Online Museum Information Systems with
Digital Representations of Collections

Phillip Wilkinson
071532341
Dr G. Morgan

Abstract

Museums have an important role in society, safeguarding the collective memories of society and human culture. They adhere to strict policies promoting the accessibility and preservation of their collections. These collections are a source of information, education and enjoyment to those willing to visit them. Though, in this age in which information can be shared across the World Wide Web and reaching a global audience, access to information stored within a museum is comparatively limited. The aim of this dissertation is research into this limitation with the outcome being a system that improves this accessibility whilst promoting the purpose of museums.

Declaration

I declare that this dissertation represents my own work except where otherwise stated.

Acknowledgements

Firstly, credit is due to my supervisor Dr Graham Morgan, who planted the seeds for this dissertation. Since research was required into areas of technology that were relatively new to me, I would like to thank the following people for their support and assistance when looking into their domain:

Mr Charlie Snelling

Project Officer for the Design and Innovation group at the Open University

Miss Jo Iacovides

PhD student in the Institute of Educational Technology at the Open University

Miss Sim Panesar

Keeper of Art at Tyne & Wear Museums and Archives

Mr Alex Croom

Keeper of Archaeology at Tyne & Wear Museums and Archives

Dr John Shearer

Demonstrator at the University of Newcastle Upon Tyne

Contents

1 Introduction

1.1 The Digital Revolution

For 40 years, the Long-playing record album was the primary medium for the publication and preservation of music. The LP stored audio signals as a physical texture embedded into the grove of a vinyl disk, representing it as a continuous wave. As computing technology advanced the introduction of microprocessors saw digital recordings become a practical means to represent analogue information. When the compact disc was launched the use of LPs quickly diminished, starting a trend towards digitization of information. This trend has continued to the present day with digital cameras becoming the standard tool for recording video and the UK switching its TV and Radio transmissions to a digital signal. With this movement the majority of information disseminated in society is now digital.

Representing documents, images, movies and audio as a series of bits has allowed the speed offered by processors to be utilised for their creation, manipulation, transmission and storage. Digital representations can be updated in real time, with instant feedback and then shared over the internet, reaching a global audience. These representations can be copied and backed up assuming that that if something is worth creating and transmitting, it is worth preserving.

Digitization has led to convergence of the computing, telecommunications and media sectors of society. Harnessing the ubiquitous and pervasive nature of computers we are now living in an age in which digital information can be accessed by anyone, regardless of geographical or temporal distances. This has led to the increased sharing of information for the benefit of collaborative research. The International Council of Museums (ICOM) stated that "*Museums hold primary evidence for establishing and furthering knowledge*"[ICOM, 3], showing that museums have an important role in society.

1.2 Museums Role in Society

The Museum Assocation agreed upon the definition of museums as: *"... institutions that collect, safeguard and make accessible artefacts and specimens, which they hold in trust for society"*[MA]; with an aritfact being any object constructed or modified by humans. Museums store artefacts to benefit society and further knowledge. Therefore their role in society is to protect and share the collections contained within. Collections reflect society's cultural progression over time, explaining why they are considered highly valuable.

The importance of these artefacts has led to museums controlling the public's access to their collections. The accessibility of these collections set by ICOM is: "*Museums have a particular responsibility for making collections and all relevant information available as freely as possible...*" [ICOM 3.2]. Thus any individual should have access to the collections held in a museum. However, due to the rarity and delicate nature of certain artefacts they must be stored in such a way that access is limited.

A museum must maintain a balance between their obligations to provide public access to their collections and to safeguard them for the benefit of future generations. The Museum Association's code of ethics states that a museum should "*Use a variety of means to improve access, such as outreach, publishing or websites*"[MA 3.9] Google recently announced that it will be digitizing the National Museum of Iraq collections, and will publish the digital images representing the collections in early 2010.

Google's work with the National Museum of Iraq highlights the benefits of information digitization. CEO Eric Schmidt is quoted as saying "*I can think of no better use of our time and our resources to make the images and ideas from your civilization, from the very beginning of time, available to a billion people worldwide*" [MAIL].

1.3 Aim of this Dissertation

This dissertation features research into the principles behind digitization; accessibility and preservation. Focussing on how the advantages of digital reproduction can be applied to the museum domain. Using direct research collated from The Great North museum and historical professionals, a system has been developed following the principles of digitization and utilizing state of the art technologies. 3D modelling techniques were used to determine the best way of producing high-quality digital representations of artefacts. Featuring a comparative look at different distribution methods, a strong case is made for the use Rich Internet Applications (RIA) for distributing models of large file sizes to as many people as possible.

Research conducted into current projects that have similar goals provided a solid background in this concept including:

- Digitization of Information
- The Implementation of Technology in Museums
- Current uses of 3D Technology
- Distribution Methods

The outcome of this research is a set of common themes and goals which can be directly applied to the ICOM code of ethics. To ensure the suitability of the developed application bespoke research was conducted into:

- A Comparative look at 3D Scanning Technology
- Information used in Historical Research
- Historical Research Methodologies and Resources

Using this research in conjunction with information elicited from historical professionals a set of functional and non-functional requirements was created. These requirements were used to develop an application that allows the viewing of 3D models.

Initially the aim of this dissertation was to increase the accessibility of museum collections to benefit historical research. Due to the commitment of museums to provide access to anyone and the opportunities presented by Rich Internet Applications this aim has been expanded to develop a system that publishes museum's collections online, making them available to anyone.

Aim: To develop a system that improves the accessibility of museums artifact to benefit historical research.

Goals:

- Research 3D technologies that are currently being utilized, focusing on availability, quality and distribution methods.
- Analyse current historical researching methodologies, including resources used and establish which information is commonly sought after.
- Elicit raw requirements from potential users and use information gathered from research to establish a set of requirements.
- Create a Rich Internet Application (RIA) that allows users to view information pertaining to a specific collection.
- Develop the RIA so that users have the ability to stream 3D models or download and store them for offline use.
- Evaluate the system and determine whether it meets the elicited requirements and determine a compilation of advancements for the system

1.4 Development Methodology

The application has been developed following the software engineering process shown in Figure 1. Including the reasons behind the strategy or methodology this dissertation has used.

The development process was then evaluated as a whole, reflectively critiquing the outcome of each stage, establishing whether they've ensured the continuous progression towards the aim of this dissertation. The feasibility of implementing the application will also be discussed, with clear definition of improvements including future developments that will further ensure the aim of this dissertation. Due to digitization still being a developing field, a speculative look at the *Digital Revolution* [SCHO] will also be discussed.

Finally, this dissertation will draw to a close by reflecting back on the progress made and will feature any conclusions that can be made, including:

- Where the original Aims & Goals met
- The feasibility of implementing the strategies discussed
- Improvements that can be made
- The technical skills and knowledge I've gained
- The potential for follow up work
- Future Research
- Final Thoughts

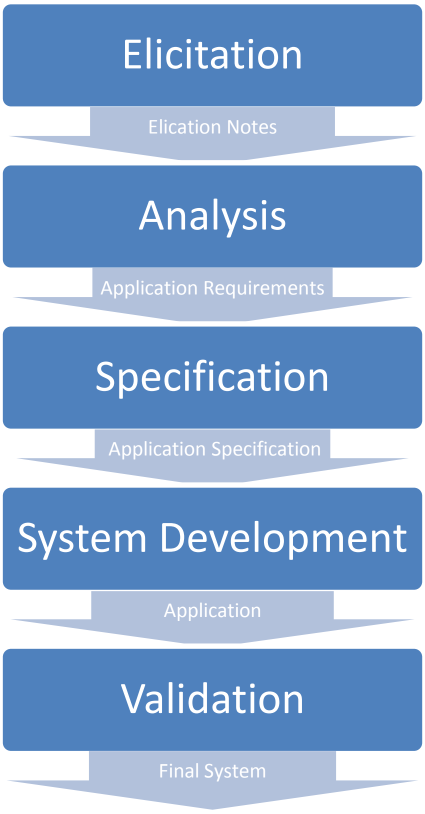

Figure 1 - System Engineering Process

2 Background Research

2.1 Information Digitization

The BBC archive holds all TV and radio published over the last 40 years. This has led to a collection of 4 million physical items. When BBC Archive expert Adam Lee was asked how the archives are being preserved for the future; he is quoted as saying: "*The BBC has put a lot of time and effort into preserving its archive and the latest thing is that we're now digitising it. So we're holding them as big digital files... storing those in computer storage in large data warehouses.*"[LEE] This has meant digitally encoding 600,000 hours of TV and 350,000 of radio content. Though everything in the digital archive is stored for 5 years, they are selective about what is archived due to costs associated with digitization. This project emphasizes the need for information representing our culture to be preserved, with the loss of such information having potentially devastating consequences.

The value of museum collections was made clear on February 23, 2009 when the National Museum of Iraq celebrated the return of 700 artefacts. Their collection was previously devastated by looters during the Iraq war, with thousands of artefacts lost. However, earlier this year digital images representing Iraqs heritage were published online thanks to a collaborative effort with Google. CEO Erich Schmidt noted the importance of making the museum collections accessible to billions of people worldwide. A common theme with digitization projects is the digital preservation of information.

American Memory is a gateway to the 9 million digitized collections stored in The Library of Congress. They provide people with online access to digital representations of their collections. These collections include prints, photographs, maps, sound recordings, motion pictures, books and sheet music, representing U.S. culture and history. The goal of American Memory is to make the collections as widely accessible as possible whilst ensuring the "*digital preservation of historical materials*" [TLC]. Though the majority of digitization projects focus exclusively on accessibility and preservation, the increased access to collections has led to greater collaboration.

