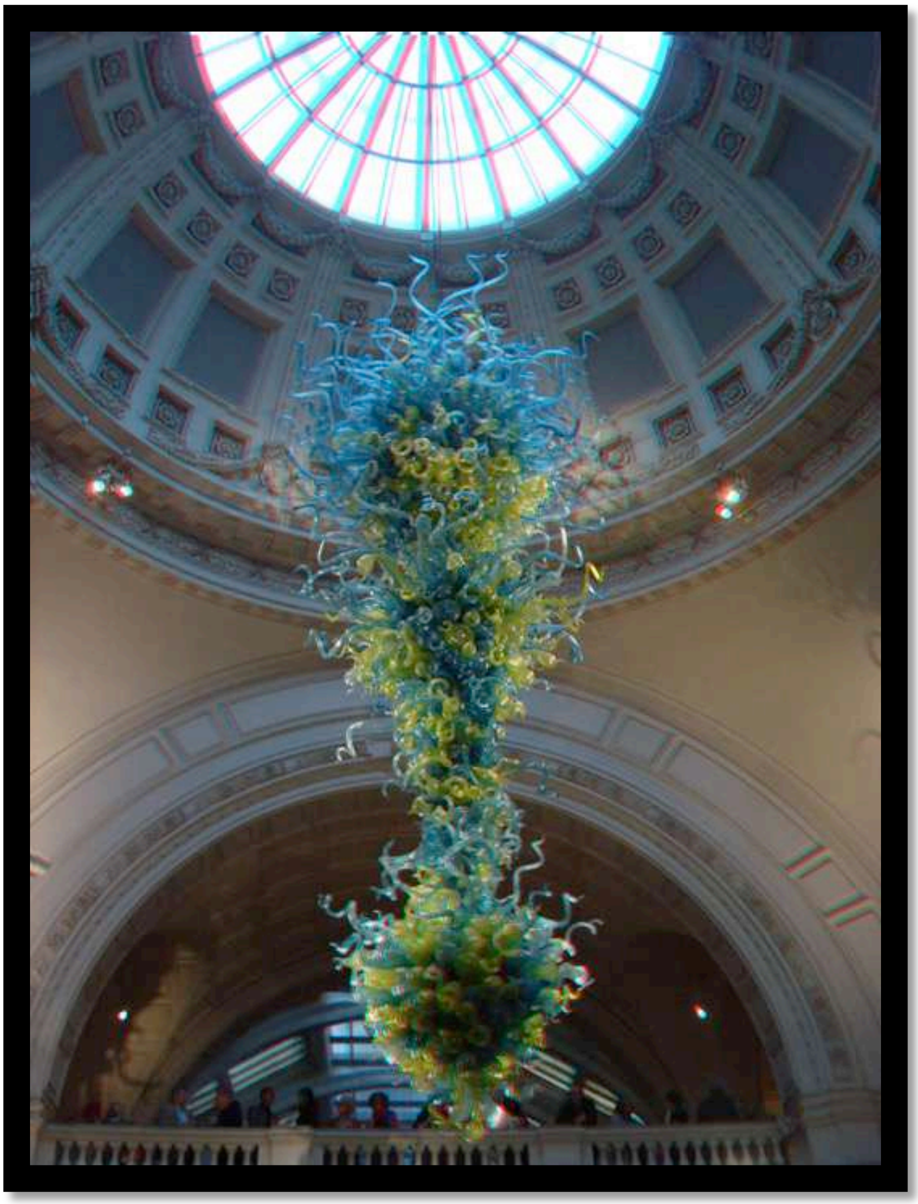


Figure 4.88 Chandelier in the Victoria and Albert Museum, London
(Source: Author)

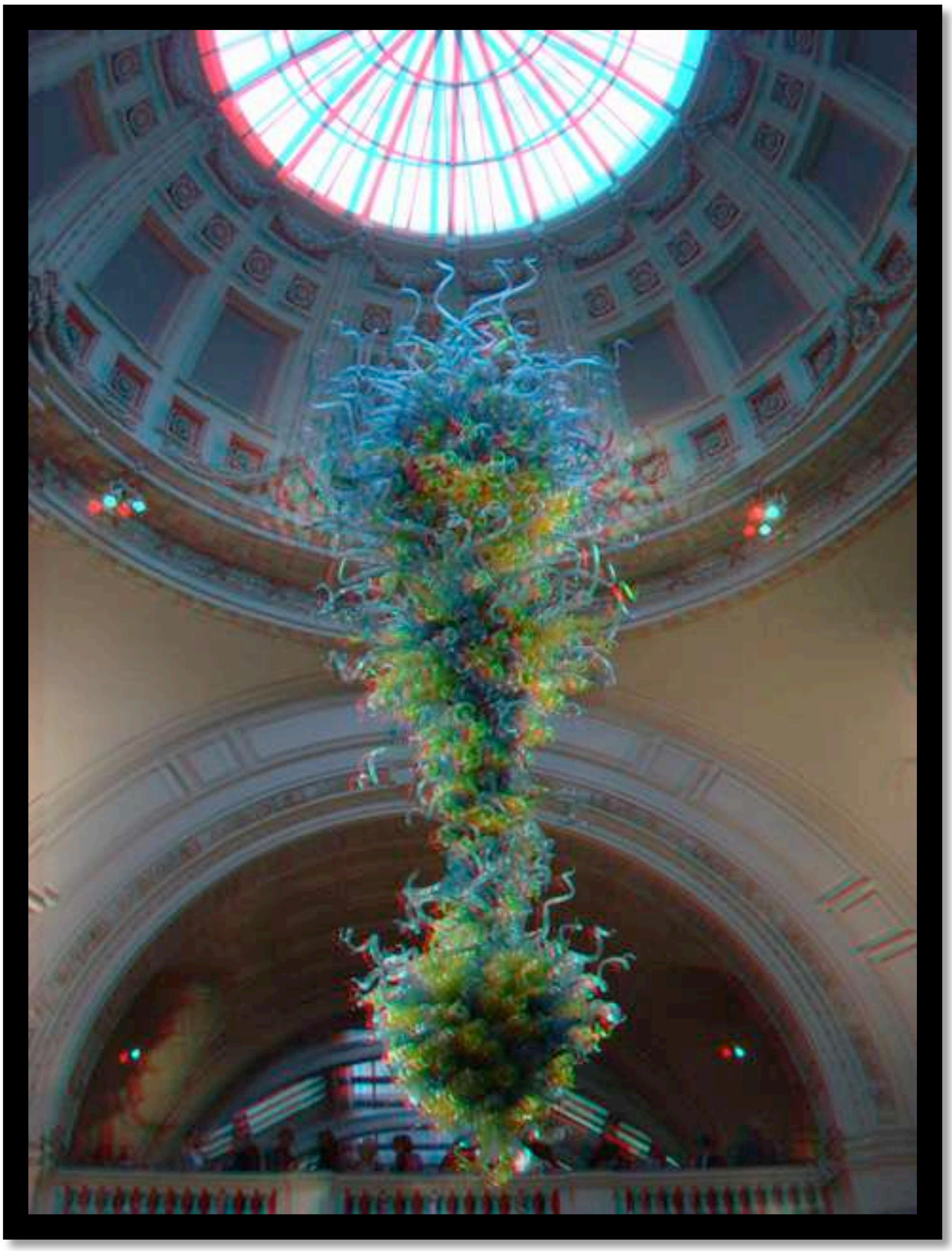


Figure 4.89 Anaglyph experiment of chandelier in the Victoria and Albert Museum, London
(Source: Author)

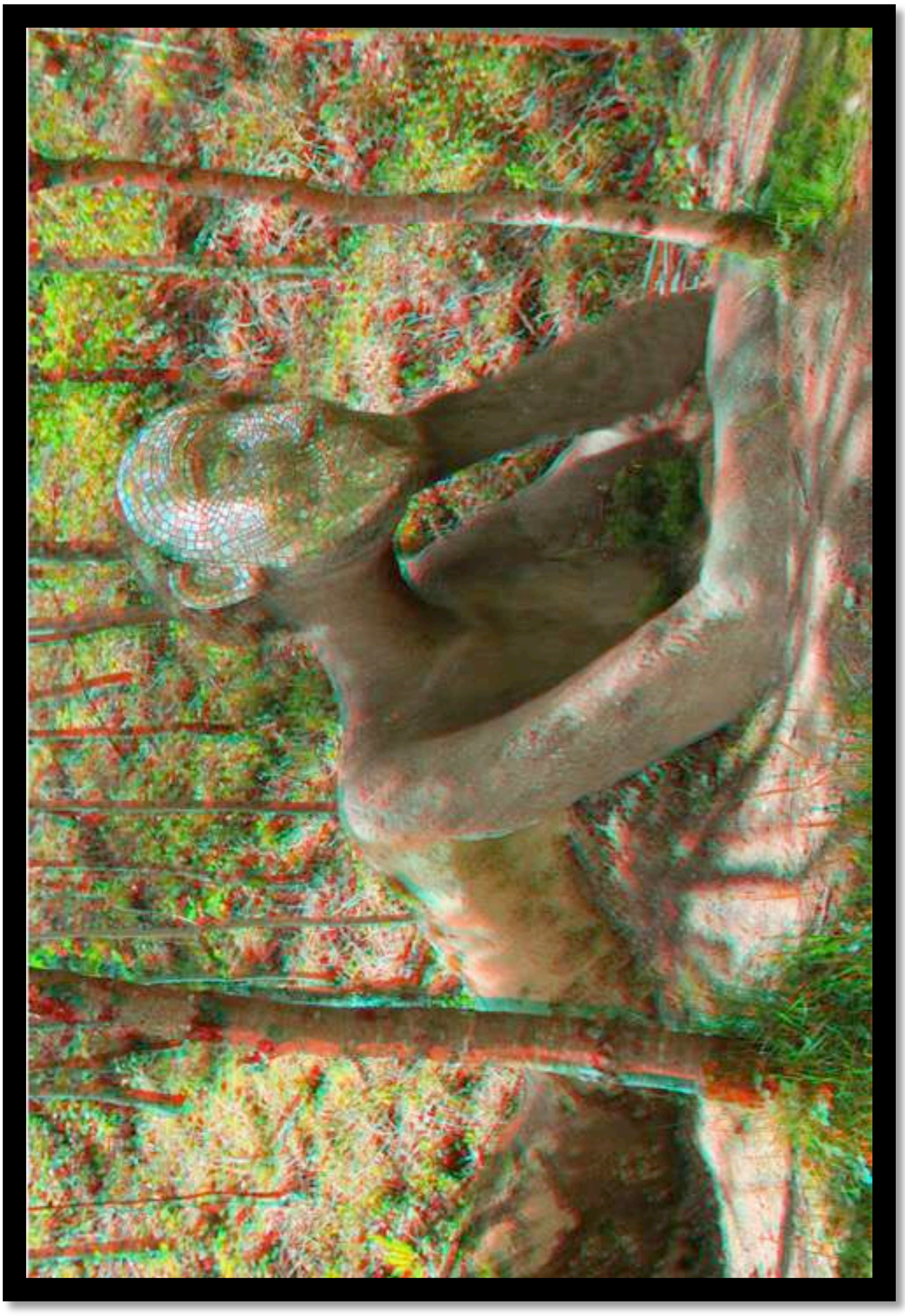


Figure 4.90 Anaglyph experiment of sculpture in the Cornwall area
(Source: Author)

4.19.3 Anaglyph conclusion

The anaglyph technique is considered a good method to produce a 3D image that could be displayed in museums. However, there is no comparison between the result of a reflection hologram and anaglyph, as the first method provides the viewer the minute details of the object that cannot be provided by the anaglyph. Moreover, viewing the anaglyph requires special glasses, while the viewer can see the hologram with the naked eye. So, holographic techniques are more suitable to be displayed in museums and have led the researcher to concentrate on producing holograms rather than anaglyphs.

4.20 Conclusion

This chapter has presented the experimental research journey, which started with the idea of displaying transmission holograms into mist. This resulted in the researcher's changing direction to investigating 3D imaging and holograms for displaying of artefacts in museums. This chapter has presented a number of different mediums and a number of experiments that led to the conclusion that the holographic medium is most suitable for displaying Saudi Peninsula heritage artefacts. Comparisons between the results of the differing holographic techniques, digital hologram, lenticular and anaglyph methods revealed the limitations of these techniques for the reproduction of images, which include lack of quality and focus and loss of fine details of the items, as well as a loss of feeling of depth. In contrast, the reflection hologram showed the same features as the original items and as such holography's importance was attested. These experiments enabled the researcher to consider the reflection hologram as the most appropriate technique for displaying Saudi Peninsula heritage items in museums.

Chapter 5

CHAPTER 5
Results and Findings

5.1 Introduction

This section presents the results of the analysis of the data collected through the distribution of survey questionnaires and interviews with participants. In the next section (5.2), the results collected from the survey questionnaire will be presented and in section (5.3) the interview results are discussed.

Table 5.1 Data collection methods and participant numbers

Types of data	**Quantitative**	**Qualitative**
Questionnaires	241 Participants	
Interview		9 participants (museum director, 1 museum owner and hall curators)

5.2 Survey analysis

In this empirical study data collected was analysed to shed light on the research matter and to find answers to the research question. To measure the variation of the degree of difference between each participant's response to each statement item, a 5-point Likert scale was used. The questionnaire form can be found in Appendix A.

The survey consisted of two sections. Section A contained the 18 main survey statements, while questions in Section B addressed the participant's background and demographic details which included gender, age group, education level, position and whether the participant had seen holograms before. A total of 400 questionnaires were distributed; 34 were discarded because they were incomplete and 83 were not returned to the researcher. The final number of valid questionnaires was 241, which were then analysed.

5.3 Questionnaire results

Organising and categorising the survey results was an important stage in this research. The results were presented in visual form such as pie charts and graphs, which helped the researcher show how the answers measured up against each another. Furthermore, these formats were intended to help the reader better to understand and appreciate the results.

5.4 Demographic profile of the survey participants

Section B of the questionnaire asked questions about gender, age group, speciality, nationality and how many times each participant had visited a museum. The surveyed participants consisted of 145 (60%) female and 96 (40%) male, as shown in Figure 5.1. The reason behind asking about the background of the participants was to find out if there was any relationship between the respondents and their background; age did not relate significantly.

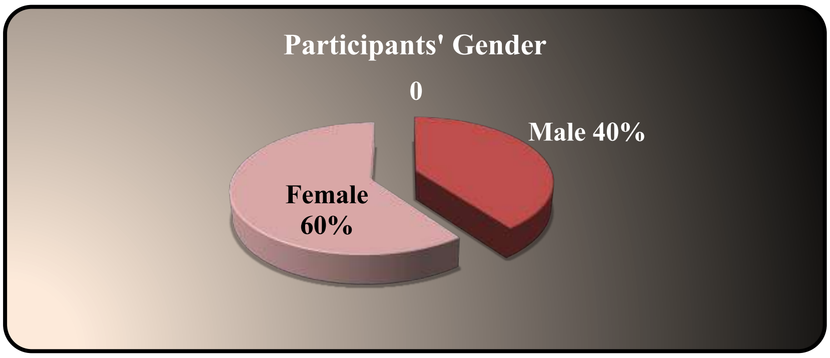


Figure 5.1 Participants' gender

Of the 241 participants 212 were Saudi nationals and 29 non-Saudi nationals, shown in Figure 5.2.

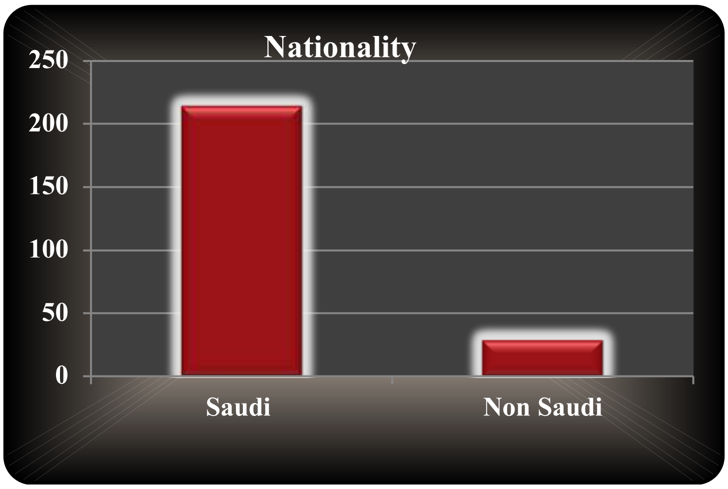


Figure 5.2 Participants' nationality

The ages of the participants were across the age ranges identified in Table 5.2, which also shows the percentage in each age range.

Table 5.2 Participants' age profile

Age Range	Number of participants	Percentage
18–25	45	19%
26–35	73	30%
36–45	25	10%
46–55	28	12%
56–65	30	12%
66–75	11	5%
Unknown	29	12%

The chart in Figure 5.3 shows the number of participants in each age range, with 30% (73) being in the 26–35 and 19% (45) in the 18–25 age range, indicating that the sample was almost equally split between under 35 years of age and over 35.

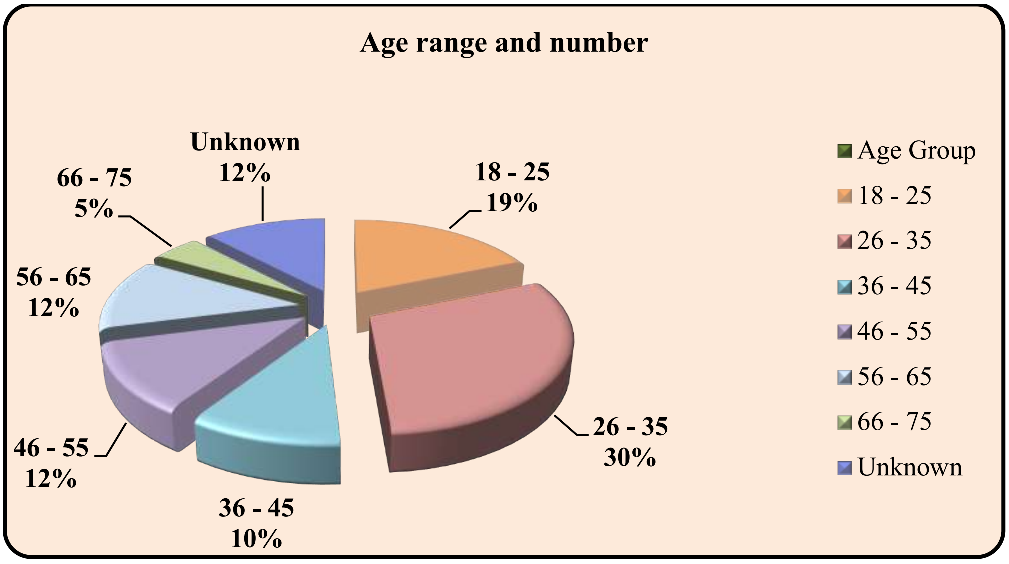


Figure 5.3 Distribution of participants in age ranges

Figure 5.4 below shows the number of times the participants had visited a museum in the previous 12 months. Over one-third of the participants had not visited a museum in the 12 months prior to completing the questionnaire.

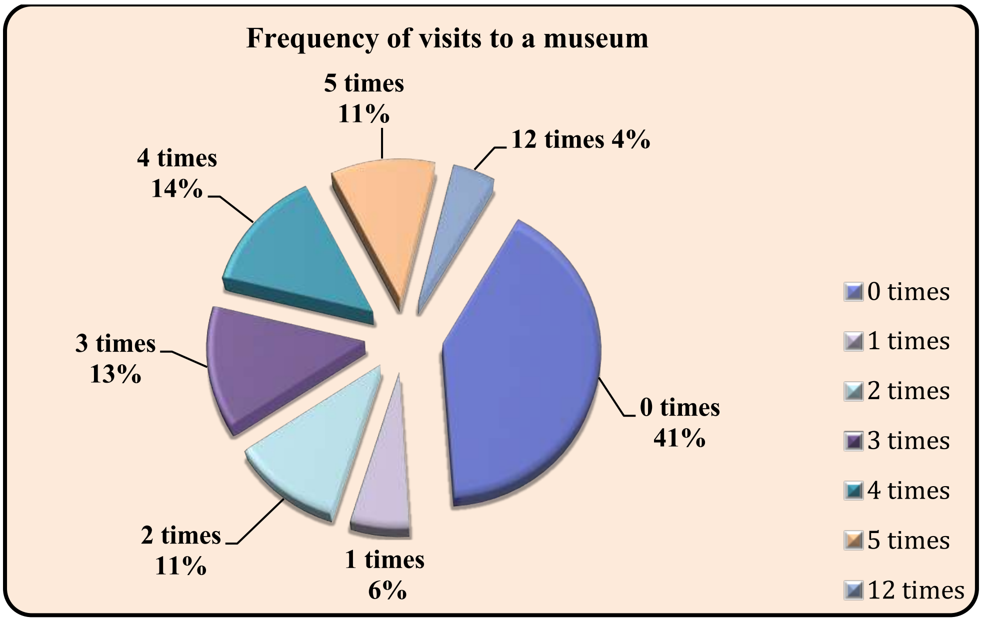


Figure 5.4 Visits to a museum in the last 12 months

The participants had a variety of specialities namely: art, design, fine art, education/teaching, medicine, economics, engineering, science/maths, linguistics, IT, management, pilot and sport.

Item 19 aimed to discover how many of the participants had seen a hologram previously, to ascertain their understanding of the technology. Of those surveyed, 88% (212 participants) stated that they had not seen a hologram previously, while 12% (29 participants) stated that they had. Most of the participants who had seen holograms before were non-Saudi (Figure 5.5 below); however, there were two Saudis who had seen holograms before, although they had been living abroad at the time not in the KSA.

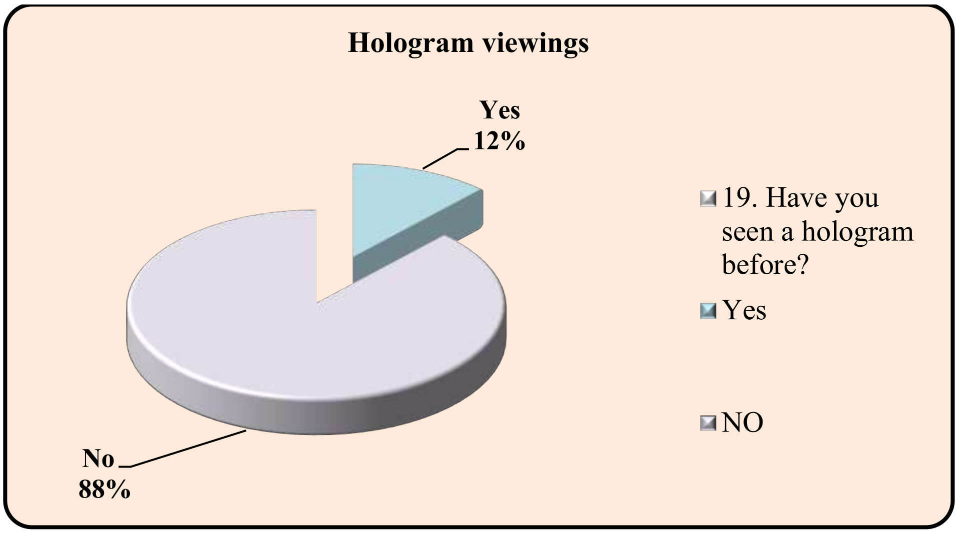


Figure 5.5 Hologram viewing

5.5 Research themes

The next sub-sections present the results under the following themes:

- *Technology and documenting heritage*
- *Original items and hologram comparison*
- *Photograph and hologram comparison*
- *Hologram preference reasons*

5.5.1 Technology and document heritage

This theme contained three statement items that focused on the value of technology in relation to documenting cultural heritage.

Item 1 sought to find out the participants' views on the following statement: *Holography is a valuable method to document heritage*. The results are shown in Figure 5.6 below. Of the sample of 241 participants, 93% (57% strongly agree; 36% agree) agreed that holography is a valuable method with which to document heritage. This was a very encouraging view, especially as only 12% (29 participants) had previously seen a hologram.

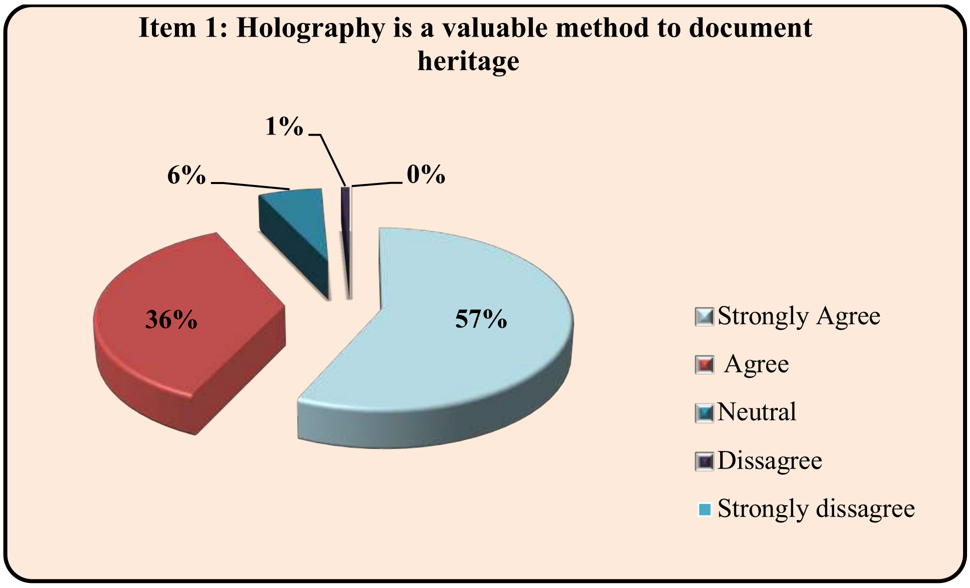


Figure 5.6 Value of holography

Item 16 stated: *I do not think holography is a good method to document heritage*, which states the opposite to **Item 1.** Of the sample 89% disagreed (57% strongly disagreed; 32% disagreed). The results are shown in Figure 5.7 below.

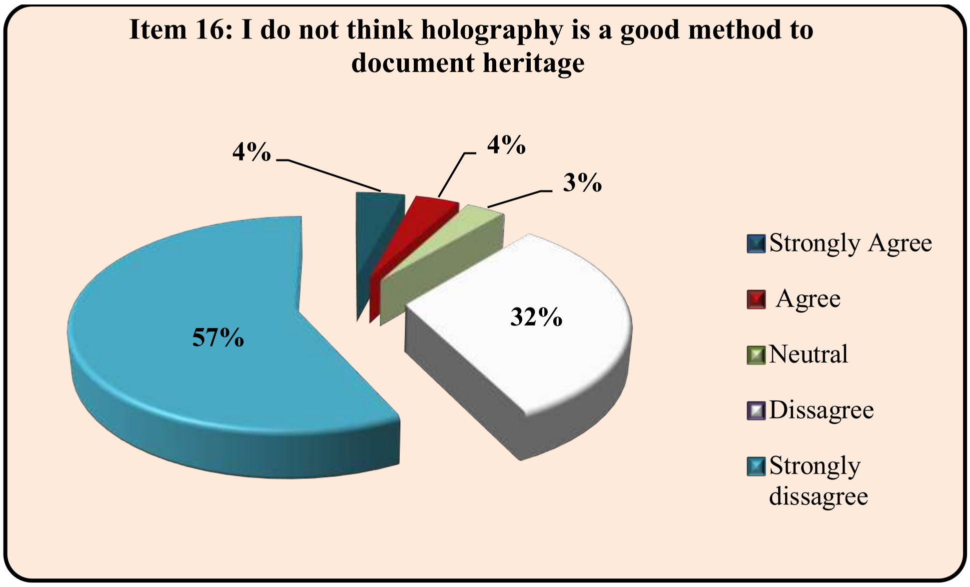


Figure 5.7 Opposite opinion to Item 1

These two statement items were presented in order to provide a crosscheck of the participants' responses regarding the value of the use of holography. The two graphs, in Figure 5.8 below, show the responses to **Item 1** and those of the negative statement **Item 16**. That the two graphs' curves are almost reflectively symmetrical indicates that the participants' understanding of both statement items was clear and consistent. Their responses strongly suggest that there is considered value in the use of holography to document heritage.

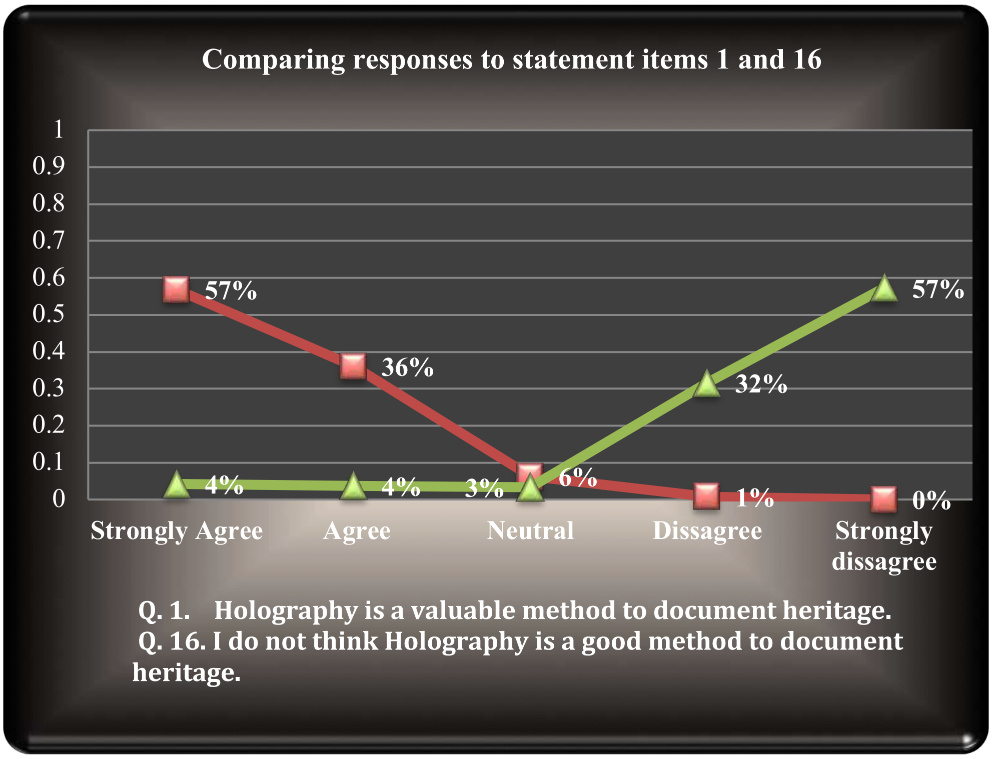


Figure 5.8 Comparison between Items 1 and 16

The purpose of **Item 2**, *Technology can keep our heritage from being lost (and our memories)*, sought to identify the participants' consideration of the use of technology to preserve heritage. Figure 5.9 below, shows that a very high percentage of the participants (68% strongly agree; 29% agree) had positive views about the use of technology to preserve heritage items. They also considered that technology can be used to preserve memories, which links to the notion of heritage artefacts stimulating people's memories.

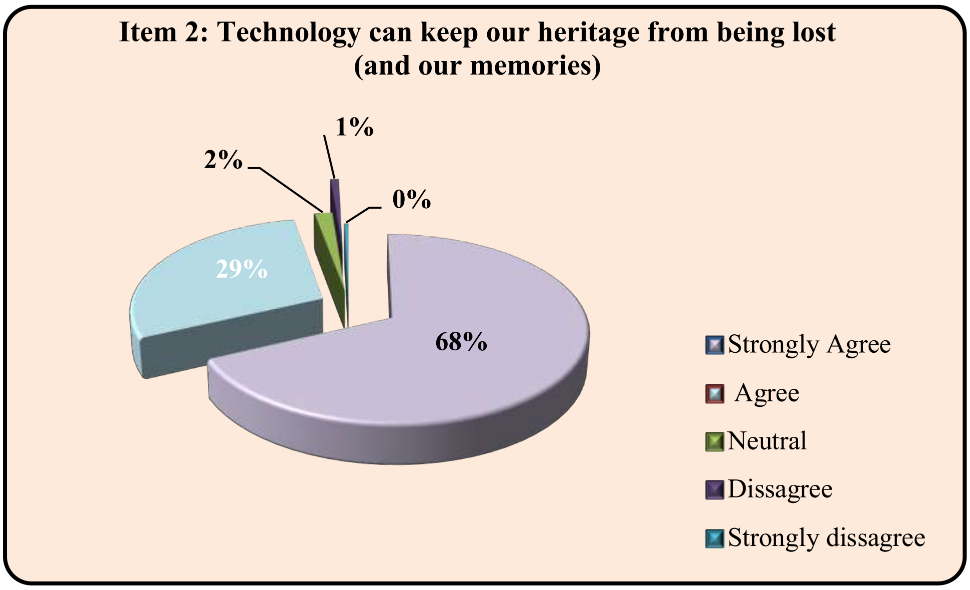


Figure 5.9 Using technology to preserve heritage

Overall, the participants' views about using technology to preserve cultural heritage shows that there was almost total support for the application of technology (holography) to be used to do this. These views are positive and encouraging.

5.5.2 Original item and hologram comparison

This theme contained seven statement items that related to the participants' attitudes regarding original items and compared to technology (holography) items.

Item 6 considered that *Even though I have seen a hologram, I prefer the original items because I like to touch them.* The results for **Item 6**, shown Figure 5.10 below, indicate that almost two-thirds of the participants strongly agreed or agreed that they preferred having the original item, instead of a hologram. This shows perhaps that there is was a connection between the participants' experiences with holography and reverting to their experience of seeing the original item, therefore their default position was a preference for viewing the original artefact directly.