The state of Minnesota is currently funding the interactive website ArtsConnectEd that displays high resolution images of the works of art from the Walker Art Center and The Minneapolis Institute of Art. The website uses PHP and the Symfony Web framework and allows users to comment on pieces and to create their own collection of favourites. This successful collaborative effort to digitize and share collections between museums is an example of the benefits of increased information accessibility.

The goals of these projects, preservation, accessibility and collaboration can be directly applied to the code of ethics set by ICOM.

"*Members of the museum profession should promote the investigation,* ***preservation,*** *and use of information inherent in the collections.*"[ICOM 8.4]

*"Museums have particular responsibilities to all for the care, **accessibility** and interpretation of primary evidence collected and held in their collections."* [ICOM 3]

*"Museums work in close **collaboration** with the communities from which their collections originate as well as those they serve"* [ICOM 6]

Due to the principles behind digitization closely matching the code of ethics upon which museums operate, as technology becomes increasingly available its implementation within museums has also increased. Bringing the principles of digitization forward this research will now focus on the current uses of technology in museums to ascertain how they've demonstrated these principles. This will show how information digitization can further the role of museums in society.

2.2 Technology Implementation in Museums

With the increasing availability of cheap computing power, museums have taken it upon themselves to utilize certain technologies. The now ubiquitous nature of the internet has meant the vast majority of museums have expanded their reach into the virtual domain through the creation and development of their websites. In a recent competition to expand internet domain names a proposal to incorporate a restricted top-level domain *.museum* was announced as the winner. This provides museums with a way to publish information from a source that is instantly recognised as credible. [MAIO]

The ability of a museum to publish credible information online has provided them with an excellent opportunity to expand their learning environments. Previously constrained by the physical building in which museum collections are contained, the usage of the internet has allowed museums to create a range of virtual learning environments. Several papers have been published by researchers, museum staff and educational professionals that advocate the use of Virtual Reality (VR) and Augmented Reality (AR) [PETRI]. This technology is still developing, and requires those with professional technical knowledge to create and maintain virtual environments.

Increasing visitor engagement is the common premise running through the papers and projects that support the use of VR & AR technologies. Online virtual environments that reflect museum collections allow for greater interactivity between a visitor and museum artefacts. This level of engagement surpasses the level of physical engagement that can be achieved due to the delicacy and value of museum collection. [LIN]

*"Museums have an important duty to develop their **educational** role and attract wider audiences from the community, locality, or group they serve. **Interaction** with the constituent community and promotion of their heritage is an integral part of the **educational** role of the museum."* [ICOM 4]

From this we can see that increasing interaction and engagement with museums visitors has lead to the expansion of the educational benefits of museums within society. Different techniques for computer aided education and historical research has been developed, one such example is ANCIENT CHARM.

Funded by the European Neutron Portal, ANCIENT CHARM [SAIN] uses neutron diffraction to extract information from artefacts. This technology is non-invasive and non-destructive but allows researchers to determine information pertaining to the construction of an artifact.This technology generates complex 3D models of scanned artefacts, but the implementation of this technology requires a high level of technical competence.

The recurring theme of the use of technology in museums is publishing information online including the use of 3D technology to create virtual museum spaces that incorporate their collections. However, the current implementations of 3D scanning technology require expensive, not readily available equipment which requires a high user skill level. Taking the current uses of technology by museums into account further research into 3D modelling techniques are required to ensure that the current trend of producing 3D representations of museum information is advanced.

2.3 3D Modelling Technology

The charity Wessex Archaeology has produced a video featuring a 3D model of Stonehenge and the surrounding landscape. The project (LiDAR)[GOSK] uses optical remote sensing technology to measure the properties of scattered light. A photo detector and receiver are attached to an aircraft and laser pulses are used to determine the shapes of objects, surfaces and distances. The technology also allows archaeologists to produce digital elevation models (DEM) of archaeological digs.

Building Rome in a Day is a project that has achieved similar results. A team at Washington University are currently collating the 2 million images of Rome already available on Flickr and finding common points to produce a 3D reconstruction of Rome [ROME]. A 3D construction of the Colosseum, using 2,106 images with 819,242 points, has already been created. Though these projects are capturing sites of great historical significance, the technology currently captures a wide area at the cost of detail. Therefore it would need to be applied on a smaller scale to accurately capture museum collections.

The National History Museum recently shared with the public 3D models of Neanderthals, mummies and extinct spiders through 3D glasses. [COX] An X-ray scanner is used to produce 3D models of objects which can then be virtually dissected. Visitors were invited to interact with models using whilst wearing 3D glasses, creating a rich and engaging experience. This approach is non-destructive and preserves the original object, but allows sophisticated research to be conducted upon it. The X-Ray technology used generates highly detailed models; however it requires specialist knowledge and expensive equipment.

With the widening availability of high-quality and low cost, digital cameras a new generation of software has evolved that generates 3D models from video. Probabilistic Feature-Based on-line Rapid Mode Acquistion (ProFORMA) is a system that generates 3D textured models in real time. [PAN] Objects are rotated by a users hand; partially generated models are displayed including instruction instructions. Currently being developed by Qi Pan, a PhD student at the University of

Cambridge, the system is not currently available though it was recently demonstrate using a standard webcam and PC. Creating 3D models requires a trade off between computational requirements; the users expected technical knowledge and the quality of model created.

The finite precision that computer systems allow means that objects are reduced to a discrete set of numbers. Sampling of a physical item (be it music, images or objects) leads to a range of values being produced to represent it. This range can be one of infinite possibilities that act of reducing this range to a finite range of digits is known as quantisation. The process of quantisation, mapping an infinite set of numbers to a limited set of numbers can lead to the loss of information. The sampling rate can be increased to produce a better approximation of an object; however, this increases the technical requirements and storage space of the computer processing it.

*"Members of the museum profession should promote the investigation, preservation, and use of information inherent in the collections. They should, therefore, refrain from any activity or circumstance that might result in the **loss of such academic and scientific data.**"*[ICOM 8.4]

Any 3D model produced that represents an artefact must be an accurate. Therefore a model must contain sufficient samples of an artefact, so that an observer will not notice any loss of information. Keeping in mind that the method used to create a model must not lead to the loss of information, whilst having low user skill expectations, the techniques used to generate a model will be looked in to.

2.4 3D Scanning Technologies

Digitizing museum collections will preserve delicate and rare artefacts and allow them to be accessible globally and for future generations. However, care must be taken to ensure the digitization process does not degrade the artefact; and that minimal information is lost.. There are numerous commercially available 3D scanners each using different methods to generate models of various qualities.

Contact scanners such as the Roland MDX40, probe objects thousands of times to produce a set of points around which a mesh is produced. This is comparatively slow process especially due to the need for multiple scans to capture all sides of an object. Though the MDX40 can produce high quality models, with a resolution of 0.04mm, repeatedly probing a delicate aritfact may degrade the original.

Due to the limitations posed by contact scanners, non-contact scanners are becoming more prevalent. The Konica Minolta VI-9i and Roland LPX-60RE emit laser pulses then detect the reflected light to determine the shape of an object. Both scanners will not degrade a scanned artifact and produce models of high quality. Though artefacts can be scanned using laser scanners, the time saved is offset by the initial cost of the equipment. A comparative look at different 3D scanning equipment can be seen in Table 1.

	Non Contact	Scan Method	Points per Scan	Point Accuracy	Resolution	Scan Rate	Cost
Konica Minolta VI-9i	Yes	Triangulation light block	300000	$^{+}_{-}0.05$	0.05	2.5	> £50000
Roland MDX40	No	Probe	1	0	0.04	4	£7000
Roland LPX-60RE	Yes	Spot-beam Triangulation	1	$^{+}_{-}0.1$	0.2	250	> £50000

Table 1 - 3D Scanning Technology Comparison

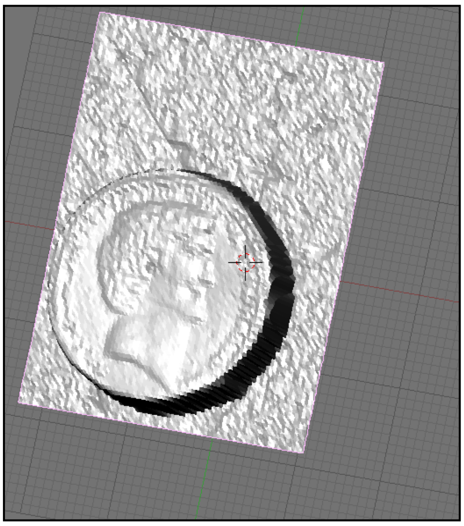

Figure 3 - 3D Model of Coin generated using a Roland MDX40 and imported into Blender.

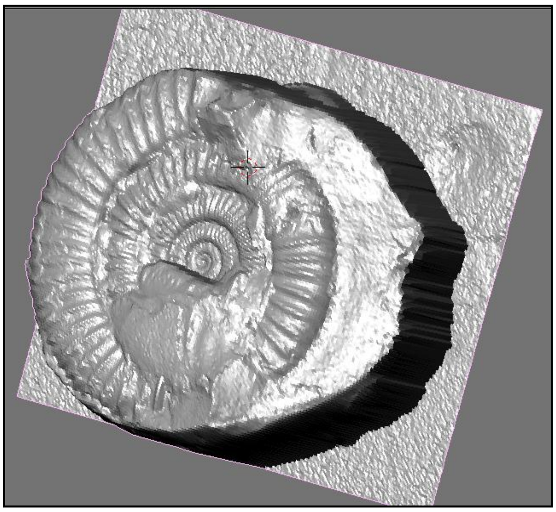

Figure 2 - 3D Model of Fossil generated using Roland MDX40 and imported into Blender.

Distributing these models online poses the problem of requiring a high bandwidth for anyone wanting to access highly detailed models. Taking onboard this need for detailed models at the cost of large file sizes, research is required into the most suitable way of hosting these objects and making them accessible online.

2.5 Distribution Methods

With Web Applications (Figure 4) the majority of data storage and processing occurs on a server with client computers requesting server resources and methods. As the performance of desktop computers increased Rich Internet Applications (RIA) were developed to utilize the processing power of the PC, whilst still maintaining the client server model. Therefore Rich Internet Applications (Figure 5) can be seen as the amalgamation of web applications and desktop applications. **Error! Reference source not found.Error! Reference source not found.** illustrates the way in which RIAs work; they can be seen as one coherent system with the front-end part of an application processed on the client. This allows an application to utilize the performance power of a desktop computer to generate rich graphical interfaces that are updated in real-time, whilst still drawing information from a remote server. RIAs are a relatively new architecture and currently there is no way to directly create an application without the use of an

additional browser plugin. Though, there are a plethora of plugins available (Table 2) with examples of their successful implementation.

Adobe Systems Incorporated, working with the BBC, recently developed BBC iPlayer using Adobe Air. A RIA that allows the streaming and downloading of TV and Radio shows selected by the BBC. It allows users to view BBC shows, online or offline whilst ensuring that its content is as highly accessible as possible. Although Adobe currently has the largest market share other RIA plugins are still in development.

JavaFX[JAVA] and Microsoft Silverlight[MICRO] were recently released as API to create and develop Rich Interent Applications. Using the JavaFX API developers can create applications that can run across browsers, desktops and mobile phones. Though JavaFX is faster than ActionScript by a factor of 12 [OLIV], only Adobe Air supports 3D graphics through the use of additional commercial open-source libraries.

It is worth noting however, that HTML5 is currently being developed with the aim of reducing need for a plug-in based Rich Internet Applications.[W3C] Though the specification is expected to reach W3C recommendation in the year 2022, some elements are currently working (<mx:canvas>). Again, there seems to be no indication of 3D support for this standard.

Due to the broad overview of the potential implementation techniques that can be utilised, further research into the current domain is required which will ensure that the application meets all the requirements of the end user.

3 Tools and Development Methodologies

The application has been developed using the software engineering process shown in Figure 1 - System Engineering Process This process splits development into different stages each with a specific purpose and outcome. Starting with the elicitation of information, and ending with the validation of the final application numerous methodologies and techniques have been utilized. This section discusses the tools and methodologies used and also give a brief explanation why.

3.1 Information Elicitation

When developing the application, it is important that the initial requirements are generated with full understanding of the domain in which the application is expected to exist, including potential users. With this in mind, the following elicitation techniques were used:

- Background Reading
- Interviewing, Questionnaires

Using reading material related to the use of technology in museums, the creation of digital content, and the purpose of museums, a clear picture of the domain was established. From this the information required for an effective digitization policy was established ensuring that the creation of the application did not create conflict. The following resources were used when researching the potential for digital artefact creation:

- Preserving Digital Information[GLAD]
    - Provided an introduction to the concept of digitizing information including specific reference to the methods and principles behind digital preservation.
- Digital Content Creation[EARN]
    - Introduction to the techniques behind the creation of digital media i.e. the conversion of real world objects to abstract digital concepts.
    - Starting a Digitization Center[ANDE]
    - Showed an effective strategy for creating a central hub, within which highly valued information is stored.
- The Digital Dialect[MITCH]
    - Presented an interesting look at how culture and society will change through the amalgamation of the virtual and real-world
- ICOM Code of Ethics[ICOM] & MA Code of Ethics[MA]
    - These codes provided a specific reference when discussing the purposes behind museums, allowing the system to developed with a clear idea of a museums domain.
- The Birth of the Museum: History, Theory, Politics[BENN]
    - Introduction to museums, their purposes and how they have developed grown along with society.
- 3D Model Databases: The Availability of 3D Models on the World Wide Web[COST]

    - Provided an overview of the availability of 3D models on the internet, including common formats and future developments.

By interviewing appropriate academic researchers and circulating questionnaires raw information was collated regarding historical research and museum usage.[Section 4.1.1] This information was used to generate a set of raw requirements for the application. The background information and raw requirements were further developed to a produce a specific set of functional and non-functional requirements.

3.2 Requirements Analysis

To establish the flow of information that occurs internally within museums, and externally with museums and visitors structured analysis techniques were utilized throughout this dissertation. These techniques and the notations used to represent them include:

- Dataflow Modelling (Data Flow Diagrams)
    - Showed the flow of information within museums and between museums and the public.
- Data Modelling (Entity-Relationship Diagrams)
    - Established the information provided by museums and information that pertains to artefacts.
- Data Dictionary
    - Provided a common glossary of terms used in this dissertation, including specification of information used by the application.

Using these techniques and the raw requirements elicited during the previous stage, a specific set of functional and non-functional requirements were produced. Designing and specifying the applications behaviour was done with these requirements providing a structure.

3.3 Application Specification

Information contained within the application is delivered visually; representational modelling was used to capture how information would be displayed. Based on the requirements established during the analysis phase the applications visual appearance and the flow of information were represented. This was done through the use of:

- Database Design
    - Establishing what and how information will be stored in the application.
- Data Flow Diagrams
    - A data flow diagram of the application was produced; showing how the flow of information would differ after it was implemented.
- System screen Diagrams
    - Including time-sequenced generation of diagrams, showing the changing appearance over time.
- Hardware-Software Interface Diagram

- Diagrams showing the digitization process from creation of a digital artifact, to its inclusion within the final system.

The designs produced allowed for the logical and systematic development of the application. However, the range of RIA plug-ins available meant that the possible frameworks available needed to be compared together to establish the most suitable.

3.4 Development

With the advent and development of Rich Internet Applications there were numerous plugins and development frameworks available. Table 2 shows a comparative look at the most widely used RIAs. The focus of this projects research into the area is on the frameworks support for 3D graphics and user interface design. As well as the reach of the final developed system i.e. what platforms the software is available on.

Framework	Software License	Programming Language	Supported Web Technologies	Performance (Speed)	Currently Supported Libraries		Supported Platforms	Current Proficiency
					3D Graphics	User Interface Construction		
Rich AJAX Platform	Open Source	JavaScript or Java	XML, HTML, CSS	Excellent	None	Adequate	Windows, Mac, Linux	Minimal
Adobe Flex	Mozilla Public License[MOZI]	ActionScript & MXML	XML, PHP, .Net, CSS, HTML	Good	Open-Source 3D libraries available	Excellent	Windows, Mac, Linux, Android, iPhone, Windows Mobile	Minimal
JavaFX	EULA [SUN]	JavaScript or Java	HTML, XML	Excellent	None as of yet	Good	Windows, Mac OS, Linux, Android, Windows Mobile	Good
Appcelerator Titanium	Apache 2[APAC]	Python, JavaScript & Ruby	HTML, PHP & CSS	Good	None	Good	iPhone, Android	Minimal
.Net Framework	Proprietary	C#, VB.NET, J#	HTML, PHP, ASP	Excellent	None	Adequate	Windows, Windows Mobile, Android, Mac OS	Minimal

Table 2 - Rich Internet Applications comparison

Based on the information in Table 2 - Rich Internet Applications comparison it was decided to pursue the development of the application using Adobe Flex for the following reasons

- Open Source License
- Excellent support for existing web technologies
- Supports 3D graphics through additional libraries
    - To implement 3D graphics the system utilizes the open source Papervision3D[PAPE] graphics library
- Facilitates easy user interface design
- Supported on multiple platforms
- Opportunity to develop skills in a new framework

Though JavaFX is still in development, there is an inclination of support for 3D graphics in the future. However, Java has a 77% penetration of the desktop PC market compared to Flash players 99%, Flash is clearly the most widely accessible web browser plug in that supports Rich Internet Applications.

After developing the application in Adobe Flex, further testing will provide feedback allowing for the evaluation of the suitability of the framework used.

3.5 Validation

To ensure system correctness, black-box testing was used with different use-cases, representing the typical interactions that will place in the application. Black-box testing refers to ignoring the internal workings of the application whilst using different inputs with a clear understanding of what is expected to be output will establish whether the application is handling information correctly. The application was tested in several areas, as show in Table 3.

Validating the application in the areas shown will establish whether the requirements elicited in initial stage of the development process have been met. This testing will also provide reference when determining feasibility of the applications implementation.

Testing Area	Description	Strategy
Data Integrity	Ability of the application to download process and display information without corruption or loss.	Store information on a remote server and analyse whether the correct information is shown.
Environment Testing	Ability of the application to run on different platforms, with various system specifications.	Install and run the application on different computers that run a variety of operating systems.
Performance Testing	How the applications performance changes when displaying models of various qualities.	Loading in models varying in quality and observe how the responsiveness of the application changes.
Load Testing	How the well the system copes with downloading models & information.	Store models varying in quality on a remote server and observe how long it takes the application to download and display it.
User Interface	How easy the application is to use.	Have a range of potential users perform a set of actions on the application.