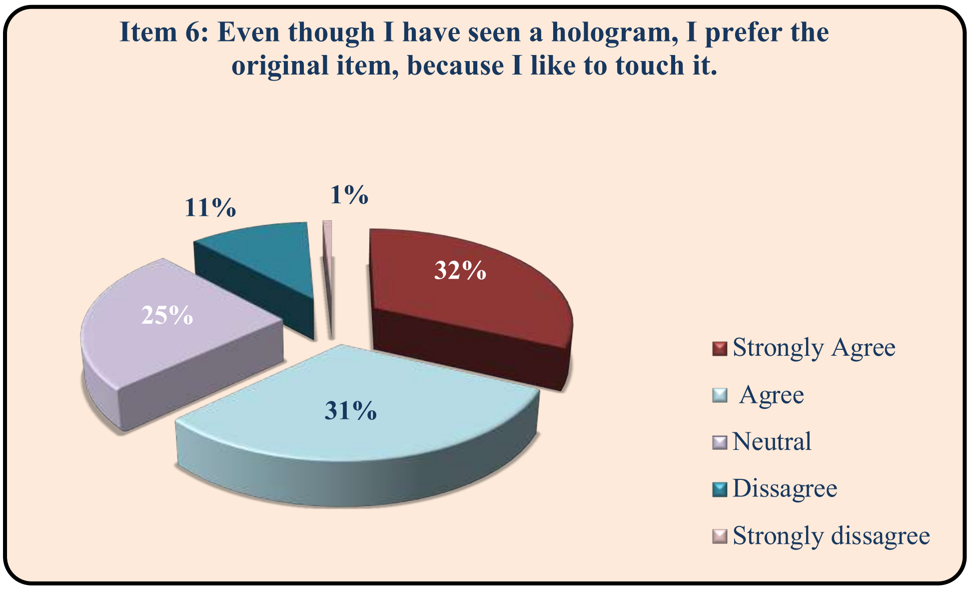


Figure 5.10 Preference for original item so that it can be touched

Item 7, *I prefer holograms only when the original item is not available,* indicated a positive acceptance of both the hologram and original item. The results, shown in Figure 5.11 below, show high agreement with 86% (57% strongly agree; 29% agree) of the participants' acceptance that a hologram of the original artefact is preferable to not having anything at all. This acceptance supports the idea of bringing holographic representations of artefacts to audiences who would otherwise not be able to view them.

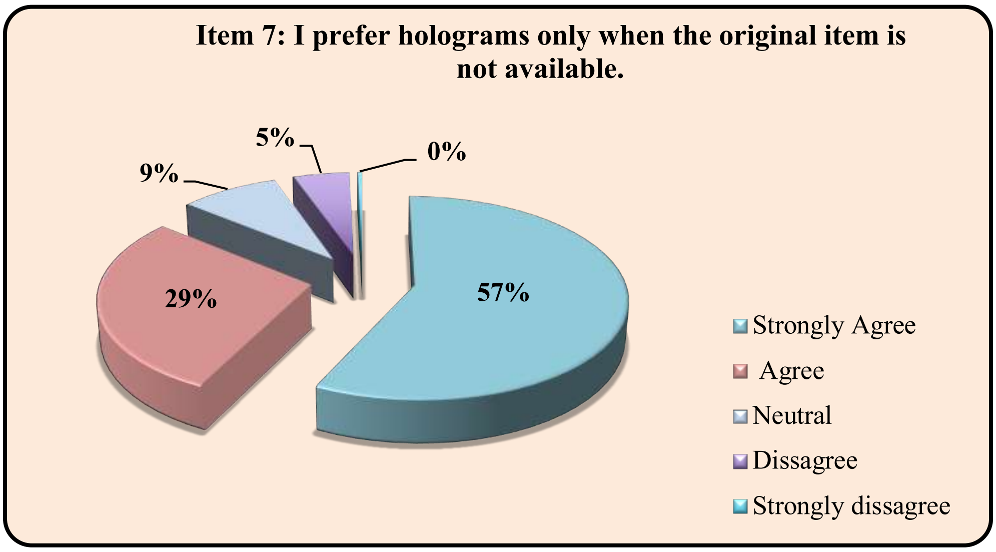


Figure 5.11 Preference for hologram when original item is not available

Item 8 sought to identify if *Holograms can be more interesting than the original items.* As shown in Figure 5.12 below, half of the participants considered that holograms can be more interesting than the original items, a quarter were neutral and a quarter disagreed.

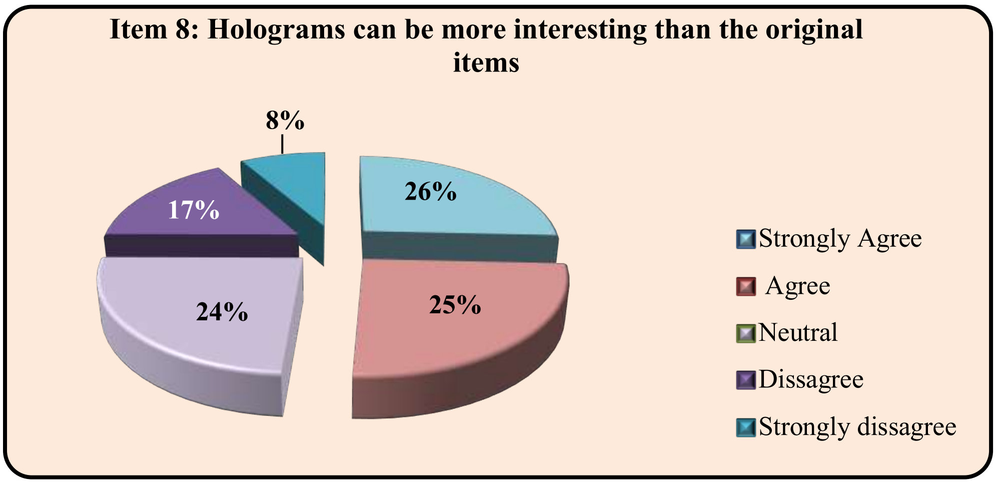


Figure 5.12 Holograms can be more interesting than the original items

The next two statement items (11, 12) offer some insight into the view as to why the participants considered that holograms can be more interesting than the original item. These are presented and discussed next.

Item 11: *It is easy to view heritage artefacts recorded on a hologram, when I am searching for traditional items.* Figure 5.13 below shows the participants' awareness of the hologram medium, which was considered by more than two-thirds of the participants as providing them with an easy method to search for and view artefacts, therefore offering convenience and availability. The implication is that holograms can provide opportunities to view heritage items that might normally be inaccessible for reasons such as being too fragile or too valuable for public display or simply not part of a particular country's heritage.

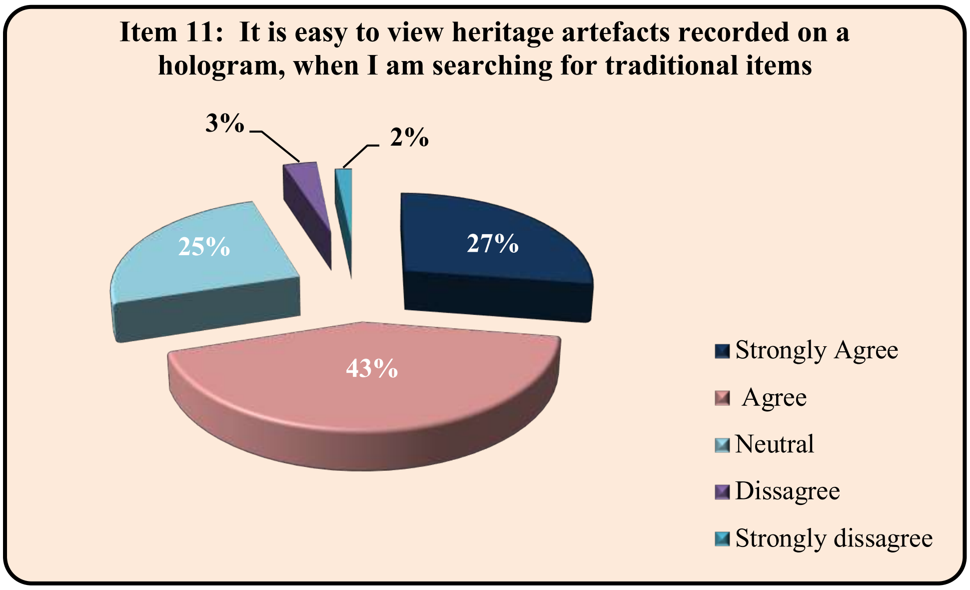


Figure 5.13 Ease of use of viewing when using holograms of heritage artefacts

Item 12: *I prefer holding the hologram of a heritage item because I can fully examine the object, rather than damage the original item.* This statement relates to the preservation and security of the original artefact. Four-fifths of the participants (see Figure 5.14 below) considered the safety of the original artefact, preserving its integrity and not damaging it. The use of a hologram not only offers safety to an original artefact, but also makes it more widely available in the form of multiple copies of the artefact.

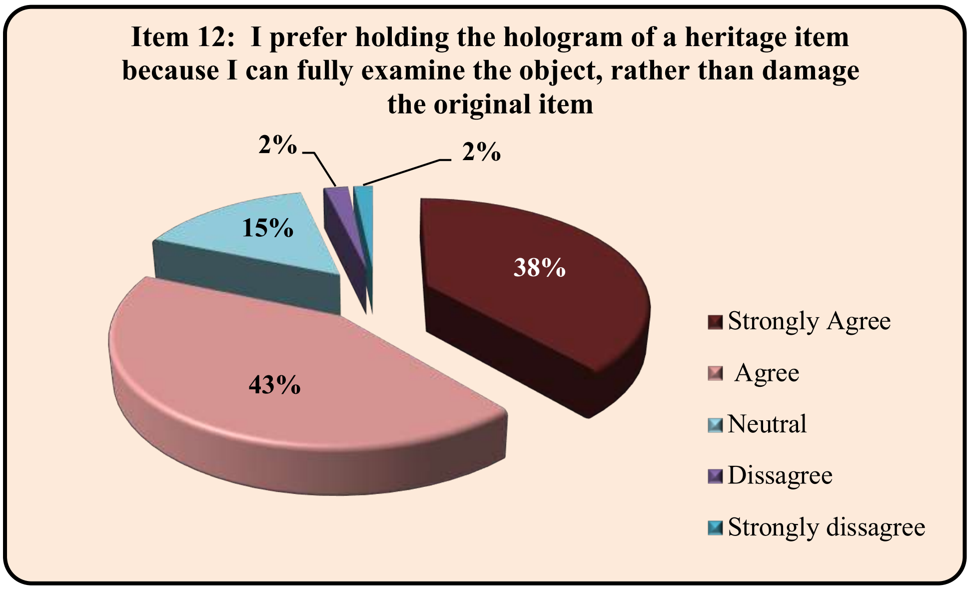


Figure 5.14 Preference for hologram rather than artefact

Item 10: *I prefer seeing traditional items since there is no need for any high tech in order to experience heritage.* This statement sought to identify the participants' views regarding the use of technology to support their museum experience of engaging with their heritage; the results are shown in Figure 5.15 below. Responses to this item statement showed that one-third of the participants were neutral to the statement. However, almost half considered that they would prefer to experience their heritage through the use of technology, while less than a quarter would prefer experiencing their heritage by seeing original items in museums. There is a connection between this item and Item 9, which is discussed next.

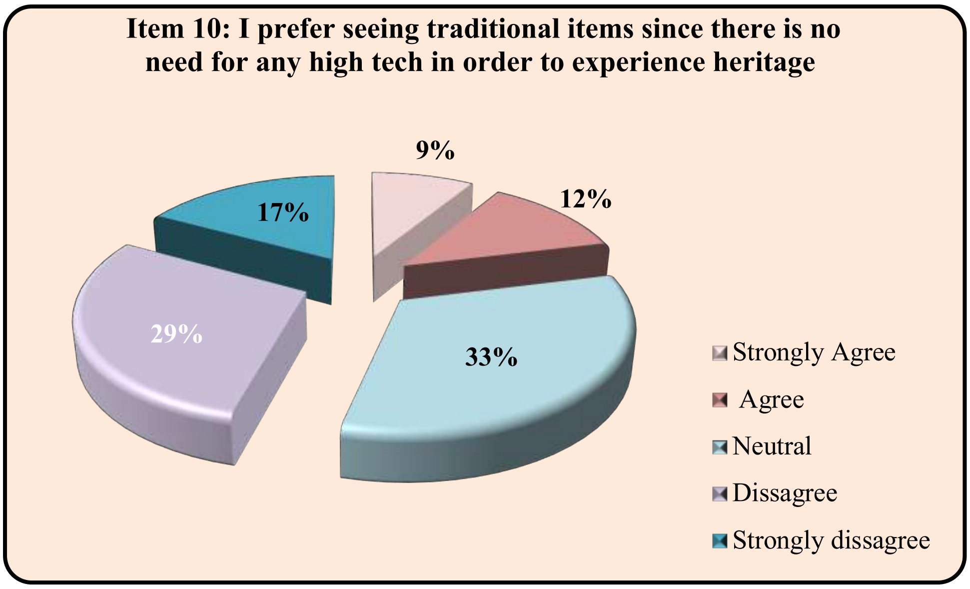


Figure 5.15 Experiencing heritage via hologram technology

Item 9: *I am a fan of technology but prefer seeing/touching real items.* While this item identified that there was support among the participants for the holographic method, more than three-quarters (76%) (Figure 5.16 below) who either strongly agreed or agreed preferred seeing or touching real items, even though they were fans of technology. This result, however, should be considered in conjunction with **Item 12** regarding the safety and preservation of the original artefacts.

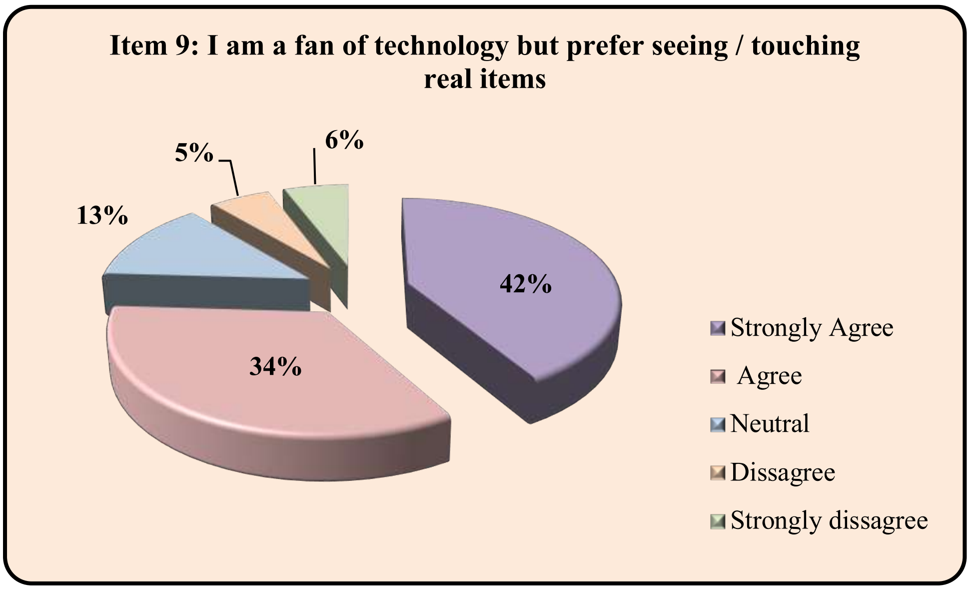


Figure 5.16 Preference for technology or touch

5.5.3 Photograph and hologram comparison

This theme contained three statement items that focused on the preservation and presentation of heritage artefacts. As these statement items relate to each other quite closely their results are presented and discussed together.

Item 4: *I think photographing of heritage items is an adequate method to save it from being lost.* Over three-quarters of the participants' responses to this statement showed agreement that photography is an adequate technique to record and preserve artefacts, with 44% strongly agreeing with it (Figure 5.17 below). The next item, however, **Item 3**, *When I want to see heritage items reproduced, I prefer photographic images (2D*) (Figure 5.18 below), revealed an almost equal split among agreement, disagreement and neutrality.

Item 5, *A 3D hologram provides more information than a 2D photograph*, explored the participants' views about the comparative value of photographs and holograms. Among the participants, even though photography was considered an adequate method to record and present an artefact, there was no discernible preference; 90% of the participants considered that a hologram provided more information than a photograph (Figure 5.19 below).

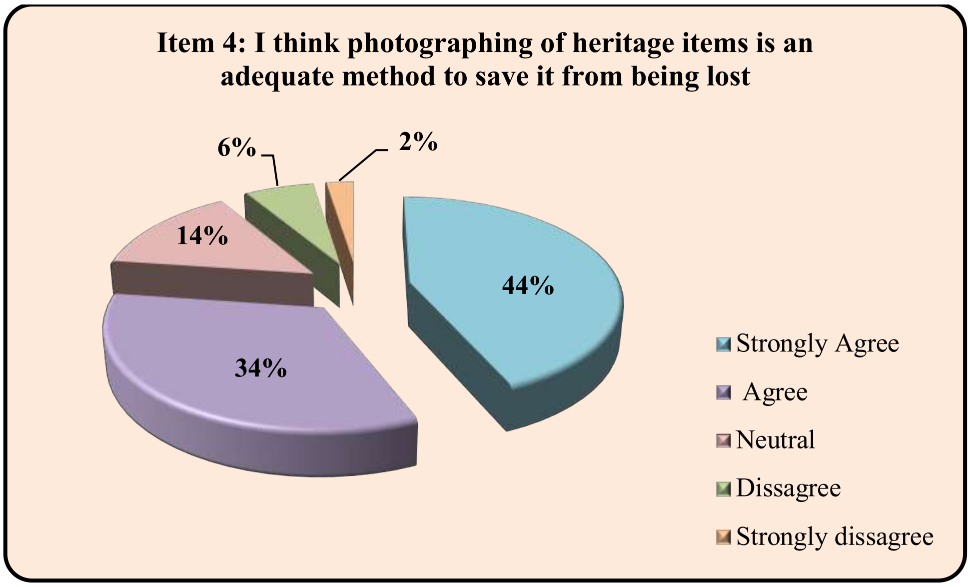


Figure 5.17 Preserving heritage items through photography

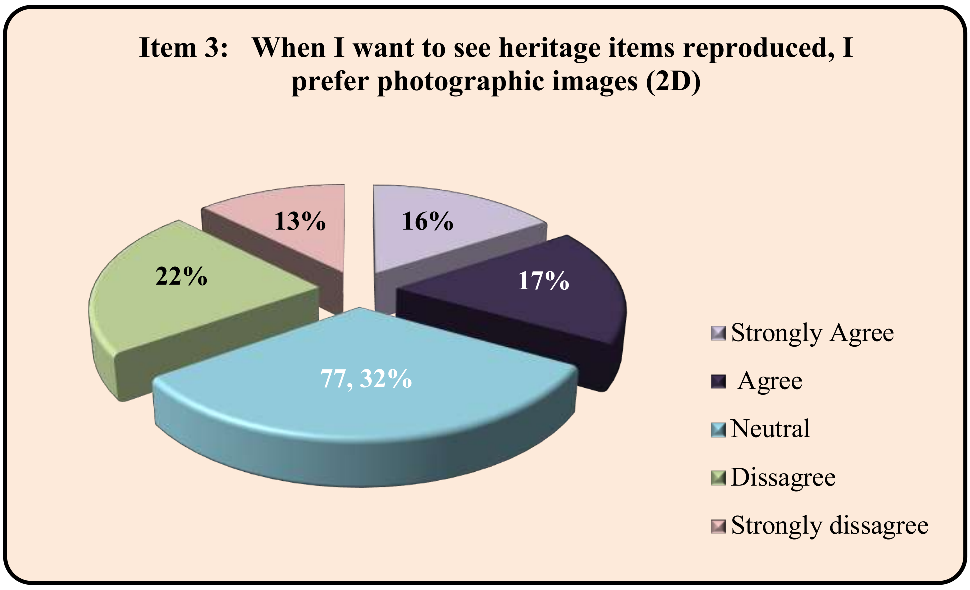


Figure 5.18 Reproduced heritage item image preferences

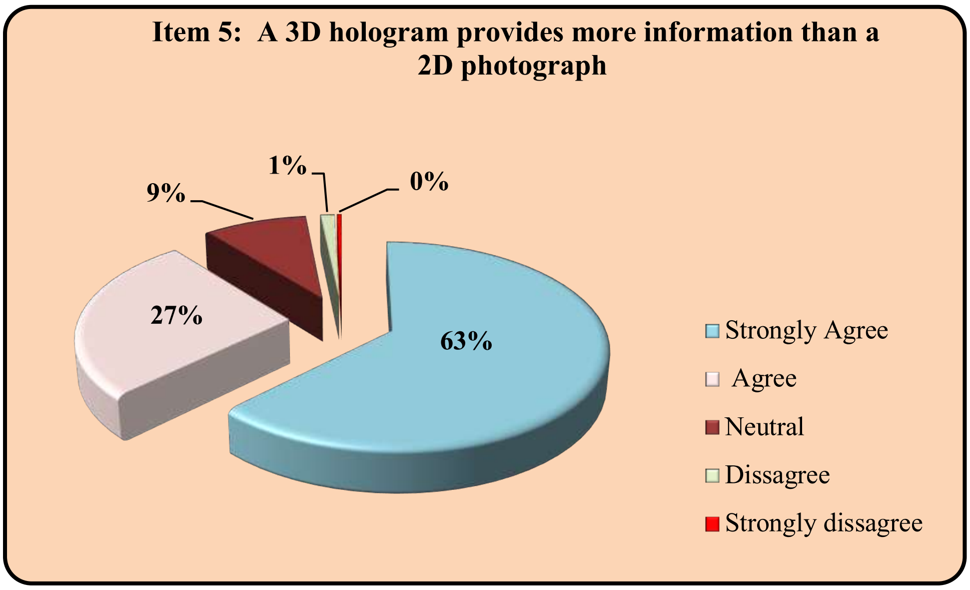


Figure 5.19 Comparison between 3D hologram and 2D photograph

5.5.4 Hologram preference reasons

This theme contained five statement items regarding aspects of holography when applied to heritage artefacts.

Item 13: *I can take my time to see and turn the hologram at different angles when examining it.* Over 80% (see Figure 5.20 below) of the participants strongly agreed or agreed that the hologram provided the opportunity for them to be able to examine the hologram at different angles. The fact that the statement mentioned taking time suggests that it presented itself as offering a more individual and personal experience. This can be of particular value when viewing extremely rare, fragile and priceless artefacts or those that are not accessible, which leads to Item 14.

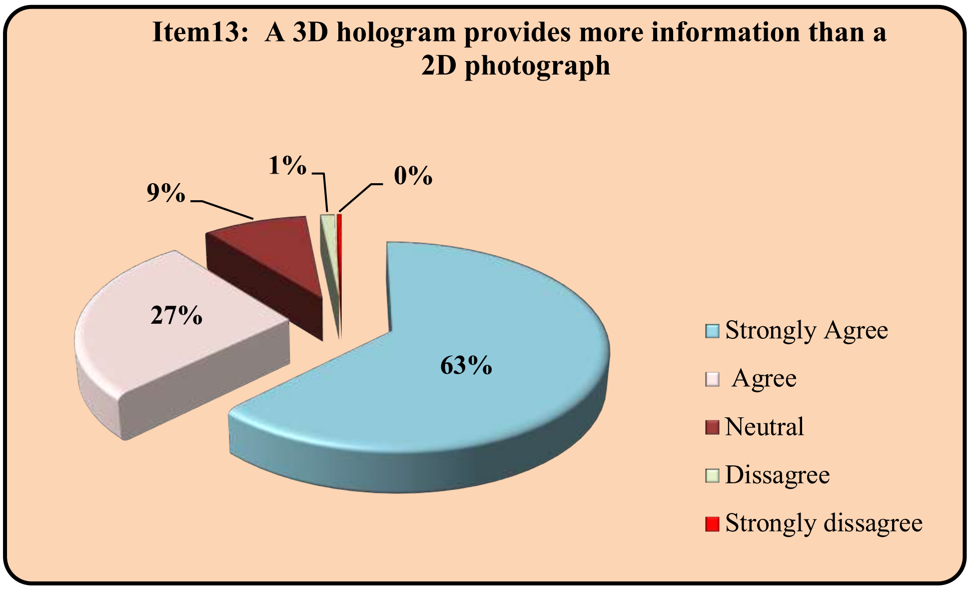


Figure 5.20 Behaviour preference regarding hologram viewing

Item 14: *Holograms will be the best choice only when I am looking at a unique heritage item, such as a priceless object.* The responses to this statement showed that three-quarters (75%) (see Figure 5.21) of the participants considered that holograms are the best choice for viewing unique or priceless objects.

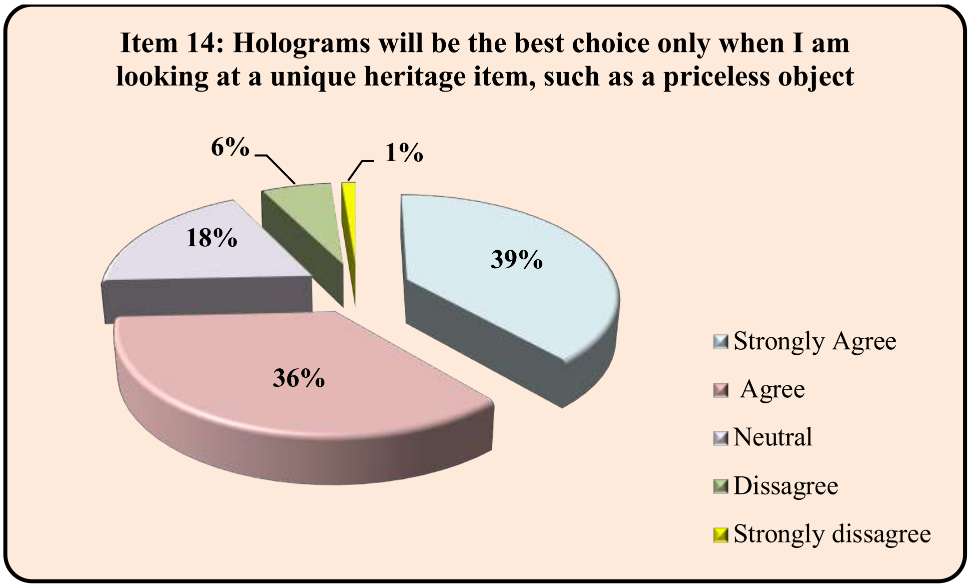


Figure 5.21 Connection between holograms and unique and priceless artefacts

Item 15: *I like looking at holograms because the smallest details can be seen clearly*. The ability of a hologram to present fine detail was appreciated by 79% of the participants (see Figure 5.22). This is significant when considered in relation to **Item 13**, as the individual can have time to appreciate the detail that a hologram can present.

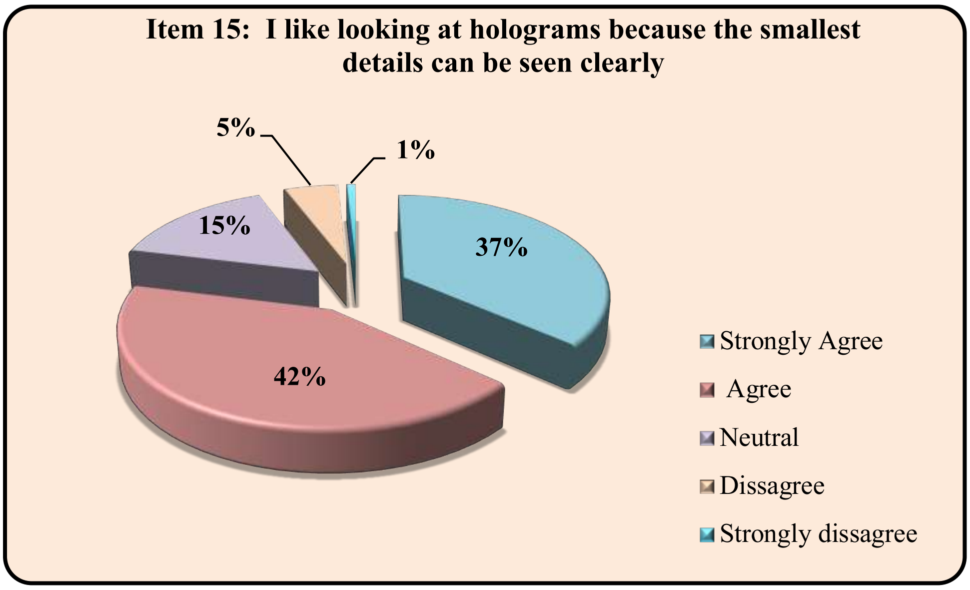


Figure 5.22 Detail in holograms

Item 17: *I like using high technology and digital materials such as software, digital media and 3D*. This statement showed that 78% (see Figure 5.23) of the participants associated holograms with high technology.

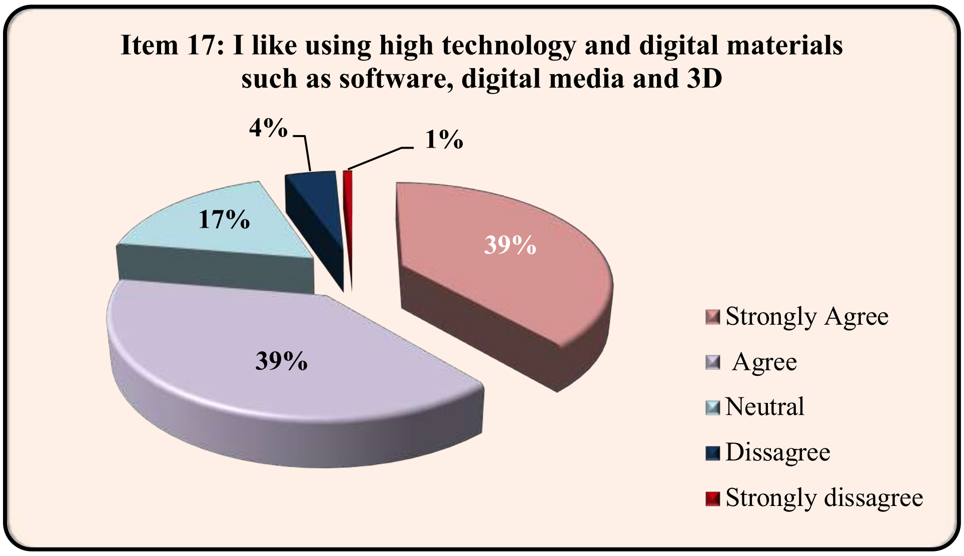


Figure 5.23 Technology use

Item 18: *I would like to see more holograms being used in museums.* The results for this item reflected the participants' attitudes suggested in the other four items in this theme. The fact that holograms can provide a personal experience of fine detail of priceless artefacts by means of new technology was clearly seen by the participants in a positive manner. Almost nine out of ten participants (87%) (see Figure 5.24) positively considered that they would like to see increasing use of holograms in museums.

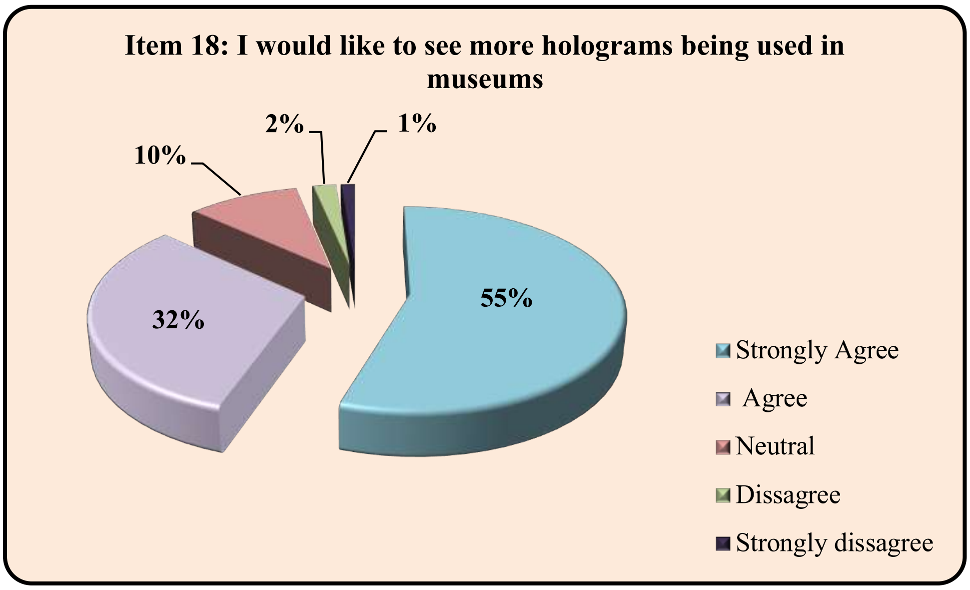


Figure 5.24 Holograms - yes or no

5.6 Summary of the quantitative data results

In summary, the results of the questionnaire show that the participants agreed that the holographic medium is an appropriate method to record and display cultural heritage items.

5.7 Interview - qualitative analysis

The interview data were collected during May and June 2016 in Saudi Arabia, when one-to-one interviews were conducted with museum directors, hall curators and a museum owner, with the aim of capturing their expert opinions on the holographic method as a way of displaying artefacts in museum settings.

The findings will be presented in themes in order to identify categories, and be coded with the most important category that is most correlated to the research questions of what museums directors, hall curators and a museum owner think of displaying holograms in museums, the importance of developing museum artefact display systems and the future of holograms in Saudi Arabia. (See interview question schedule in Appendix A).