Table 3 - Testing Areas and Strategies

4 Application Development

4.1 Elicitation

The purpose of this stage of the engineering process was to develop a fundamental understanding of the applications intended domain. A set of elicitation notes act as the culmination of research into literature, staff and pre-existing methodologies. This raw information is then used in the creation of the set of functional and non-functional requirements for the system. To effectively elicit useful information the focus of this stage was on the stakeholders within a museum and the current historical researching methodologies used. Therefore the intended content of the elicitation notes was information on:

- The current historical research methods used
- Resources commonly used for historical research
- Information pertaining to artefacts that is considered important
- Raw requirements of the system
- Intended behaviour and constraints of the final system

4.1.1 Quantitative Research

Establishing the historical research methods and information commonly used was done through an online questionnaire [Appendix]. This questionnaire was disseminated amongst staff working at the Great North Museum and students studying archaeology related degrees. Using the resources and relating to museums as a base, students and staff were encouraged to choose which they felt was important for historical research. The results of this can be seen in Figure 4.

Which of the following resources do you use for your work or research?

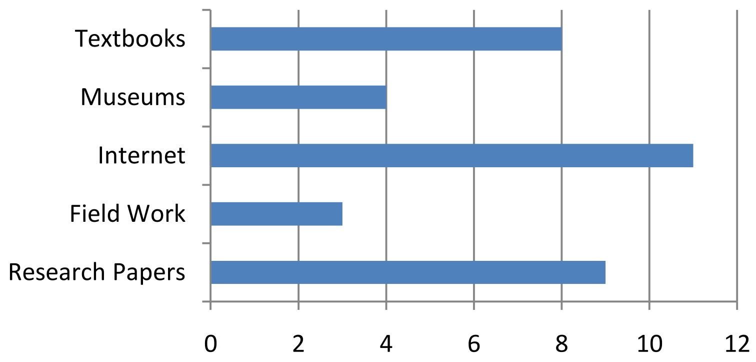

Figure 4 - Information Commonly used for Historical Research

The use of local, national and international journals was also introduced. Clearly, the internet is the most used resource for historical information, most likely to its now ubiquitous nature and the increasing prevalence of credible high-quality information online. Comparatively, museums are rarely used as a resource for historical research which is reflected in Figure 5.

How regularly do you visit museums, to view artefacts for work / research?

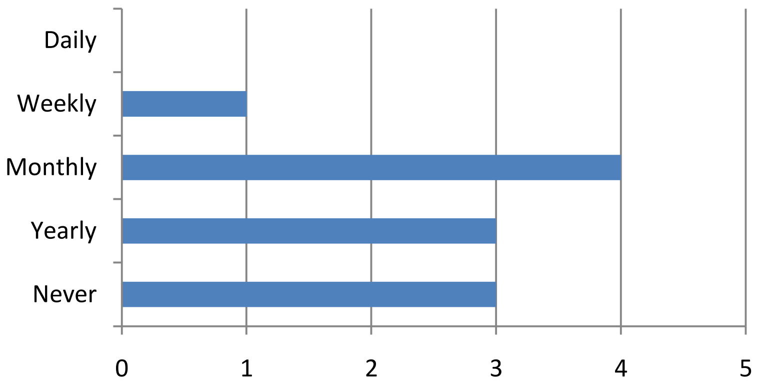

Figure 5 - How often museums are used for historical research

Low visitation numbers could be explained by the accessibility of information on the internet, compared to the process required to access artefacts. Though when comparing museum visitation figures to the amount of people online, there is no obvious trend. When asked for the main reason behind not visiting museums for historical research the most popular cited reason was the availability of credible and high-quality information elsewhere. The information commonly sought after can be seen in Figure 6.

What information do you feel is important when your research includes references to specific artefacts?

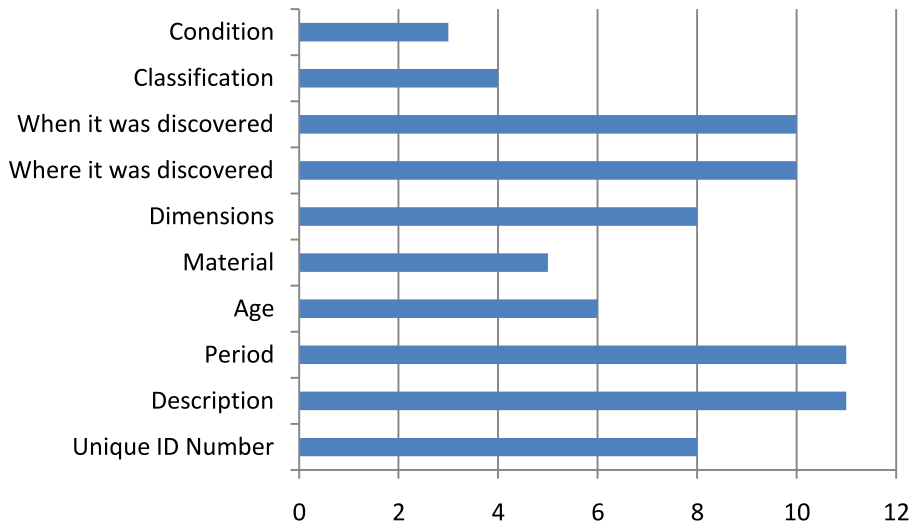

Figure 6 - Information Commonly used for Online Research

Suggestions were also put forward to include if, and where a collection is on display. But these results indicate which information is critical when researching historical artefacts. The most important being:

- Period of Origin
- Description

    - This is still quite ambiguous, the level of detail required within a description will different for users. Therefore, the same level of detail that is shown in museum displays will be used when writing the description for an artifact.
- Date & Location of discovery
- Dimensions
- Age

From the results there is no clear indication as to which information must be included with the digitized artefacts. Information will differ in importance to researchers depending on the area of research they are focussed upon. However, this research, combined with background reading, provided a good understanding of the domain and was used when establishing the applications requirements.

4.1.3 Elicitation Notes

4.1.3.1 Raw Requirements

For the application to be suitable for implementation by a museum it must meet and further the purposes set by the ICOM code of ethics. As previously discussed in this project the ethical code touches upon many areas including:

- Safeguarding and preservation of collections
- Continuous improvement of museum accessibility
- Collaboration with other institutions
- Commitment to improving visitor engagement and interaction
- Duty to develop their education role within society
- Hold information for establishing and furthering knowledge

Combining these different areas with the information elicited from a museums domain, provided a solid base upon which the applications functional and non-functional requirements were established.

4.1.3.2 Application Behaviour and Constraints

From previous research it is clear that a balance must be struck between the detail level of a model and the file size of a model. Making these models as accessible as possible requires low computational requirements to download and view them, i.e. the application should run on a standard PC. Therefore the system must behave in such a way to meet the following constraints:

- Low model file sizes
    - Ensuring the low storage and bandwidth requirements
    - Each model will have an associated Digital Object Identifier (DOI)
- High model quality
    - Ensuring digital artefacts contain the same information as their real-world counter parts
- Easy dissemination of information

    - Information pertaining to an artefact must be presented in such a way that it is easily readable by the general public, but still of value to historical research professionals.
- Low system file size
    - Ensuring it is as distributable as possible
- Low technical skill requirements
    - The system should require minimal technical knowledge to view artefacts

4.2 Requirements Analysis

Before the application was designed the domain in which the application will exist was clearly defined. This domain includes; the potential users of the system, the environment the application will run in and how it will function. Functionality is further broken down into functional and non-functional requirements. Specific application behavioural constraints are defined by the functional requirement; non-functional requirements refer to what the application must do to be implemented in the museum domain. Information elicited in the previous stage was used in the creation of these requirements.

4.2.1 Application Domain

Figure 9 shows the current flow of information between museums, collections and the general public. Regarding the public requesting to view a specific artefact, the permission to do so can usually be assumed; especially in cases were collections are stored in public view. However, researchers wishing to view a particularly rare artefact of historical significance will have to submit a written request. The process of submitting a request, the museum granting permission and the researcher visiting the artefact can occur over months.