This section focuses on the interview results of the nine interviews conducted by the researcher. Due to the ethical embodiment of this research, the names of these participants were coded, and they are addressed as **P1-NR**, **P2-NR**, **P3-NR** etc. where P = Participant, N = National museum, R = Riyadh, D = Dara and J = Jeddah.

Table 5.3 Participants' demographic background

Museum	In Museums in KSA								
Participant Code	P1-NR	P2-NR	P3-NR	P4-NR	P5-NR	P6-NR	P7-NR	P8-NR	P9-DJ
Country	All interviews were conducted in Saudi Arabia								
Gender	The sample group included 4 males and 5 females								
Specialty	Five of the participants specialise in archaeology Two of the participants specialise in ancient monuments One of the participants is an artist specialising in fine art								
Positions	One participant is a General Director of Saudi Museums One participant is a General Manager One participant is Chief Curator of the National Museum One participant is a museum owner Three of participants are hall curators								

Participant 1: General Director of Saudi Museums, with more than 36 years experience in the field of archaeology. Graduated from King Saud University, Riyadh in 1982 and holds a BA in Ancient Archaeology and a MA and PhD in Archaeology. Has made many contributions to museum display material and archaeological exploration, as well as publishing a number of books and papers in relation to antiquities. Has participated in a number of workshops at Lyon University, France and in Cairo, Egypt.

Participant 2: Chief Curator of the National Museum in the Saudi Commission for Tourism and Antiquities in Riyadh. Participants 2's Masters dissertation investigated the theme of "*Women's Traditional Ornaments in Asir Province*" and their PhD thesis is entitled "*Al Sadw and Traditional Knitting in the Kingdom of Saudi Arabia*". Participant 2 has also published a number of books and papers in relation to museums and is a member of a number of association including: the History and Archaeology Association in the (GCC) countries, a member of the museum education committee, a member of the consultancy committee at the National Museum and a member of the subordinate committee at the exhibition of "*Masterpieces of the Islamic Art Collection*" held at the Louvre Museum, Paris, France. Has participated in a number of workshops.

Participant 3: Director of National Museums in Riyadh.

Participant 4: The owner of a private gallery that opened in January 2000 and international award-winning artist known for traditional style artworks. Participant 4 has more than 46 years of painting history and has published a number of books, including *Saudi Arabia: An Artist's Look at the Past* and *A Three-Decade Journey with Saudi Heritage.*

Participant 6, 7, 8 and 9: Hall curators in a museum in KSA.

5.8 Interview findings

5.8.1 Photographing heritage items

Regarding the question of whether photographing heritage items is a good method of documenting and cataloguing artefacts for future generations, all the interview participants answered in the affirmative. The frequently offered view referred to 'documenting' archaeological items. Participants **P1-NR**, **B P2-NR**, **P3-NR**, and **P8-NR** all agreed that photographing heritage items is a method of documenting these items. Participant **P1-NR** said that this is because "*museums rely on descriptions, photos, and the history of the archaeological and heritage items*", whereas Participant **P2-NR** mentioned that the documentation of heritage objects at the National Museum was performed through a special electronic record containing all the displayed and non-displayed museum artefacts.

For the other participants, photographing heritage items was considered to be a good method of documenting and cataloguing these items. For example, **Participant P6-NR** believed that "*although photographing prevents them from being lost, it cannot substitute the actual items*". **Participant P6-NR**, considered that holography is a very advanced method of recording heritage items by keeping images and details of the heritage items and by giving a realistic feeling of their dimensions and details. Participant **P9-DJ,** on the other hand viewed that "*photographing is intended for classification and cataloguing*". As a museum owner, part of her activities includes photographing every item and recording all information regarding their size, quality, origin and source.

5.8.2 Technology as an aid in documenting cultural heritage

The interview participants were asked about how technology could be an aid in documenting cultural heritage. All of them agreed that technology could benefit archaeological preservation and documentation. One of the participants, a museum manager, worked with other personnel at the museum using new technology. **P1-NR** considered that "*as long as it does not damage the heritage items, we utilise modern technology to store data and use automatic storage methods*". Similarly, **Participant P6-NR** believed that

> *technology should be exploited and maximised, such as through holography, which is a distinctive technique that can be adopted to display a digital image of rare, precious items in different places together by documenting them using computer programs.*

Participant P3-NR explained that

> *technology can serve as an aid in documenting cultural heritage through many ways. For example, it is used in geometrical survey, and laser scanning, which all contribute to heritage conservation, documentation, and registration; and hologram is an addition to these.*

Participant P3-NR apologised, however, for not having extensive knowledge about hologram technology but was certain that, just as in archaeological fieldwork, "*holographic technology should also be used to examine and record heritage objects*". As pointed out by **Participant P9-DJ**, "*every era has its benefits from technology*", and **Participant P9-DJ** identified holography as "*a modern development*", and cited "*the* *photographing of statues in Iraq, which helped in re-assembling these statues*". **Participants P1-NR and P7-NR** both conveyed the idea that the actual objects could be preserved by displaying only their technology-created replicas using holograms, where the details of the original objects are shown. As previously discussed, this points to the recording of artefacts that may be too precious or fragile to be subjected to general exposure.

5.8.3 Holography as a valid method of record cultural heritage

All participants except one agreed that holography is a valid method for recording heritage. Participant **P1-NR** suggested that "*holography is faster and easier to use in museum exhibits since it can replace the conventional copying method*".

Participant P2-NR claimed that

> *at present, the images of the archaeological items are being documented, catalogued and copied. Hologram is a very good method for developing museum exhibits and documenting cultural heritage.*

Despite agreeing that holograms are a good method for heritage recording, participant **P3-NR** doubted if this technique was indeed ready and accessible. He further said:

> *I'm not trying to underestimate holography, but what I'm trying to say is it's still a new technology under test and experiment and it requires special laboratories and specialised personnel.*

Participant P9-DJ believed that holography is an appropriate method to display heritage artefacts and is considered an aspect of the technological evolution that is suitable for use in museums to develop recording of artefacts. **Participant P7-NR** claimed that it is a suitable method because of the modern technique of displaying the artefacts for a longer period of time.

5.8.4 Participants' comments about the hologram they saw

All the participants gave positive comments about the hologram that they saw. **Participants P1-NR**, **P6-NR** and **P5-NR** described the hologram as "*amazing*", whilst **Participants P3-NR**, **P8-NR**, and **P9-DJ** described it as "*beautiful*". **Participants P1-NR** and **P6-NR** even mistook the holographic image for an actual artefact and

Participant P6-NR considered that "*the hologram is not only beautiful but it is amazing as well as an honourable artwork and an excellent technique*". **P6-NR** also added that

> *I could not differentiate the holographic image from the actual artefact until a colleague informed me.*

Participant P2-NR, on the other hand, said that "*it is a useful technique for the development of museum display and I hope to see it in the museum soon*", whereas, **Participant P3-NR** praised the recorded hologram plate of the artefact that he saw as "*a beautiful and an astonishing artwork*". Conversely, **Participant P8-NR** said that "*it was both a beautiful and a sophisticated 3D image of the actual object*", whilst **Participant P7-NR** described it as "*a creative and an attractive piece*".

Participant P9-DJ talked about the potential of holography to "*attract visitors to the museum*", but also acknowledged its costliness:

> *Holograms are rather expensive, so to reduce the cost a hologram laboratory must be built and developed in the KSA and a specialised department must be created.*

P9-DJ furthered mentioned that

> *recording holographic artefacts overseas is more expensive than building a hologram laboratory in the country.*

However, **P9-DJ** did point out that the large museums such as the National Museum should adopt the idea of building (opening) a holographic lab.

The participants were also asked whether they considered that holograms could be an important visual art. All participants, except **Participant D P4-NR**, answered in the affirmative.

5.8.5 Views on holograms for recording heritage

The participants were each asked the question: ***To what extent would you agree that holograms could record heritage***? **Participant P1-NR** considered that "*80–90 percent it could*" and **Participants P7-NR** and **P3-NR** also suggested a high percentage of "*80 percent indeed it could*". However, **Participant P2-NR** thought that whether holograms could record heritage would depend on the archaeological objects, as some are difficult to transfer from place to place. **Participant P5-NR** stated that holography could be utilised to aid in saving heritage items. **Participant P8-NR** considered that holography is a developed technology and can record and display a country's cultural heritage.

5.8.6 Recommending holography as a high-end technology

The participants were each questioned about whether they would recommend holography as a high-end technology that is essential to the future development of visual arts. Although most of them claimed that they were not art experts to answer this question, they generally answered 'yes', except for **Participants DP4-NR** and **P9-DJ**, who both said that they did not know.

5.8.7 Opinions on where to display the holograms

The participants were asked for their opinions about the right place to display holograms, and the answers they gave are shown in the following table.

Table 5.4 Participants' consideration of location

Hologram display location	
Participant **P1-NR**	Museums
Participant **P2-NR**	Museums, art galleries and auctions
Participant **P6-NR**	Museums, art exhibitions and international fairs
Participant **P4-NR**	Exhibitions and art galleries
Participant **P5-NR**	Exhibitions
Participant **P3-NR**	Art exhibitions, museums and international fairs
Participant **P8-NR**	Art exhibitions, public areas and museums
Participant **P9-DJ**	Jewellery exhibitions, shows and art galleries
Participant **P7-NR**	Museums and art exhibitions

Participant P1-NR was asked whether he agreed that it would be best that the actual artefacts be kept and only the holographic images should be sent and displayed in international exhibitions in which he participates. He said that he absolutely agreed with this, as it is safer to do it this way. A benefit that can be obtained from doing this is ensuring the safety of the heritage items from possible loss, theft, damage and fraud.

5.8.8 Participants' views on hologram display in museums

When the interviewees were asked their opinions on whether holograms can be displayed in museums, all of them said that it is absolutely possible. **Participant P1-NR** even stressed that his experience was that he and other museum personnel (staff) would usually go to experts to copy the artefacts (replicas), which was more difficult than the procedures entailed in recording objects through the use of hologram technology. **Participant P4-NR** pointed out that he expected hologram technology to be applied in specialised museums. Interviewee **P2-NR** stated that:

> *Actually, we have a travelling museum abroad and we have sent artefacts and archaeological items, and while the original items are travelling around in the mobile museum we replaced them with photographs of the items in the National Museum, so we can replace them with holograms instead of photographs, Or we can send the holograms abroad instead of sending the original items.*

5.8.9 Advantages of adopting holographic technology in museums

Participants P1-NR and **P7-NR** considered that the unique presentation style of holographic technology is an advantage for adopting it in museums. **Participants P6-NR**, **P3-NR**, **P8-NR** and **P9-DJ** claimed that an advantage of using holography is its capacity to attract visitors, whilst **Participant P4-NR** said that its benefit is in its usability to temporarily replace the actual objects.

5.8.10 Reasons for people's fascination with holograms and 3D representation of objects

Most of the participants believed that people are usually fascinated by new and high-level technology, which is why they are fascinated with hologram (holographic) technology. It provides a chance to see the details of an object despite its not actually being there. **Participant P6-NR** pointed out that "*people may become fascinated by a hologram because of its high accuracy display*". Alternatively, **Participant P4-NR** said that "*the reason for this is because it is a new technique with a kind of visual deception*".

Participants **P2-NR**, **P9-DJ**, and **P7-NR** agreed that holographic method is important in the development of museums in Saudi Arabia. All of them also agreed that integrating hologram technology with art could help in the development of Saudi museums' display systems. As Participant B **P2-NR** said:

It is an integral process with the museum's objectives. I expect an integrative association. Holograms are complementary to the museum's objectives in the development of display method.

5.9 Interview discussion

The findings revealed that the participants in the interviews and those who took part in the questionnaire showed satisfaction with viewing holograms of artefacts. The interviewees emphasised the importance of improving the current methods of displaying and recording cultural heritage artefacts in the museums in the KSA. Moreover, they also expressed their desire for the establishment of facilities for producing 3D images and for building a laboratory in the KSA that would reduce the cost of producing holograms.

The next chapter discusses the findings from the results of both data collection methods. It presents an overall set of conclusions and makes recommendations. It also identifies future research work in this field.

Chapter 6

CHAPTER 6
Discussion, Conclusions, Recommendations and Future Work

6.1 Introduction

This chapter draws the findings together and discusses their outcomes. It starts by discussing the experimental research which is then followed by an in depth discussion of the exploratory research. Next, conclusions are drawn and recommendations and future research identified.

6.2 Discussion

6.2.1 The Experimental research

This research was not just about looking at the impact of 3D images, but also to consider all kinds of display strategies in an attempt to influence and improve museum recording and display systems in the KSA. The researcher explored and implemented innovative methods and technologies, which could be used in the presentation of actual 3D artefacts and how they may be used as installations in museums. This was done to help the researcher explain and measure the effects of the displays on museum visitors through their engagement and interaction with the recorded hologram plates displayed in museums. The research limited the context to Arabian Peninsula heritage in order to exploit the possibilities of high technology for recording unique heritage items that offer the ability to preserve history. The Arabian Peninsula has a rich heritage and history and makes a potentially immeasurable contribution to the history of the region. This research was conducted in order to establish a method to display artefacts of historical importance to as wide an audience as possible. Additionally, recent regional events resulting in the destruction of culturally significant heritage sites in Iraq and Syria, for example, show the need to record valuable artefacts for documenting purposes.

The researcher has experienced difficulties in documenting heritage artefacts accurately; in fact, it was difficult to document heritage items by accurate dates as a result of the lack of people who are interested in chronicling dates of historical items. This situation encouraged the researcher to find out and accurately record dates of Bedouin jewellery items (selected to be documented in this research). This is a particularly significant goal as the original craft of Arabian Peninsula jewellery production relied on handcrafting skills. The beauty of Bedouin jewellery in particular, its design, the tiny detailed accuracy, and ethics behind its creation are the reasons for choosing this jewellery to be recorded using the holographic technique. Furthermore, the researcher chose each piece specifically in order to display a complete set to any audience. This is why the researcher reconsidered the original features and the value of these collections when using the holographic technique to reproduce 3D images of them to assist in developing new forms of display systems in Saudi museums.

There are numerous references in books, journals and on websites that have recorded Bedouin jewellery through 2D photography, which makes it easy to find similar photos of items that have been recorded. To answer how to devise a potential method of projecting 3D images, the researcher conducted a number of experiments testing different techinques and methods in the holographic laboratory and the studio, including analogue, digital holography, lenticular, anaglyph and photogram. This was undertaken to identify systematically the best 3D imaging technique that would be successful and appropiate for use in display systems in museums in the KSA. The advantage of using holography in museums is that it will protect items that are precious, delicate, fragile, irreplaceable and valuable, by providing holographic images in their place. For an artist to apply technology within artwork, Oliveira (2013, p5) suggests that:

> *from previous research undertaken there appears to be a difference between artists who use technology to develop their work and those who believe that technology is a science and therefore has no place in the world of art.*

This present research found that looking at holograms for the first time attracted audiences who thought they were viewing the original item, as the holographic technique has the ability to capture the minute details of items due to its facility to show the depth of a real object. However, it is worth noting that it is not only important to apply the holographic technique to capture the details of the artefacts, but also to capture "*the 'soul' of the object, before they can accurately 'stand in' for the original*" (Pepper, 2008, p7). This research also therefore considers the artistic aspect of the representation of Arabian Peninsula jewellery heritage. Capturing the beauty and the quintessence of the jewellery is as important as capturing its 3D form in the holographic process. "*Using different diversity of different holograms in art enriched visual expression and figuration also it enlarged the limitation of many branches of art*" (Işik, 2014, p24).

Until quite recently, holographers used a variety of holographic plates to record holograms, until colour holographic^{Tm} plates, giving a high quality of resolution, were launched. These high-quality plates were used by the researcher in the experimental project (a first by a researcher). The result of this tool was stunning and clearer than the one that had been used in this researcher's earlier experiments (Experiments 1, 2 and 3), which used ILFORD HARMAN$^{©}$ Ltd red and green sensitive plates. Color Holographic^{Tm} plates could be described as having a high level of brightness, reproducing colour and hue variations and eliminating lines of light wave diffraction (spreading to the edge of the plates). From my experience as an artist holographer, I believe that my peers or colleagues, who work in the holographic field, would agree with me about the results achieved by using such plates and that they are good general purpose sensitive plates, and as such, they would suit the widest spread of image design and subjects. Inevitably, as a holographer, I received a number of requests to know which type of plates I had used to record the holograms, as a result of plates in question having produced marvellous and shining results.

This research does not state that holograms should replace the original and valuable historical artefacts in museums, but it seeks to develop a method of documenting ancient heritage that can assist museums in recording and cataloguing valuable artefacts. Furthermore, holograms allow for greater accessibility to wider audiences due to their portability and their ability to be safely displayed in different locations, including crowded areas. As Pepper (2008, p2) pointed out, "[*t*]*he act of preservation precludes physical contact by millions of visitors*". Holography can therefore offer a method that could allow wider accessibility in museums when dealing with rare and valuable artefacts. Furthermore, the size of a hologram the same size as the original item.

6.2.2 The exploratory research

The interviews gathered qualitative data and addressed a number of main issues. Firstly, the researcher wanted to understand what Saudi museum directors think about developing the display systems in museums in Saudi Arabia. Two questions were asked in relation to this point and it became clear from the findings that the interviewees considered that the hologram technique is interesting and that it is an appropriate method to record heritage. The first consideration is that holograms can assist and encourage visitors to be creative in their thoughts about and considerations of the viewed artefact. Secondly, the majority of hall curators and museum staff were in agreement that display systems in Saudi museums would benefit from using the holographic technique and that it is a good method to document heritage. Museum staff and owners stated that they took photographs of original items to indicate the importance of heritage and to keep copies of the original items for documenting purposes – in other words, to keep the presence of an artefact on display even in its absence. Museum directors, hall curators and a museum owner confirmed that they often relied on photographic media for artefacts in Saudi museums.

The first question of the interview was: "*Do you think photographing heritage items is a good method to prevent them from being lost and record them for future generations?*" The answer to this question identified that eight out of nine interviewees agreed that holography is a good method to document heritage. Furthermore, 88% of the survey participants claimed that seeing a holographic image was completely new to them. This strongly suggests that the holographic technique is considered as unique and has not yet been used for museum display in the KSA.

The researcher considers that there is a positive reaction to the holographic medium and the people who are involved in the museum sector agreed and confirmed this. Although all nine interviewees agreed that the holographic technique is a suitable method to document heritage, they also maintained that photographing artefacts is also very important in documenting. This is logical because digital cameras offer a good resolution as well as being easy to use; additionally, smart phones now incorporate good quality cameras. Photographing items is very important in documenting, as participant P9-DJ pointed out:

> *photographing heritage items is a necessary stage to prevent them from being lost. In my opinion, photographing should be taken to every piece for classification and cataloguing purposes and to return to it when needed. We photograph every single item.*

Most of the interviewee sample agreed that holograms present fabulous 3D images and are better than photographs. One interviewee considered "*... that the hologram is an incredibly valid method to document the cultural heritage and for the development of museum displays*" (Participant P3-NR). These results proved that the holographic medium would enrich museum documenting and display system development. Overall, it is evident that the interview participants very much liked the creative process of the holographic technique and believed that the holographic medium plays an important role in documenting heritage. Ultimately, the cooperation between and aim of museum directors, with the support of SCTH, is to develop their display and cataloguing systems. The results show that they are optimistic about building a holographic laboratory in the KSA to produce holograms of museum items.

The directors and hall curators of Saudi museums have ambitions for improving museum display systems; the important principles in the development of museums galleries and exhibitions; evaluation and museum visitors' visions; and the use of technology in the development of museums and exhibitions. It appears that there is potential for using the holographic medium in museums for visitors to have fun, although they might come with an intention of adventure and to discover what is behind the 3D image frame. Despite their intention of creating an entertaining time in museums and discovering modern techniques for displays in museums, the interviewees agreed that the holographic image is more beautiful and shiny than the original item, due to its clarity, it also shows more detail and depth than 2D photographs.

Museum visitors generally visit museums for amusement purposes and to be educated by the history in the museum, and it is recognised that there is no problem in combining the two in museum settings. The most important principle in the development of museum exhibitions is attractiveness. The holographic medium offers the ability to document artefacts due to the high quality of resolution and the ability to capture the minute details and the authenticity of the object. Furthermore, "*... it is not difficult to carry and display hologram technology compared to the original item*" (Participant P3-NR).

This research has proved that holography is a useful medium that could improve display systems in museums as well as adding value itself in attracting museum visitors. Additionally, the findings show that improvements in documentation and display systems in museums in the KSA should be continued. Museum staff, owners and hall curators should play their role in developing museums and displays and providing an attractive, organised environment so that visitors can spend an enjoyable time visiting museums.

There are no museum curators in Saudi Arabia, just hall curators, for the following reason:

> *... we do not have specialized majors in museum science in all Saudi Universities and museum science study at King Saud University is within the heritage department, but we do not have a specialized department in museums science, we do not have a dedicated museum education jurisprudence.* (Interview, 2016).

The aim of interviewing experts and people with an interest in heritage care and museum hall curators in Saudi Arabia was to gain a deep understanding about the functioning of museums and to add to the knowledge obtained from the few relevant pieces of literature the researcher was able to find. The researcher was told in an interview with the director of Saudi museums that

> *... when over 320 archaeological masterpieces and antique pieces are removed from the national museums to be exhibited, they can be replaced by replicas in the display. Holograms could be a good alternative for the items to be displayed instead of the original in mobile exhibitions.* (Interview, 2016)

6.3 Conclusions

Museums and cultural heritage play an important role in communities, by saving, presenting and displaying history from different eras. Technology design and use is important from several viewpoints. It is considered as a major resource in the world to motivate and develop the evolution cycle in museum development and recording. The hologram display system in museums is an underused method in the KSA.

This research has obtained respectable results for a number of successful holographic images that resulted from the research experiments. This investigation study of traditional artefacts using holography has increased our understanding of the relationship between art and science and how the utilisation of technology affects and improves our lives. Handmade designs existing in museums are valuable and unusually sophisticated when compared with similar designs elsewhere that are not handmade. In this case, holography has allowed an audience to appreciate the artistic level of such artworks. The findings from this research can contribute to the academic appreciation of art forms, such as visual art displayed in museums.

At present, museums in the KSA are using traditional methods for recording artefacts, which are recorded and catalogued using digital photography together with a written record of the history of every item. An electronic identification system is used that gives every item a number, photograph, history, where it was found and all the information of the piece can be found digitally on the website of SCTH. However, introducing a holographic system would add a further level of detail to this process. In addition, it could reduce time, travel and risk if the hologram removes the need to move artefacts between countries. Regarding the museum visitor, this research has identified that the hologram is both interesting and attractive. This view is exemplified by the following comment:

> *The holographic method is not to document heritage and monuments only, but it also helps sometimes, like giving us a field that is possible through the image of hologram so that we show as if we are offering cut and repeat displays in several museums, instead of using the traditional method (replica) … this is the first time I have seen such a kind of hologram of an object.* (Participant P1-NR)

The practical approach that this research took and the results prove that museum artefacts in Saudi Arabia could be displayed using holograms in a more efficient way than previously. Also, holography offers the flexibility of displaying the same artefact through holograms at multiple locations across the whole country, or even further afield. Furthermore, the result of the survey also proved that it could be an appropriate method to display, and possibly document, heritage artefacts. This has achieved the main aim of this research and answered the research question.

Diversification by utilising multiple techniques is important and is required, due to the size of heritage items such as archaeological pieces. However, in this research it was impossible to record such items in a laboratory because of their size. However, it is possible to record such items using techniques such digital holograms. An example of these in Saudi Arabia, which is consider a country rich in history, includes The Holy Mosque, within which is the Ka'abah and towards which every Muslim around the world faces five times a day in their prayers (Al masjid al-Nabaoy). This is where the Prophet Mohammad came, stayed and died, in the Mada'in Saleh (see Figure 4.78). We only have photos of it and of the holy mosque in Makkah and Madinah unfortunately do not have 3D images of it. As I am a proud Muslim I hope and wish one day to record these holy areas in the Kingdom. This wish inspired me to learn about such 3D techniques in order to be able to record such amazing areas and introduce them to the world. Vast archaeological sites must be documented to show and offer Saudi Arabia's amazing cultural history to other societies in different areas of the world. This is the case even for Saudi people themselves, many of whom do not have a chance to visit such rich historical areas in other regions of the KSA. This is a considerable issue requiring such technology to be developed for heritage documentation, preservation and display.

6.4 Recommendations

This research makes the following recommendations.

It is essential to develop display systems in museums using the holographic technique and museum developments need to be funded and supported by the government of Saudi Arabia.

- The findings strongly indicate that a permanent holographic laboratory should be built in the KSA, as it is fundamental that the museum service in the KSA catches up with developments around the world in this area.

Requirements of the current Saudi museum industry, including advertising, holographic design and archiving, need enhanced quality of documenting and display systems.

- One way to meet these requirements is to improve the current technique in displaying and documenting in the KSA. The lack of display technique and the current method of documenting in museums in the KSA both require improving and developing and are considered a fundamental requirement.

The absence of technology for documenting and display, using modern holographic design, requires attention.

- Develop experienced, qualified and skilled holographic specialists and experts in Saudi Arabia.

Most important is the need to disseminate knowledge about the identity of Islamic heritage and its aesthetic to the world. Adopting the holographic medium is essential to meeting these targets.

6.5 Future Work

As a result of this research study, future experimental research can be undertaken:

1. To investigate the feasibility of using holograms in public places such as airports to advertise and to attract people to visit museums.
2. To develop a full picture of the holographic medium, additional studies will be needed to explore the advantages of three-dimensional imaging in a variety of field.
3. To investigate the teaching and appreciation in Saudi society of the holographic medium, digital holograms, lenticular, anaglyph and photogram; this is a fundamental step to be taken seriously.
4. To investigate how to develop a holographic laboratory in the KSA and to provide possibilities to use different 3D imaging techniques.

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Appendices

Appendix A

Forms

1.1 Questionnaire Forms

1.2 Interview Form

1.3 Ethical Approval & Consent

An Investigation Into The Potential Of Variable Particle Size Volumetric Mist Screens For Use In Three-Dimensional Display.

Consent form

Issue	**Respondent's initial**
I have read the information presented in the information letter about the study " An Investigation Into The Potential Of Variable Particle Size Volumetric Mist Screens For Use In Three-Dimensional Display."	☐ Yes ☐ No
I have had the opportunity to ask any questions related to this study, and received satisfactory answers to my questions, and any additional details I wanted.	☐ Yes ☐ No
I am also aware that excerpts from the interview may be included in publications to come from this research. Quotations will be kept anonymous.	☐ Yes ☐ No
I give permission for the interview to be recorded using audio recording equipment.	☐ Yes ☐ No
I understand that relevant sections of the data collected during the study may be looked at by individuals from De Montfort University, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my responses.	☐ Yes ☐ No

With full knowledge of all foregoing, I agree to participate in this study.

I agree to being contacted again by the researchers if my responses give rise to interesting findings or cross references.

☐ No

☐ Yes

if yes, my preferred method of being contacted is:

☐ telephone ……………………………………………………..

☐ email ………………………………………………………….

☐ other …………………………………………………………..

Participant Name:		Consent taken by	Amani Althagafi
Participant Signature:		Signature	
Date		Date	

Version 2.0 02.03.2009

Interview Consent Form

Dear participant

This research has been approved, as required, by De Montfort University. This study aims to investigate of holographic recording and display of Saudi arabian heritage for museum application. And to develop a novel holographic process that may be applied to three-dimensional displays and contribute to our better knowledge of applied optics including laser speckle and light dispersion through diffused surfaces to obtain the degree of Doctorate of Modern Holography from De Montfort University. This interview will be conducted by email or face to face. You have the right to withdraw from the interview without penalty. Your responses will be kept strictly confidential and your name will not be linked with the research material unless you give me permission to do it. Moreover, if you have any question regarding the research you have the right to ask either the researcher or her supervisor.

Contact Information:

Supervisor name: Prof. Martin Richardson

Faculty of Technology
De Montfort University, office: 2.27 Queens Building
MRichardson@dmu.ac.uk
Tel: +44 (0)116 207 8678 (ex: 8678)

Researcher name: Amani Althagafi

P11037404@myemail.dmu.ac.uk
Mobile number: +447466674606

I confirm that I have read and understood the information above and consent to take part in this online interview:

-- -------------------------- ---------------------------

Name of Participant Date Signature

☐ I agree to have my name and job role quoted in the thesis or academic publications based on this research (tick box)

Or

☐ I prefer my name and details to be kept anonymous in the thesis and any academic publications (tick box)

Recording Culture: An Investigation Of Holographic Recording & Display Of Saudi Arabian Heritage For Museum Applications

PhD Researcher: Amani D. Althagafi

Dear Participants:

The following survey aims to investigate and develop a technique of archiving heritage by using a high-tech novel holographic process to capture a three-dimensional presentation of historical artefacts in particular of the Saudi Heritage. I would appreciate it if you could spare 10 minutes of your time to answer the following questions.

Definition:

Hologram: a three-dimensional image recording and displaying of original objects with use of coherent laser light.

Section A: Main Survey Questions

Please read each of the following statements carefully and indicate the extent to which you agree or disagree by simply circling a number from 1 to 5. Please do not exclude any item.

For example:	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I like watching hologram more than the original traditional items.	(1)	2	3	4	5

1. Holography is a valuable method to document Heritage.	1	2	3	4	5
2. Technology can keep our Heritage from being lost, (and our memories).	1	2	3	4	5
3. When I want to see Heritage items reproduced, I prefer photographic images (2D).	1	2	3	4	5
4. I think photographing of Heritage items is an adequate method to save it from lost.	1	2	3	4	5
5. A 3D Hologram provides more information than a 2D photograph.	1	2	3	4	5
6. Even though I have a Hologram, I prefer the original items because I like to touch it.	1	2	3	4	5
7. I prefer Holograms only when the original item is not available.	1	2	3	4	5
8. Holograms can be more interesting than the original items.	1	2	3	4	5
9. I am a fan of technology and prefer seeing / touching real items.	1	2	3	4	5
10. I prefer seeing real items since there is no need for any high-tech in order to experience heritage.	1	2	3	4	5
11. It is easy to view Heritage artifacts recorded on a Hologram when I am searching for traditional items.	1	2	3	4	5
12. I prefer holding the Hologram of a Heritage item because I can fully examine the object, rather than damage the original item.	1	2	3	4	5
13. I can take my time to see and turn the Hologram at different angels when examining it.	1	2	3	4	5
14. Holograms will be the best choice only when I am looking for a unique Heritage item, such as a priceless object.	1	2	3	4	5

Questionnaire Form P.1

15. I like looking at Holograms because the smallest details can be seen clearly.	1	2	3	4	5
16. I do not think Holography is a good method to document Heritage.	1	2	3	4	5
17. I like using high technology and digital materials such as software, digital media and 3D.	1	2	3	4	5
18. I would like to see more Holograms being used in museums.	1	2	3	4	5

Section B: Background

Please fill in the following information by ticking (✓) the appropriate box or writing your response in the space provided.

19. Have you seen a hologram before?

Yes ☐ No ☐

If yes please specify where: ……………………………………

20. What is your Specialty?

Engineering ☐ Medicine ☐ Scientific ☐

Art & Design ☐ Management ☐ Education/ Teaching ☐

Other please specify ……………………………

21. **Gender** Male ☐ Female ☐

22. **Age** 18 - 25 ☐ 26 - 35 ☐

36 - 45 ☐ 46 - 55 ☐

56 - 65 ☐ 66 - 75 ☐

23. **What is your nationality?**

☐ Saudi ☐ Other, specify: ………………………

24. **How many times did you visit museum in the last twelve months?**

Thank you for your time and effort. It really makes a difference!

Questionnaire Form P.2

Recording Culture: An Investigation Of Holographic Recording & Display Of Saudi Arabian Heritage For Museum Applications.

Ph.D Researcher: Amani D. Althagafi

1. Do you think photographing Heritage items is a good method to prevent them from being lost and archive them for the future generations?

2. In your opinion how could technology aid us in saving our cultural heritage? Please provide examples?

3. Do you think holography as a valid method of documenting Heritage? Why / why not?

4. What are your comments about the hologram that you saw?

5. To what extent would you agree that the holograms could archive heritage?

6. Would you recommend that holography could be used as a high-end technology, essential for the future development of visual arts?