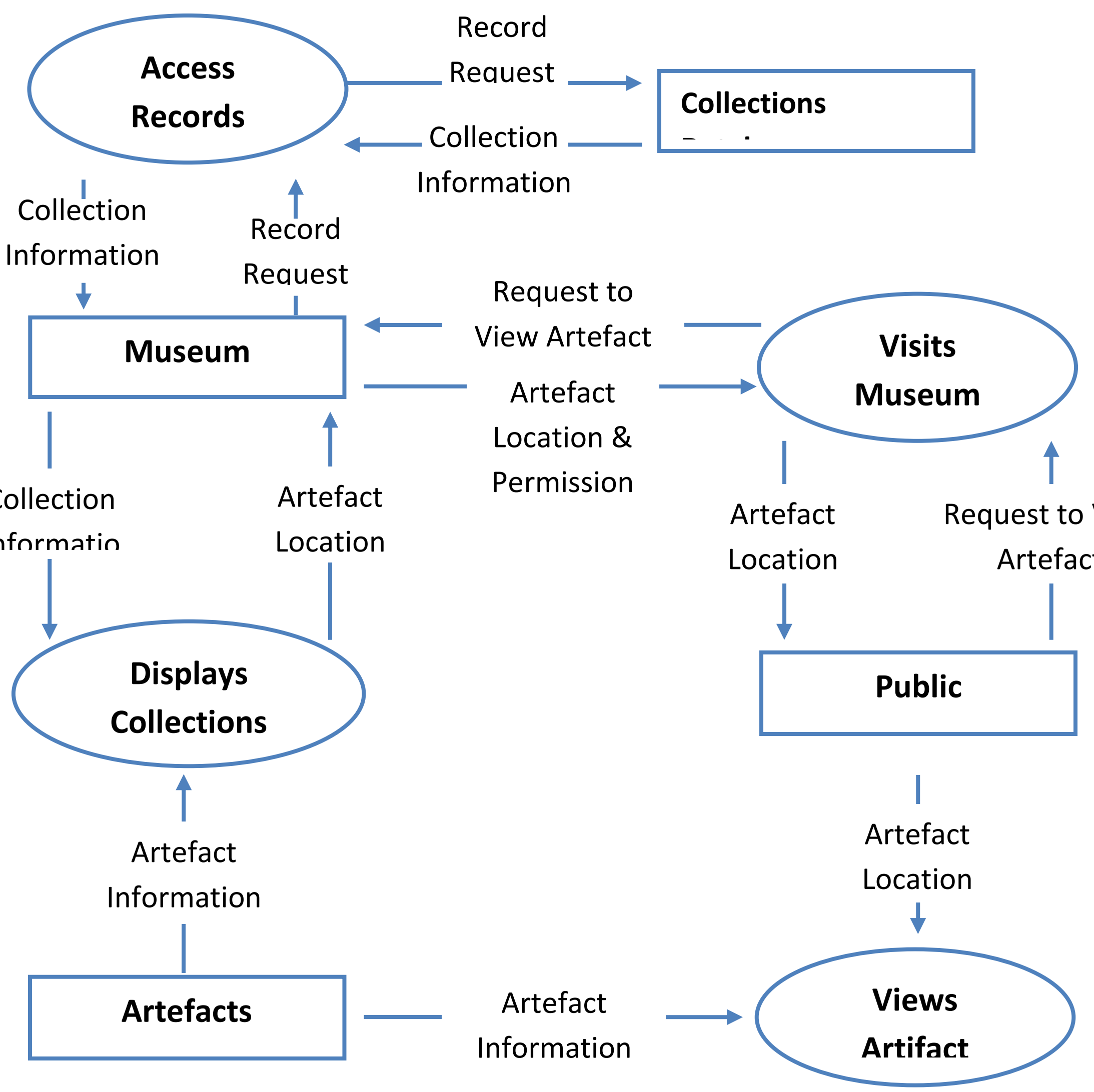

Figure 7 - Museum DFD

From the current flow of information, it is worth noting the limited interactivity available between the public and an artefact. In the majority of cases, the public will only have permission to view an artefact and information pertaining to it. However, researchers may be allowed to handle an artefact, though they'll have to submit a request, follow strict guidelines and the time they have to do so will be limited. Records pertaining to museum collections are currently stored electronically. However, access to this electronic information is, in the majority of cases, limited to certain staff members.

From the entity relationship diagram (ERD) shown in Figure 10 the relationships between visitors, artefacts and museums can be seen. Visitors have been sub-categorized based on their intentions when visiting a museum. Researchers are there to further historical research, whereas the public are there for enjoyment, education etc.

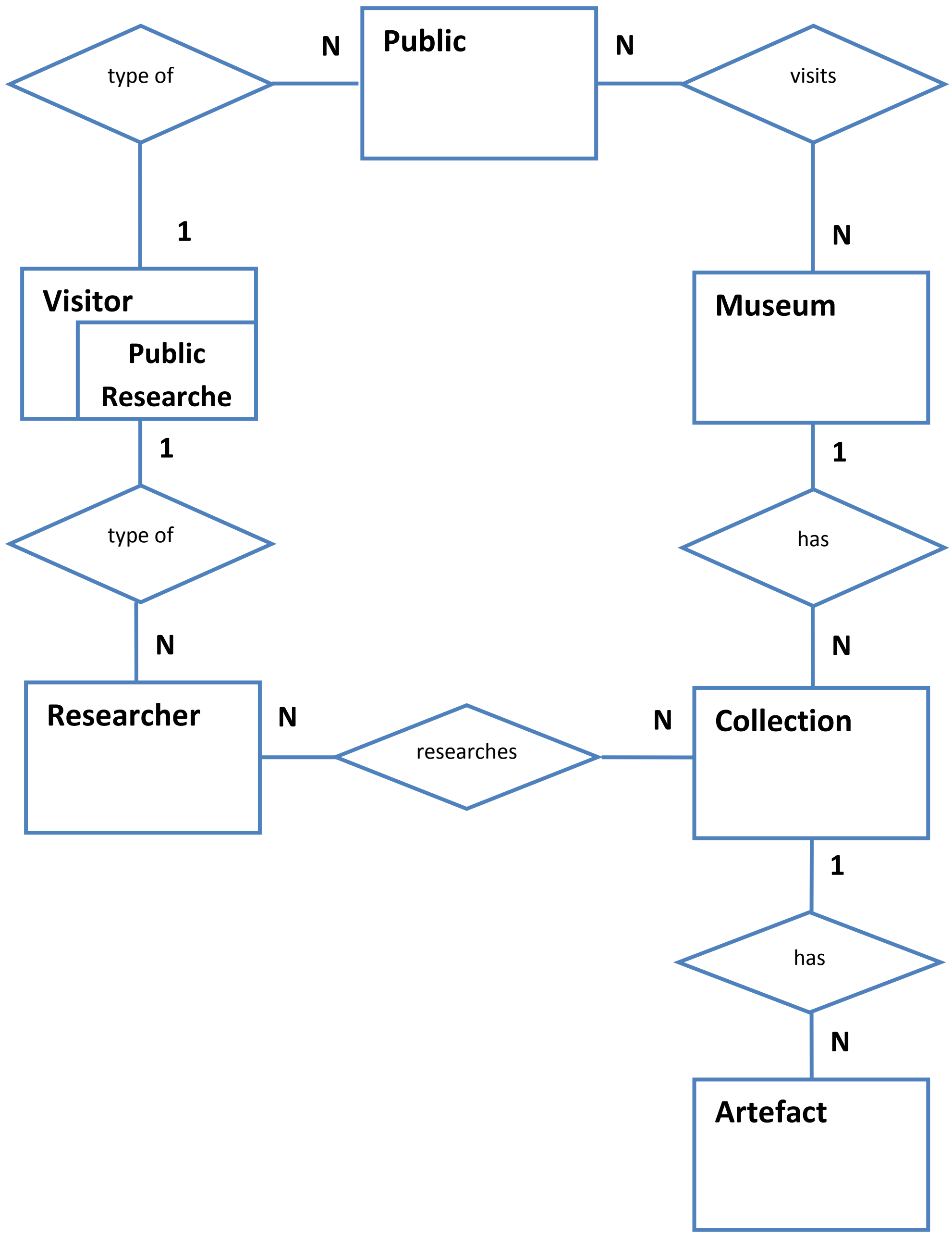

Figure 8 - Museum ERD

Visitors can view many collections by visiting many museums; museums contain many collections that consist of many artefacts. Though collections can be viewed and researched into by many visitors this is determined by its accessibility. Those of great historical importance will have limited access due to a museums commitment to their preservation, though following the correct procedure; they can be visited by many researchers though. It is worth noting that museums often share their collections to ensure the purpose of furthering knowledge. However, artefacts are associated with the museum they are currently on display in.

Having correctly modelled the museum domain and elicited information from the people involved the specific requirements of the application can be established.

4.2.2 Non Functional & Functional Requirements

Using the raw requirements and system behaviour procured in the elicitation stage combined with the museum domain models produced the functional and non-functional requirements of the application have been established. The requirements have been sub-categorized, fitting in directly with the purpose behind museums, they are as follows:

Preservation

NFR1 - The digitization process will not modify or degrade the artefact being scanned.

NFR2 - Relevant information pertaining to collections will be included with 3D models.

The application will include:

FR1 – Relevant Information:

- Unique Identifier (DOI)
- Name
- Period of Origin
- Description, including:
  - Information with the same level of detail as the records displayed with museum collections.
- Date & Location of discovery
- Dimensions
- Material
- Age

FR2 – A link to the credible source of the information included.

FR3 – Digital images and 3D models representing an artifact

NFR3- Models produced must be accurate representations of the artefacts they are based upon.

FR4 - 3D models will be generated using >10 000 polygons.

Accessibility

NFR4 - The application will utilize web technologies ensuring models are accessible online.

FR5 - Adobe Flex will be used as the framework for the application utilizing: PHP, CSS & HTML

NFR5 - The application will run on across multiple platforms.

FR6 – The final application will be compiled to .air format utilising the Adobe Air runtime environment

NFR6 - The application will run on a standard desktop PC.

FR7 - The minimum requirements for the application are as follows:

Windows: Intel® Pentium® III 1GHz or faster processor, 512MB of RAM

Mac OSX Intel Core™ Duo 1.83GHz or faster processor; 512MB of RAM

Linux: Intel® Pentium® III 1GHz or faster processor, 512MB of RAM

FR8 – The size of the final application will be < 5MB

NFR8 - Users will have the option of streaming models or downloading them for offline use.

FR9 - Model sizes will be limited to < 10MB

Interaction

NFR9 - Users will be able to view models from different angles and from different distances.

FR10 - Models can be rotated through 360 degrees around the x, y & z axis

FR11 – Users will be able to view a model from a translated range of 1mm to 1m.

NFR10 - Anyone with access to a PC will be able to use the application.

FR12 - The application will provide instant feedback to user input.

FR13 – The application will have an intuitive user interface

With these requirements and the established domain models the design and specification of the application was then formed.

4.3 Application Specification

Using the functional and non-functional requirements generated the intended outcome of this stage was an unambiguous design for the application. Screen designs were created to represent the user interface with these designs showing how information is displayed to the user. Incorporating a database design and a data flow diagram into the specification facilitated the modelling of the flow and storage of information of within the application. To provide a clear overview of the process of including 3D models in the application a hardware-software interface diagram was produced.

4.3.1 Database Design

Taking the material produced from the elicitation stage, the following database design includes the necessary information established in **FR1** & **FR2**.

Artefact Database		
Field Name	**Data Type**	**Purpose**
DOI	Text	(Digital Object Identifier) A unique identifier for an artefact.
Description	Text	A brief description of an artefact.
Name	Text	The historical name given to an artefact.
Period	Text	The age in which the artefact was created.
Material	Text	What the model was created using.
Dimension x	Real Number	Representing the length of an artefact.
Dimension y	Real Number	Representing the height of an artefact.
Dimension z	Real Number	Representing the depth of an artefact.
Discovery Location	Text	Where the artefact was discovered.
Discovery Date	Time-Date	When the artefact was discovered.
SourceURL	Text	A link providing a credible reference for information displayed.
ModelURL	Text	A link to the 3D model representing an artefact.
ImageURL	Text	A link to a picture of the artefact.

Including dimensions for an artefact allowed for the creation of a bounding box which was used when incorporating the requirements **FR10** & **FR11** within the application. Requirements **FR2** & **FR3** were met by including URLs to external resources. The flow this information, and the use of these URLs is illustrated in Figure 11.