7. In your opinion, what would be the right place to display such holograms?

8. Do you think holograms will be displayed in Museums?

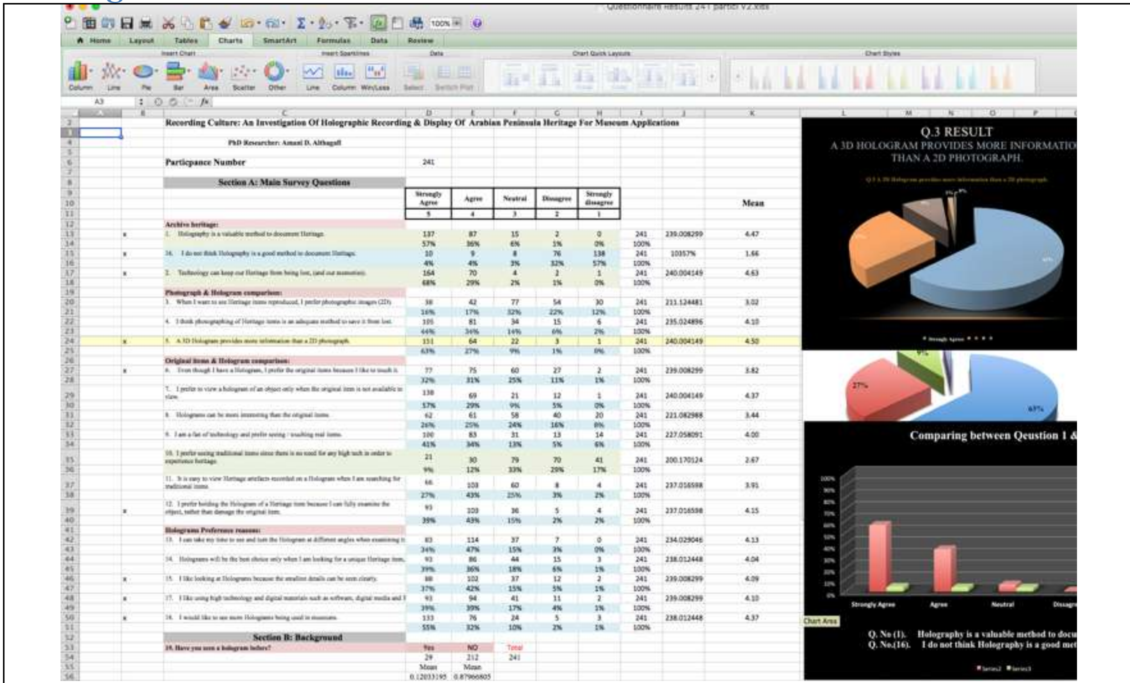
9. Advantages of adopting holographic technology in museums.

10. Why do you think people are fascinated by holograms and 3-D representations of objects?

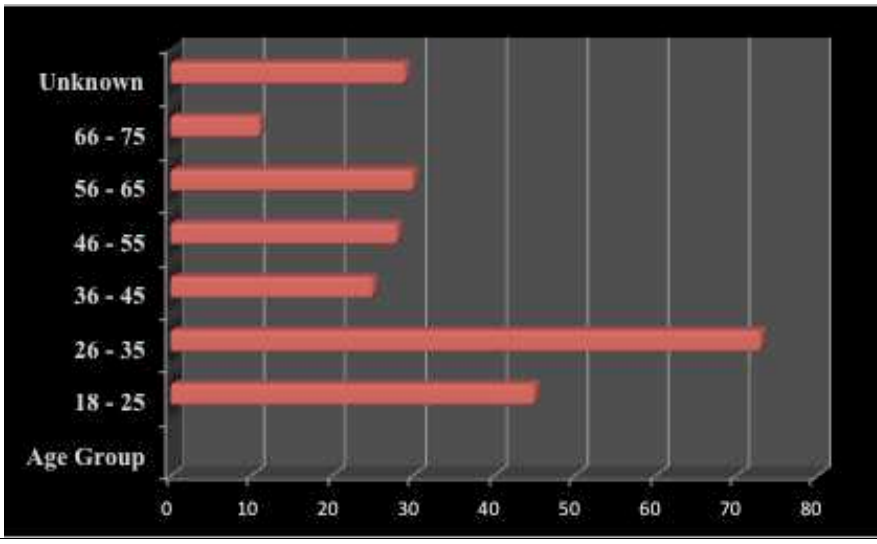
Thank you for participating

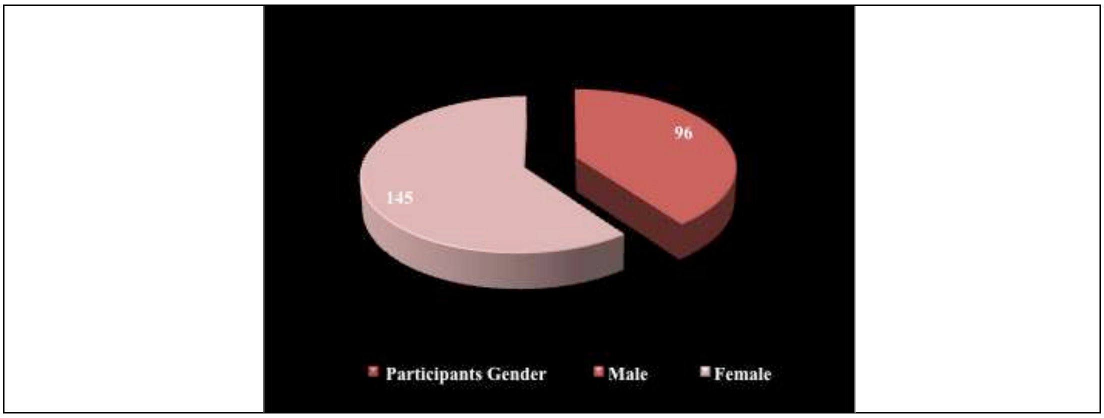
Appendix B

Findings

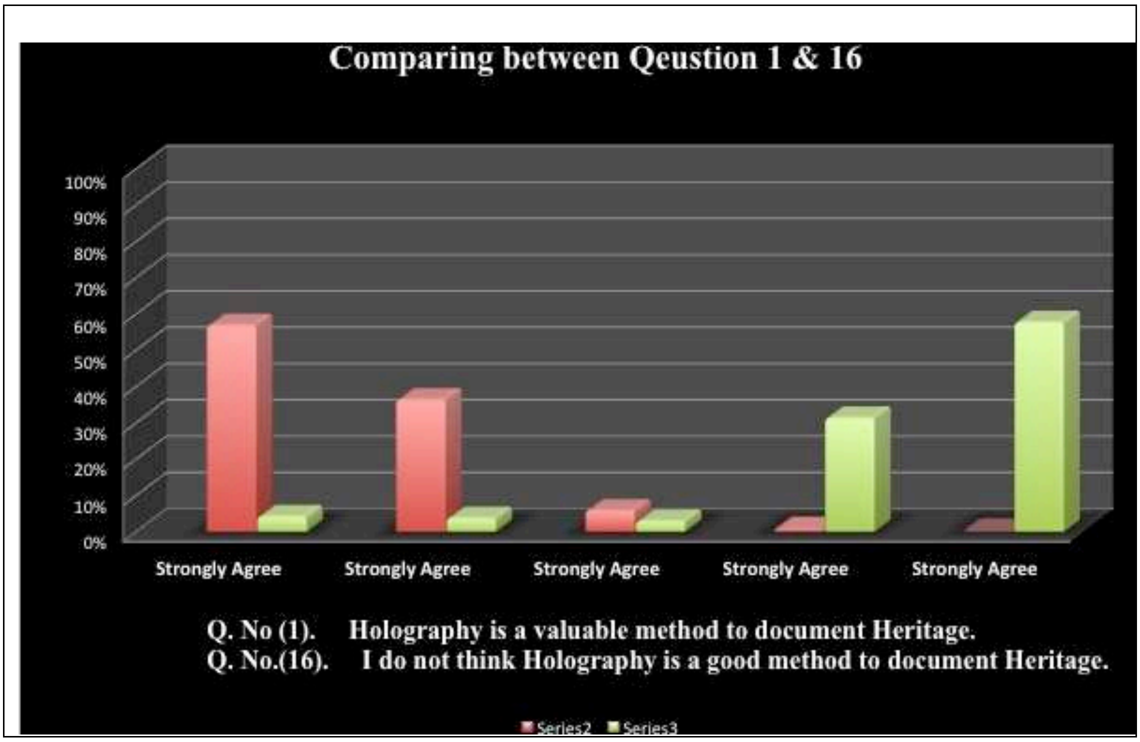


The Questionnaire results excel Worksheet





96
145
Participants Gender
Male
Female



Comparing between Qeustion 1 & 16
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Strongly Agree
Strongly Agree
Strongly Agree
Strongly Agree
Strongly Agree
Q. No (1). Holography is a valuable method to document Heritage.
Q. No.(16). I do not think Holography is a good method to document Heritage.
Series2
Series3

Appendix C

Certificates

1 Conferences paper. Number: 2

- SPIE OPTO Symposium – Part Photonics West ,7–12 February 2015 San Francisco, California, United States
- 14th International Meeting of Art and Technology: # 14.ART: Art and Human Development, Portugal, 7–11 October 2015

2 Poster

- The 6th Saudi Scientific International Conference at Brunel University, London, 11–14 October 2012
- The 8th Saudi Student Conference at Queen Victoria Elizabeth II Conference Centre, London, 31 January–1 February 2015

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February 7, 2015

Mrs. Amani Althagafi
De Montfort Univ.
United Kingdom

CONFIRMATION OF ATTENDANCE

This is to confirm that Mrs. Amani Althagafi
De Montfort Univ.
attended

SPIE OPTO Symposium –Part of Photonics West 2015
7-12 February 2015

San Francisco, California, United States

Title of the Paper Presented: Archiving Saudi heritage using the holographic medium
Paper Number: 9386-15

Marilyn Gorsuch
Director, Technical Programs

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Althagafi. A. De Montfort University, Leicester, Faculty of Technology, The Imaging & Display Research Group, 2.27 Queens Building, The Gateway, LE1 9BH, UK. E-mail: amany_abed@hotmail.com & Professor Richardson, M. De Montfort University, Leicester, Faculty of Technology, The Imaging & Display Research Group, 2.27 Queens Building, The Gateway, LE1 9BH, UK. E-mail: mrichardson@dmu.ac.uk

Archiving Saudi heritage using the holographic medium

ABSTRACT

This paper focuses on the use of the Yuri Nikolaevich DENISYUK holographic recording process to document, archive and display Saudi heritage. The goal of this research is to develop a technique of archiving heritage by using a high-tech holographic process to capture a three-dimensional presentation of ancient jewelry artifacts of the Saudi Heritage in particular. This study concentrates on five particular items of handmade authentic ancient metal jewelry from different parts of Saudi Arabia. When conducting this research experiments were conducted using both red-green sensitive plates sensitive to 633 nm and 532 nm respectively. Material thickness ranged between 1.5 and 3 millimeters were used, consequently in the dark room, varied chemicals for developing the holograms were employed. Red and green laser devices were also used with exposure times between 8 to 18 seconds of laser light dispersion through diffused surfaces in reflection holography. The outcome in each case was varied. The holograms captured the jewelry pieces with all the engravings and minute details, thus archiving the Saudi Heritage of that time. What makes holograms a revolutionary method for presenting valuable and/or ancient artifacts is the fact that they offer a more practical and convenient solution to travel around the world than displaying the originals items. Thus, museum visitors can enjoy and appreciate the precious artifacts otherwise unseen and lost without holography.

Key words: Holograms, Yuri Nikolaevich DENISYUK hologram, laser beam, recording material, reflection hologram, display, Antique, archive, traditional jewelry, museum artifact and Saudi heritage.

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Participant Certificate, Portugal

Portugal Conference Symposium paper, published cover

Althagafi. A.[1] PhD Student at De Montfort University, Leicester, Faculty of Technology, The Imaging & Display Research Group, Leicester Media School, 1.32d Queens Building, The Gateway, LE1 9BH, UK. E-mail: amany_abed@hotmail.com & Richardson, M. De Montfort University, Leicester, Faculty of Technology, The Imaging & Display Research Group, Leicester Media School, 2.27 Queens Building, The Gateway, LE1 9BH, UK. E-mail: mrichardson@dmu.ac.uk & Azevedo, Maria Isabel Post-Doctoral Researcher in Art Studies-Image Holography, University School of Arts of Coimbra, Portugal, Research Institute for Design, Media and Culture. UK & Portugal. E-mail: mifcmazevedo@gmail.com

Documenting Saudi Antique Jewelry By Using Digital Holography

This paper examines the use of Modern Holography to document antique jewellery from Saudi Arabia using both traditional and digital holography. It provides a review of recent improvements and applications in the holographic recording of museum artifacts. Moreover, the advantages these developments offer to exhibit valuable or distant artifacts in great three-dimensional detail. This paper investigates the use of holographic space, together with its interactive element and the possibility to show artifacts in animated full color. We propose a new kind of Museum in Saudi Arabia that displays and showcases Saudi Heritage through holography.

Keywords: Digital Colour Holography, 3D Image, Saudi Antique Jewelry, Artefacts and Virtual exhibition.

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Portugal Paper Abstract


Saudi Scientific International Conference
المؤتمر العلمي السعودي الدولي
Investing in knowledge تستثمر في المعرفة

CERTIFICATE OF PARTICIPATION

This to certify that

AMANI ALTHAGAFI

Has participated in
the 6th Saudi scientific international conference
11th – 14th October 2012 at the Brunel University
Sponsored by
King Fahd University of Petroleum & Minerals

Dr Sahel N. Abduljawad
President of the Secretariat of Scientific Committee

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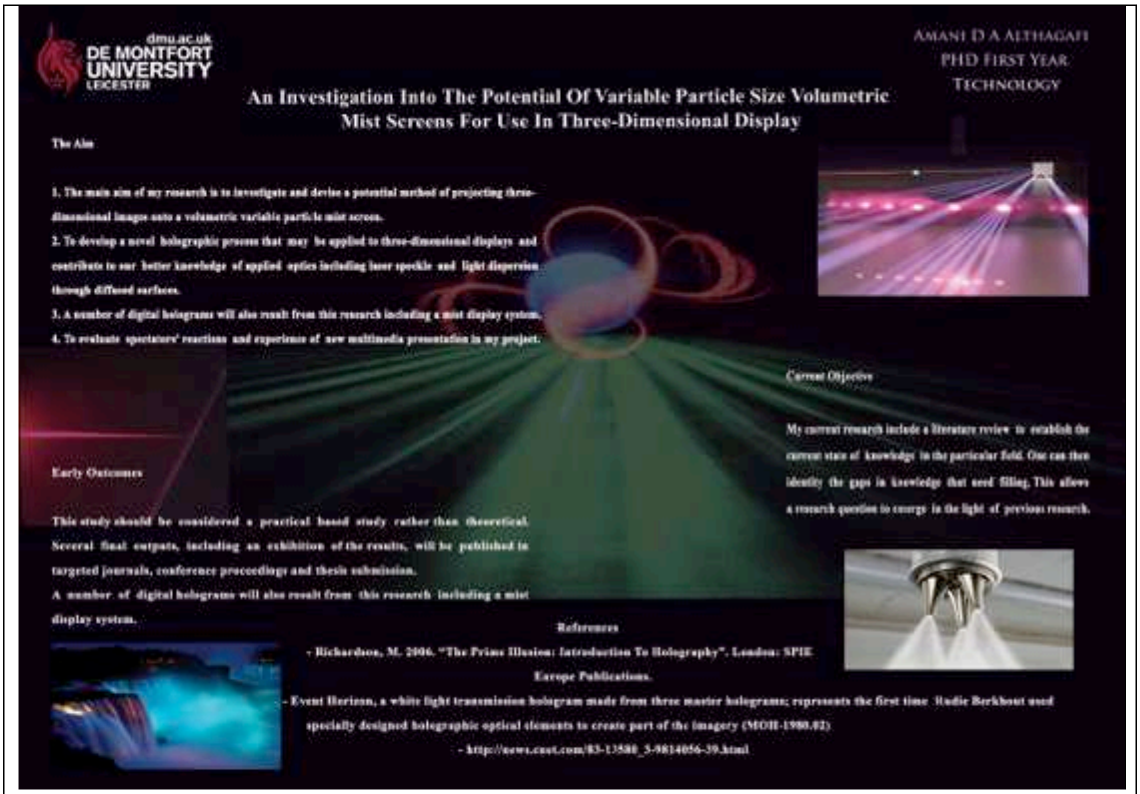
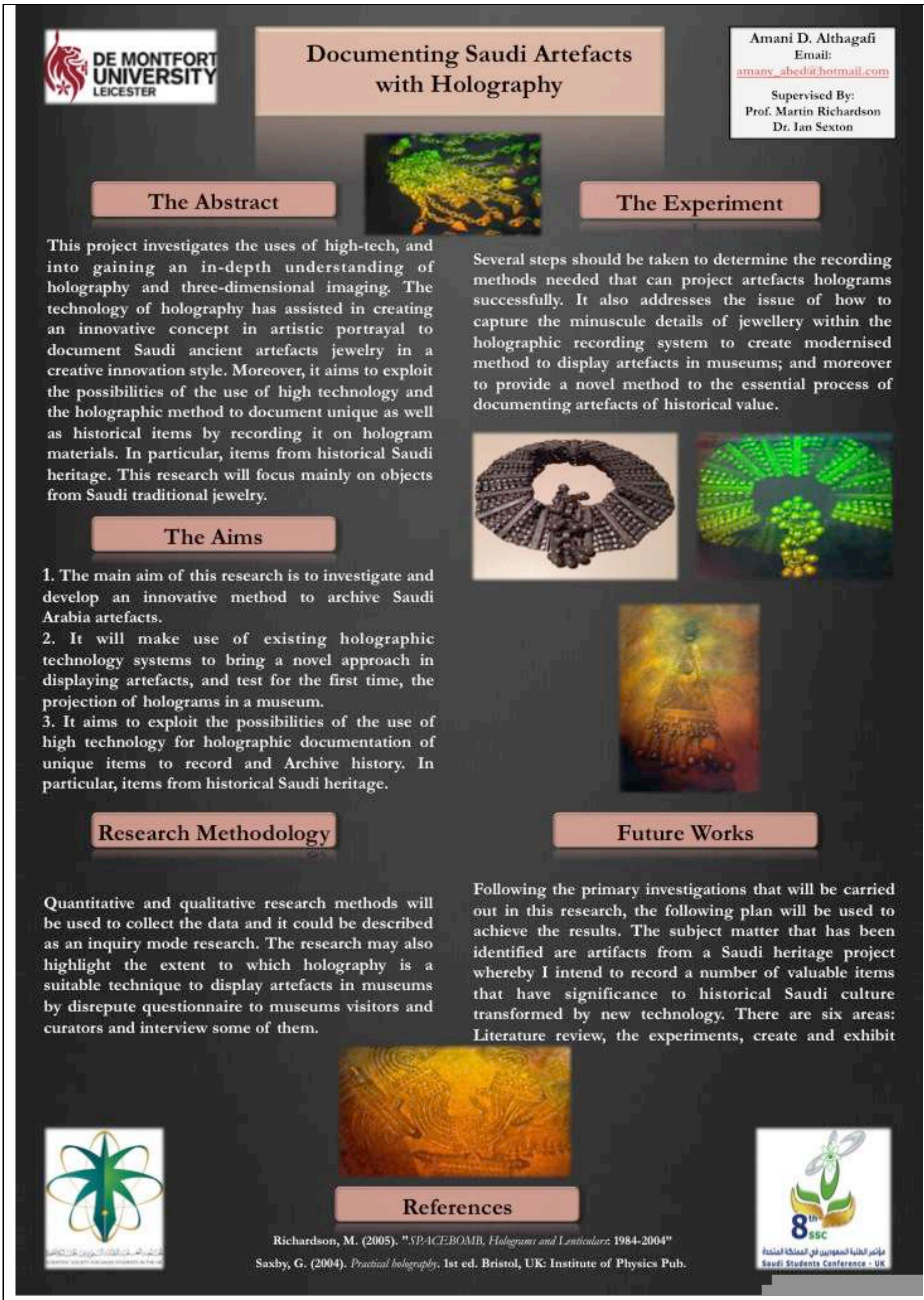


A photo of the Poster of the 6th Saudi Scientific International Conference

Certificate of Poster Participation of the 8th Saudi Student Conference at Queen Victoria Elizabeth II Conference Centre, London.