4.3.2 Dataflow Diagram of Final System

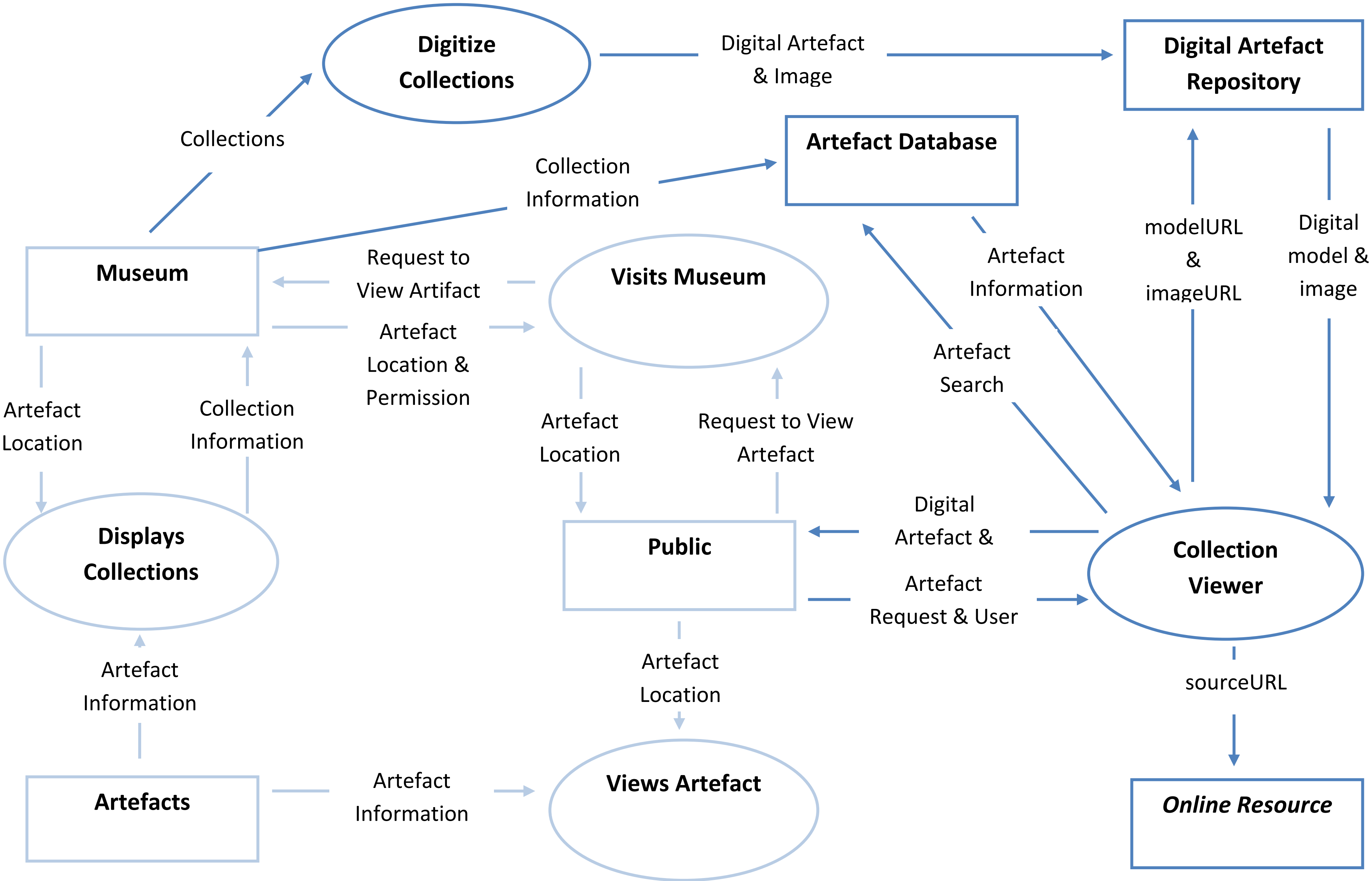

Figure 9 - DFD showing the flow of information within the application

4.3.3 Screen Designs

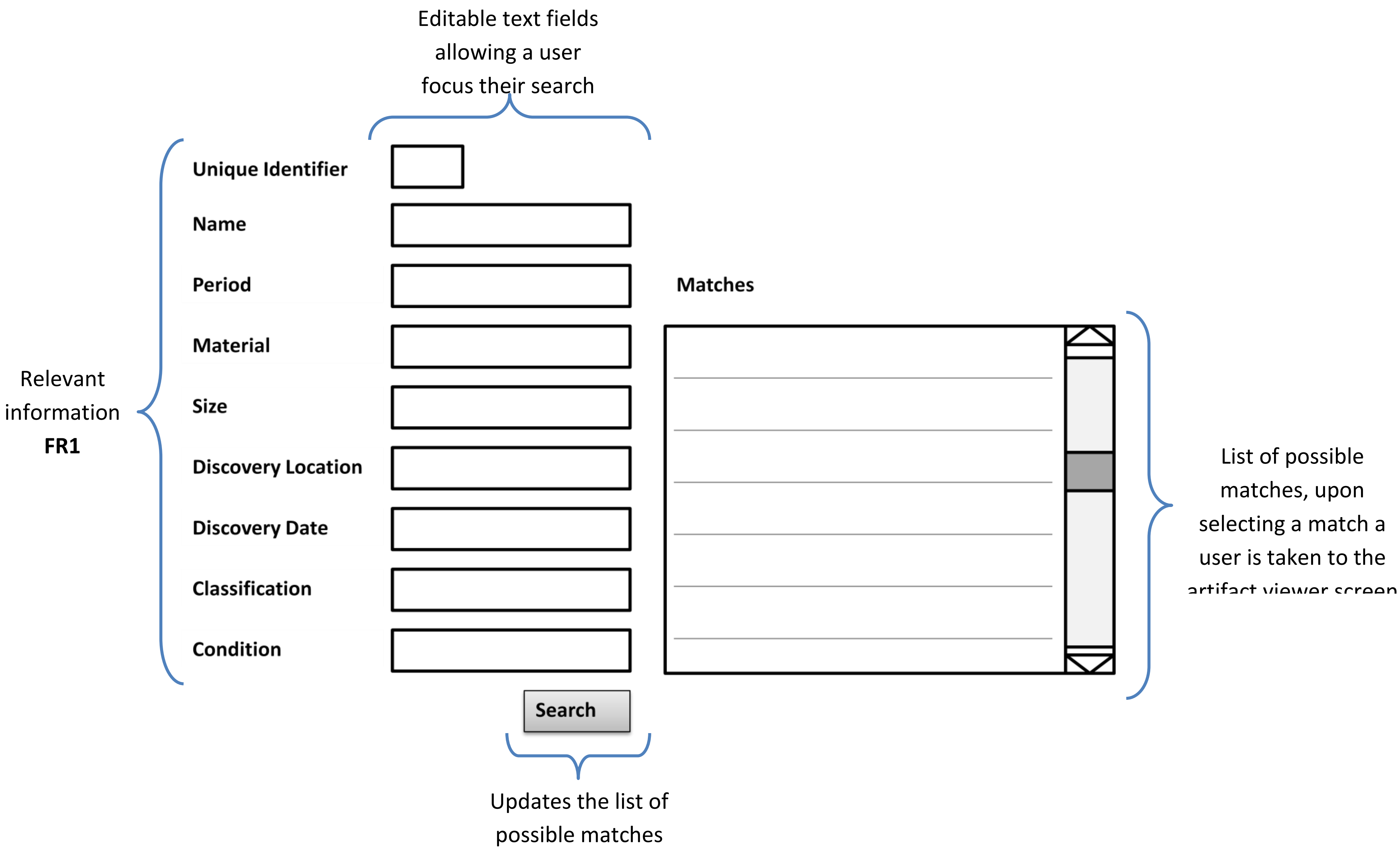

Figure 10 - Screen design of application home screen

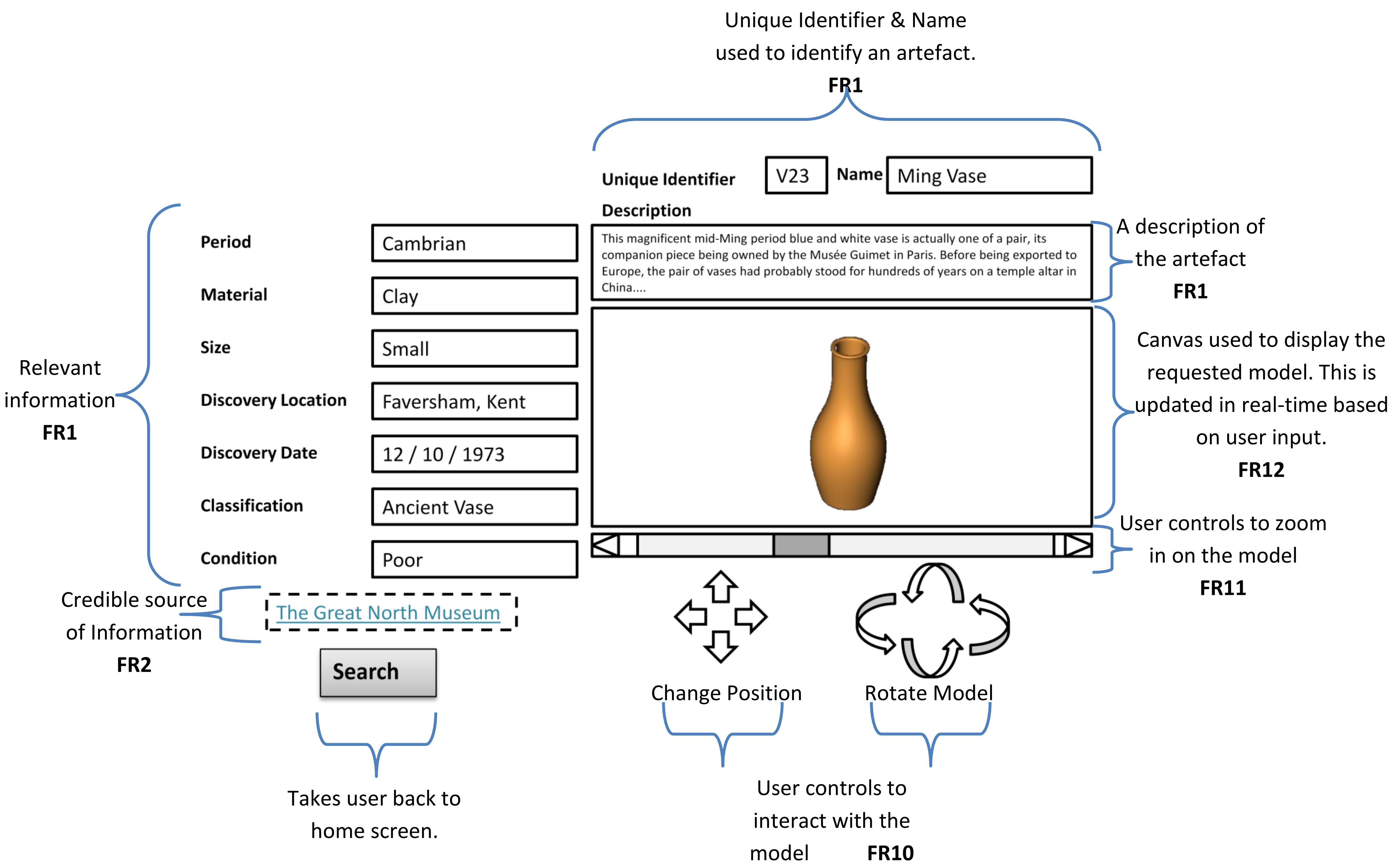

Figure 11 - Screen design of application artefact viewer screen

4.3.4.1 Screen Change over Time

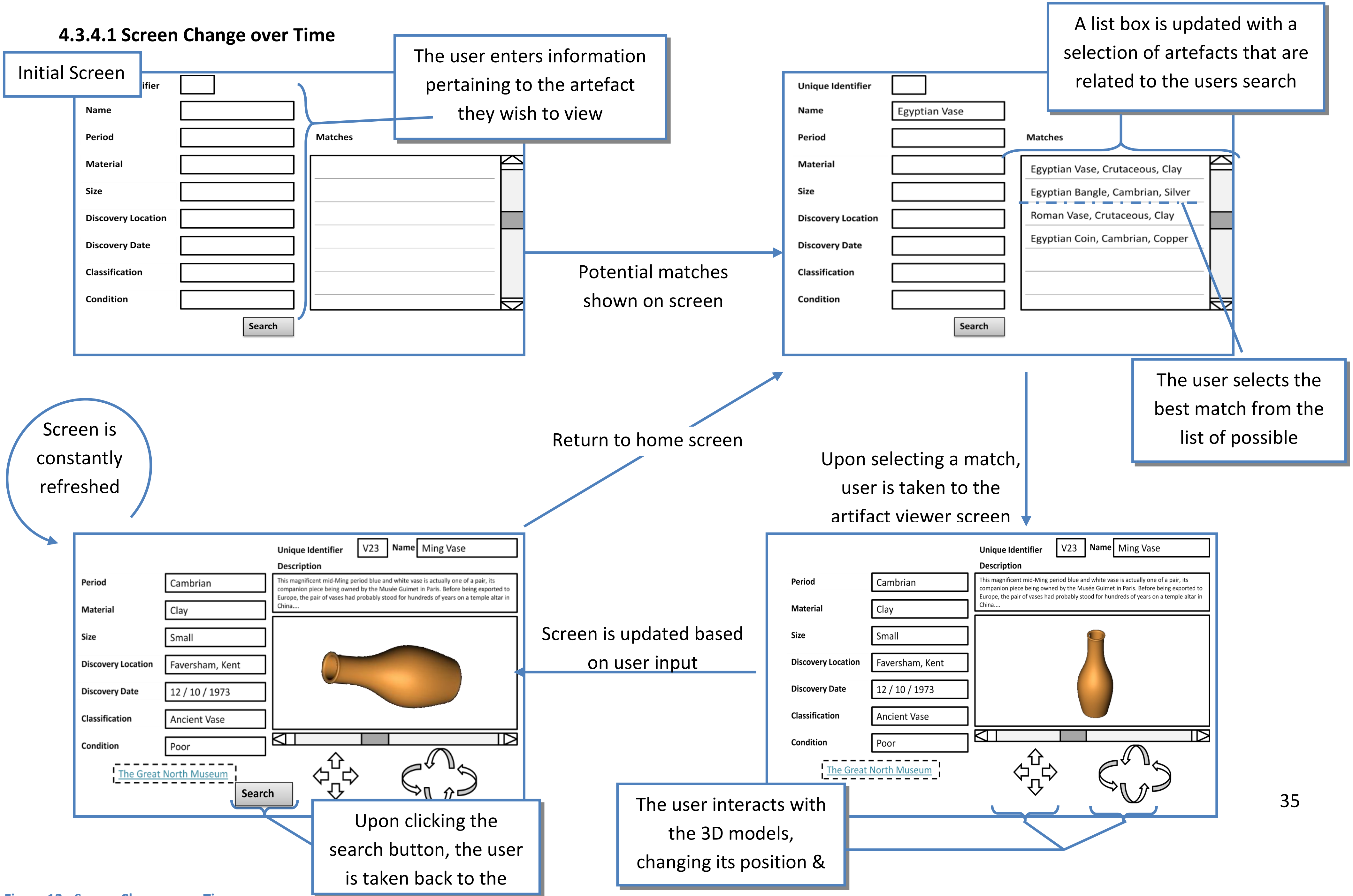

Figure 12 - Screen Change over Time

4.3.4 Hardware-Software Interface Diagram

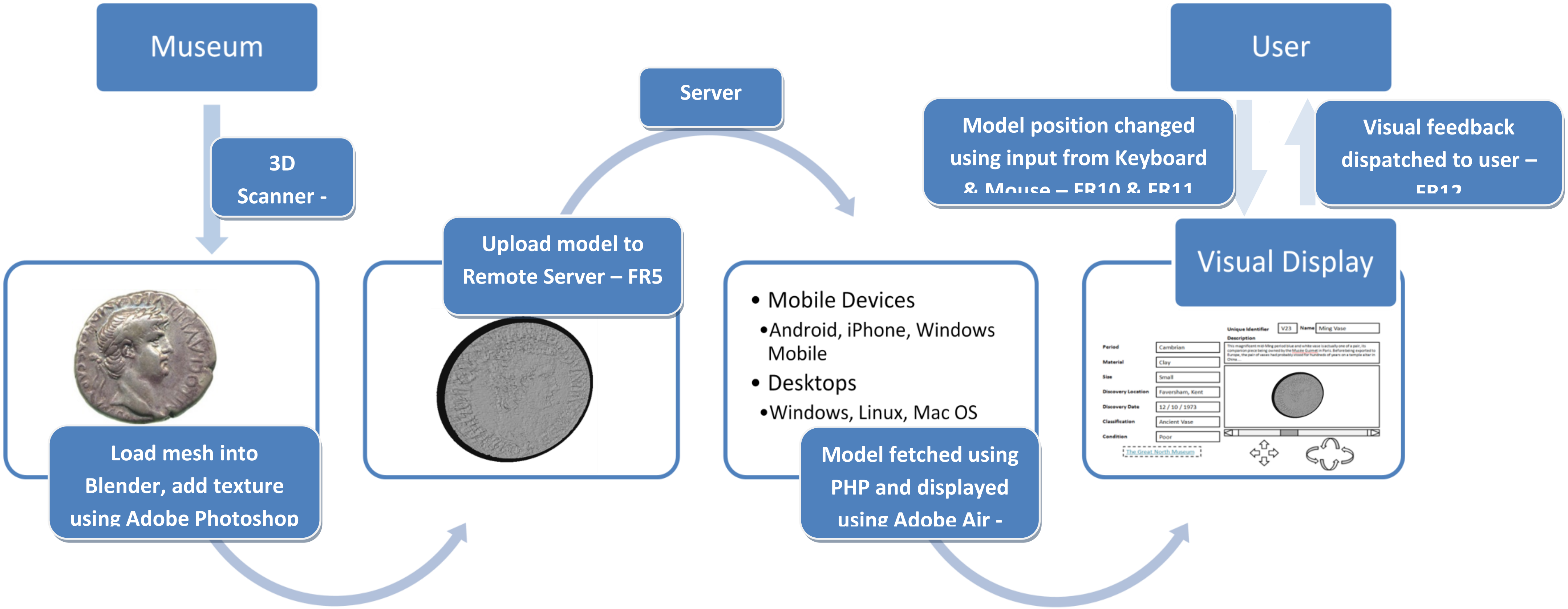

Figure 13 - Diagram showing the different hardware used and their relationships

4.2 System Implementation

Using the previously established requirements and the designs and models produced as a basis, the implementation of final application was started. During this stage, the application was developed in an incremental manner, with each new version adding to the functionality of the previous, thereby meeting the requirements in a logical order. Throughout this stage, several hurdles were encountered, resulting in tweaks to the original design of the application.

4.2.3 Development

4.2.3.1 Version 0.1 – Initial Development

Figure 14 - Screen shot of version 0.1

The initial version of the system read in data from an .xml file, as the xml format is easily read in by Air applications. Information is separated and assigned to specific text fields with information displayed to the user at run-time. The layout was defined using MXML and information was bound to a layout component using ActionScript 3.0.

V0.2 achieved similar results; however the .xml file being read from was stored on a remote server. Information was correctly displayed with no discernable between reading in information locally or remotely. Having established a basic layout that displays remote information the application was further developed to allow users to search for specific artefacts.

4.2.3.2 Version 0.3 & 0.4 - Ability to Search

V0.3 saw the introduction of a basic home screen (Figure 18) that is displayed when the application is initialized, when the user clicks the search button this screen is updated (Figure 17). Text boxes act as data entry fields and the use of a combo box simplifies the process of searching for information concerning a specific period.

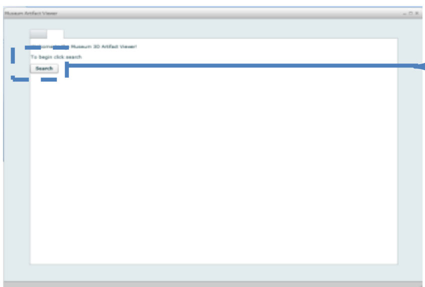

Figure 17 - V0.3 Home Screen

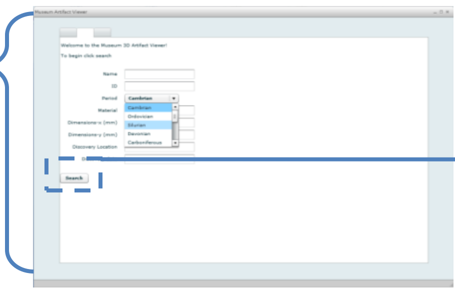

Figure 16 V0.3 Home Screen after user clicks *'search'*

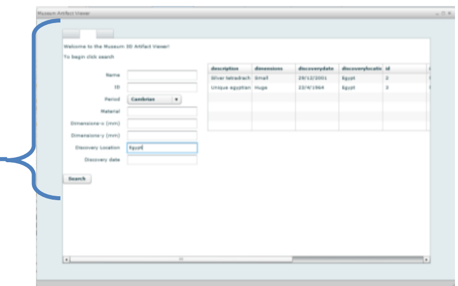

Figure 15 - V0.4 Displaying search results

Building upon the previous version, V0.4 provides the user with feedback from their search request populating a list component with potential matches (Figure 19). Upon selecting an artifact which they want to view more detail upon, the user is taken to the screen shown in Figure 16. Searching, at this point, was achieved through reading through a remote .xml file. A simple string matching technique was used to generate results.

4.2.3.3 Versions 0.5 to 0.8 – Inclusion of 3D models