A photo of the Poster of the 8th Saudi Student Conference

Appendix D

Letteres

1. Holographic Support Letter
2. Research collecting Data (Field Trip) Arrangement Letters.

الهيئة العامة للسياحة والتراث الوطني
Saudi Commission for Tourism & National Heritage

الرقم:
التاريخ:
المرفقات:

الى من يهمه الامر ١٤٣٧/١٠/١٧هـ

السلام عليكم ورحمة وبركاته،

إن مستقبل الصور الثلاثية الأبعاد (الهولوجرام) واعد، ونحن نعتقد أنه طريقة جيدة لتوثيق التراث، لأنه يعطي الإحساس بالعمق من خلال المشاهدة.

أماني درويش عابد الثقفي هي طالبة دكتوراه وأطروحة بحثها بعنوان " تسجيل الثقافة: التحقيق في التصوير المجسم لتسجيل وعرض تراث شبه الجزيرة العربية لتطبيقات المتحف". وهي مبتعثه من جامعة أم القرى، مكة المكرمة، للدراسة في المملكة المتحدة.

وقد قدمت الباحثة في المتحف الوطني محاضرة عن استخدام تقنية الهولوجرام في المتاحف، ولذلك، فإننا نعتقد أن يكون الهولوجرام مشروع مستقبلي ذو قيمة.

وتقبلوا تحياتنا وتقديرنا ،،،،

مدير عام المتحف الوطني
جمال بن سعد عمر

General Department of the National Museum
Saudi Commission for Tourism & National Heritage

ص ب ٦٦٦٨٠، الرياض ١١٥٨٦، المملكة العربية السعودية، هاتف ٨٨٠٨٨٥٥ ١١ ٩٦٦+ فاكس ٨٨٠٨٨٤٤ ١١ ٩٦٦+
P O Box 66680, Riyadh 11586, Kingdom of Saudi Arabia, T: +966 11 8808855 F: +966 11 880 8844
info@scth.gov.sa www.scth.gov.sa

Holographic Medium Arabic Support's Letter from SCTH

Kingdom of Saudi Arabia
Ministry of Education
Umm Al-Qura University
(031)

المملكة العربية السعودية
وزارة التعليم
جامعة أم القرى
(٠٣١)

سعادة / وكيل الجامعة للدراسات العليا والبحث العلمي رئيس اللجنة الدائمة للابتعاث والتدريب

حفظه الله

السلام عليكم ورحمة الله وبركاته .. وبعد،-

نسأل الله لكم العون والسداد ...

افيد سعادتكم علماً بأن المبتعثة لمرحلة الدكتوراه/ اماني درويش عبدالله الثقفي ، قد قامت برحلة علمية للمملكة العربية السعودية من ضمن متطلبات إنجاز أطروحتها للدكتوراه وذلك في الفترة (من 16 th April 2016 إلى 15 th July 2016) والتي استمرت قرابة ٩٠ يوماً ، وقد كنت المشرف العلمي عليها خلال فترة رحلتها العلمية والتي أنجزت فيها الطالبة ما يتعلق بالجزء الميداني لموضوع رسالتها.

لذا اطلب من سعادتكم مخاطبة الملحقية الثقافية بلندن بأن المبتعثة المذكورة قد اتمت متطلبات الرحلة العلمية في الفترة المحددة وذلك لإستكمال باقي الإجراءات اللازمة.

وتفضلوا بقبول وافر التقدير......

عميد كلية التصاميم

د. عبد المجيد بن محمود صباغ

A Letter that proved the researcher completed a field trip in the KSA

ukgroupa@uk.mohe.gov.sa >

طلب مقبول

February 26, 2016 at 8:14 AM

اسم الطالب	اماني درويش عبدالله الثقفي
رقم الهويه	1017799956
رقم الطالب فى الملحقيه	UMU375
رقم الطلب	13500633
نوع الطلب	طلب رحلة علمية
تاريخ تقديم الطلب	11-02-2016
تاريخ آخر تحديث	26-02-2016
حالة الطلب	مقبول
ملاحظات	السلام عليكم، نود الإفاده بأن طلبك وردنا من قبل جهة الإبتعاث بالموافقة على الرحلة العلمية لمدة 90 يوماً اعتباراً من تاريخ 16/04/2016م الموافق 09/07/1437هـ. مع تمنياتنا لك بدوام التوفيق اضغط هنا لتقييم الخدمة

Acceptance Letter (via email) to travel for a field trip, from Saudi Bureau in London.

To whom it may concern

This is to confirm that Amani Darwweesh Althagafi is a PhD student under my supervision at De Montfort University, Leicester. I confirm that Amani is required to make Field Trip's based on her research is based on museums for the period of 3 months. From Saturday 16th April 2016 To Friday 15th July 2016

Yours Sincerely,

Martin Richardson PhD ARPS
Professor Holography

Faculty of Technology
Imaging & Display Research Group
2.27 Queens Building, The Gateway
Leicester LE1 9BH

T: +44 (0) 116 207 8678 (ext: 8678)
E: mrichardson@dmu.ac.uk

رسالة هاتفية

سعادة الملحق الثقافي السعودي ببريطانيا سلمه الله

السلام عليكم ورحمة الله وبركاته

بالإشارة إلى الاستدعاء المقدم لنا من المبتعثة/ أماني بنت درويش عبدالله الثقفي ، (السجل المدني ١٠١٧٧٩٩٥٦) رقم الملف (U375) المتضمن ، انها تقدمت بطلب القيام برحلة علمية للمملكة لمدة ثلاثة أشهر اعتباراً من ٢٠١٦/٤/١٦م ، عبر البوابة الالكترونية لوزارة التعليم العالي إلا أن طلبها تم رفضه بسبب عدم وجود خطاب من الجهة التي سوف تتولى الاشراف عليها اثناء قيامها بالرحلة العلمية ، وبعد مخاطبة الكلية التابعة لها المبتعثة فقد وردنا خطاب سعادة عميد الكلية والذي يفيد بأن الكلية سوف تتولى الاشراف عليها اثناء قيامها بالرحلة العلمية .

عليه أمل من سعادتكم التكرم بالاطلاع وقبول طلبها حتى يتسنى لها القيام بالرحلة .

شاكرين تعاونكم ورعايتكم لأبنائنا المبتعثين .

وتقبلوا خالص تحياتي ......

المشرف العام على إدارة البعثات

٢١/٤/١٤٣٧هـ

د . أحمد بن يوسف بن أحمد برقاوي

الرقم: ٢٢٠٠٥٦٠٠٤٢٧ التاريخ: ٢١/٤/١٤٣٧هـ المشفوعات:

٢٦٥/د
٢٠/٥/٢٧ ١هـ
بدر

سعادة / مدير عام المتحف الوطني **حفظه الله**

السلام عليكم ورحمة الله وبركاته

نفيد سعادتكم بأن طالبة الدراسات العليا/ أماني درويش الثقفي بصدد إعداد رسالة الدكتوراه (تقنية الهولوجرام) ويتطلب البحث توثيق وحفظ الحلي السعودية والتقليدية الأثرية بهذه التقنية، وترغب في زيارة المتحف الوطني لجمع المادة العلمية لإنجاز رسالتها.

أمل التكرم بتسهيل مهمتها، ويمكن التواصل معها على العنوان التالي:

ايميل amany_abed@hotmail.com.

وتقبلوا تحياتنا وتقديرنا،،،

مدير عام البحوث والدراسات الأثرية

د.عبدالله بن سعود السعود

صادر

الرقم : ٨١٩٩

التاريخ : ٣٠/ ٥/ ١٤٣٧

المرفقات : بدون

٧٠٠١٤٠٢٩٠٣

سعادة رئيس قسم الآثار بكلية السياحة والآثار بجامعة الملك سعود حفظه الله

السلام عليكم ورحمة الله وبركاته

نفيد سعادتكم بأن طالبة الدراسات العليا/ أماني درويش الثقفي بصدد إعداد رسالة الدكتوراه (تقنية الهولوجرام) ويتطلب البحث توثيق وحفظ الحلي السعودية والتقليدية الأثرية بهذه التقنية، وترغب في زيارة متحف الآثار بجامعة الملك سعود لجمع المادة العلمية لإنجاز رسالتها.

أمل التكرم بتسهيل مهمتها، ويمكن التواصل معها على العنوان التالي:

إيميل amany_abed@hotmail.com.

وتقبلوا تحياتنا وتقديرنا،،،

مدير عام البحوث والدراسات الأثرية

د .عبدالله بن سعود السعود

٢٦٤/د
٢٠/٥/١٤٢٧هـ
بدون

سعادة / مدير عام المتاحف حفظه الله

السلام عليكم ورحمة الله وبركاته

نفيد سعادتكم بأن طالبة الدراسات العليا/ أماني درويش الثقفي بصدد إعداد رسالة الدكتوراة (تقنية الهولوجرام) ويتطلب البحث توثيق وحفظ الحلي السعودية والتقليدية الأثرية بهذه التقنية، وترغب في زيارة عدد من المتاحف الحكومية والخاصة لجمع المادة العلمية لإنجاز رسالتها وهي:

- **المتاحف الحكومية**

١. متحف العاصمة المقدسة
٢. متحف قصر خزام
٣. متحف قصر شبرا بالطائف

- **المتاحف الخاصة**

١. متحف السلام عليك أيها النبي بمكة المكرمة
٢. متحف التراث الإنساني بمكة المكرمة
٣. متحف العمودي بمكة المكرمة
٤. متحف عبدالرؤوف حسن خليل بجدة
٥. متحف الجفيني بجدة
٦. متحف الشريف بالطائف

آمل التكرم بتسهيل مهمتها، ويمكن التواصل معها على العنوان التالي:
ايميل amany_abed@hotmail.com.

وتقبلوا تحياتنا وتقديرنا،،،

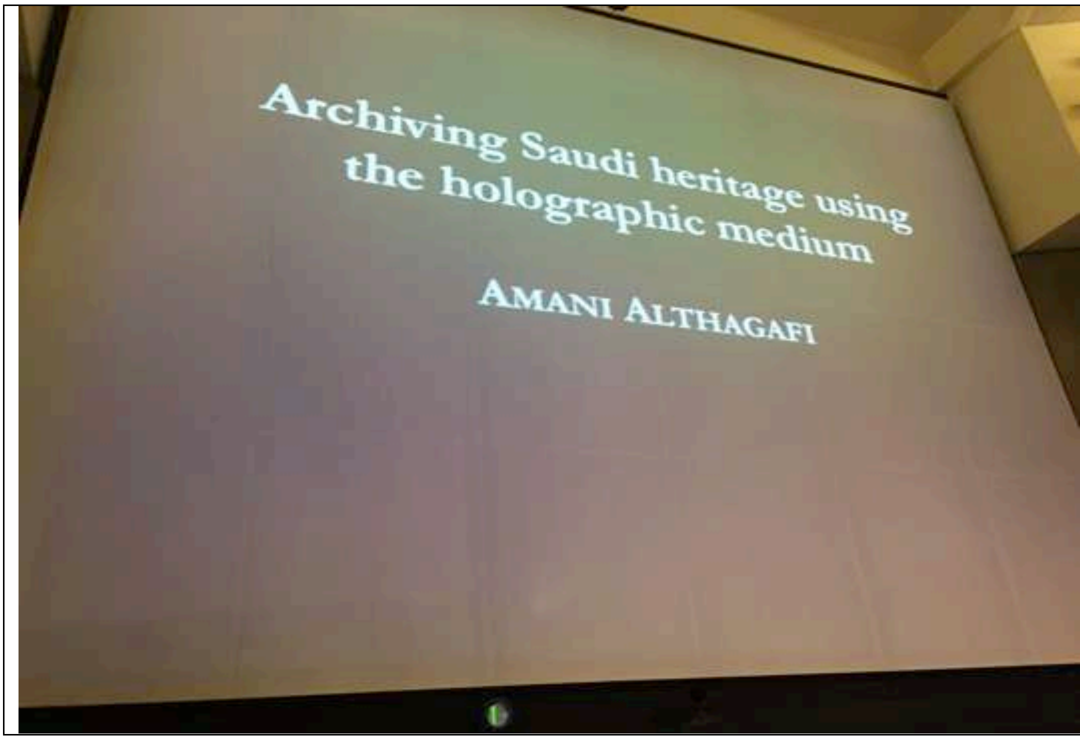
مدير عام البحوث والدراسات الأثرية

د.عبدالله بن سعود السعود

Appendix E

Photos of the Researcher through Ph.D Journey

The researcher displaying her first poster at the Saudi Students' Conference in London, 2012



The researcher giving a talk about the 3D medium, inside The National Museum Dar Al-Tawheed Hall in Riyadh, KSA, 2016

Appendix F

Darkroom Chemicals
Reflection Holograms process
Important observations

- Coated sensitive green or red plates required for recording hologram procedure.
- Preparing the liquids (developer and bleach) to reveal the hologram.
- Firstly, remember every time you change the substance that you are using, it is important to use different tools, otherwise contamination will occur.
- Attention: when you drop the plate in the liquid, remember that the glass must be turned down, and the emotion side must always face up on the tray. Otherwise, the sensitive plate could be scratched.

Procedure

1) Protect the recorded sensitive plate with any empty box to take it to the darkroom; there place it through the subject.
2) When you enter the holographic laboratory: lock the laboratory – that will show that someone in the room is using a laser and no one will be able to enter in the laboratory. (Remember: turn the key on and then click reset.)
3) With a white box and a weight, "stop" the laser and turn out the safe light (green one); wait for some minutes.
4) Now be careful take out that white box (the shutter) to expose the laser to the plate for 18 to 20 seconds. It is important to be careful with the table (Pinch). Don't lean on it in the holographic laboratory as any extra vibration can destroy the hologram process.
5) After that, take the plate to the darkroom; remember to put it in the right box.
6) In the darkroom, you should take two beakers and put 1000ml of water (doesn't need to be distillate – can be from the tap).
7) Put the beaker into a machine that, with a little plastic pellet, will mix the liquid completely (don't forget to put on gloves).
8) Drop the liquid to clean your plate, then wipe the plate carefully with tissue, also a small squeegee, remove the excess of the liquid.
9) To finish: wash the plate with water, drop the liquid from the first beaker into the plate, once again wash in the water and drop the liquid from the second beaker (formula below) onto the plate to take on the dark appearance.

Finally, you can soak the sensitive plate once again in clean water, then wipe it carefully with soft tissue and finally dry it with hair dryer.

Theoretically, those k=beakers liquids, cannot be used more than once, because the reaction between the liquid and the air make the PH of the liquid change (oxygenation of the liquid).