Including 3D models within the system proved the biggest obstacle when developing the application. Adobe Flex, like the other RIAs discussed in this dissertation, does not provide out of the box support for 3D graphics. Therefore, the use of an additional library was necessary. Papervision3D was used in the development of the application due its compatibility with Adobe Air, and the fact it is open source. However, because it is a third party library there was little supporting documentation included with it.

The biggest hindrance developing this was the fact that if a model is not displayed on screen, it could have been for a plethora of reasons i.e. model failed to load. However, no error would be thrown and there would be no output to the console. Because of this the majority of time developing the overall system, was spent including 3D models within the application. Though, eventually, version 0.5 was created, which included a very simple 3D model. After adjusting the models position with respect to the camera, the model is clearly displayed. It is worth noting that V0.5 did not include texture mapping.

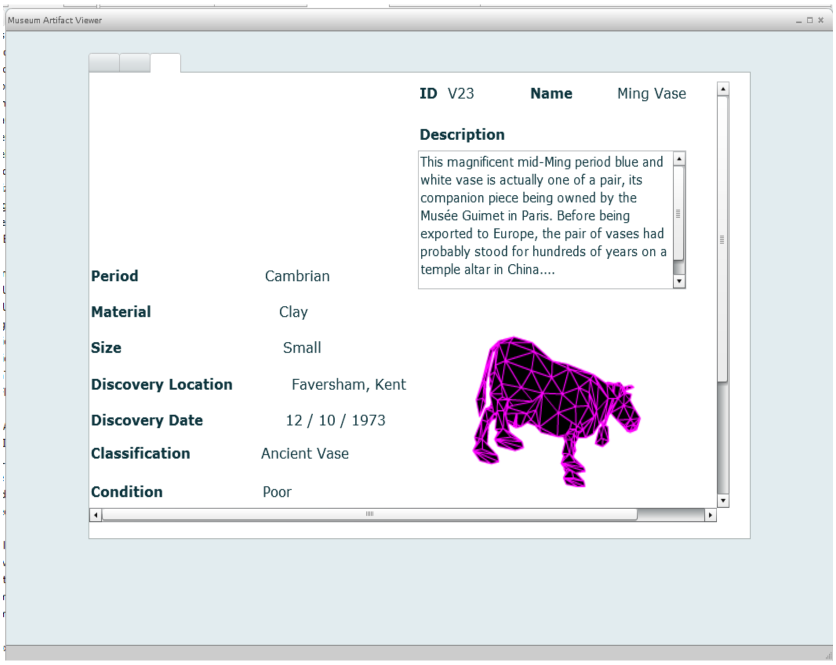

Figure 18 - V0.5 including simple 3D model

The lack of textures is due to the way in which the models are created. Only models saved as a COLLADA file are compatible with Papervision3D. COLLADA is an open standard using XML schema, the use of these models fits in with a museums purpose the way in which textures or materials are added varies.

With 3D models established within the system, versions 0.6 to 0.8 were concerned with the developing a user's ability to interact with an artefact. V0.8 allows users to fully rotate a model, to changes its position, and to zoom in and out. Though zooming was achieved in the same way set out in the specification, rotating a model and changing its position were done differently. As opposed to clicking on screen buttons, users can now 'grab' the model using a mouse and rotate it by moving the cursor across screen. Similarly, changing the x, y coordinates was achieved using keyboard input. The direction keys are mapped to a function which moves the model in the respective direction.

4.2.3.4 Version 0.9 – Database Integration

Due to the potential volume of artefacts that may be stored within the system, this focus behind version 0.9 was to implement a better data storage strategy than a series of xml files representing artefacts. To do this information is now stored within a mySQL database, with each record including a URL showing the absolute path to the appropriate model and image. PHP scripts were then included within the system, with these scripts generating mySQL queries to pull relevant information from the database.

4.2.3.5 Version 1.0 – User Interface Redesign

After reviewing version 0.9, a number of improvements came about. One issue that came to light was to do with the ease of use of the system. Based on the specification a user would enter the home screen, select an object to be viewed then be taken to artefact viewer screen. Then, if they wanted to search for another artefact they'd have to return to home screen, just to be sent back to the viewer screen. Due to the repetitive nature of searching in previous versions, the how and viewer screen were amalgamated (Figure 22).

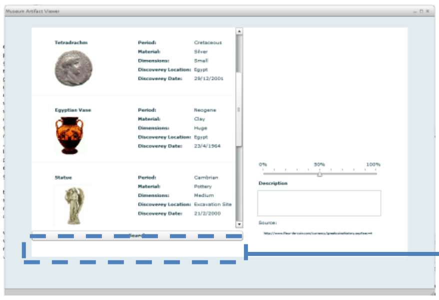

Figure 19 - V1.0 Initial screen after the user interface had been simplified

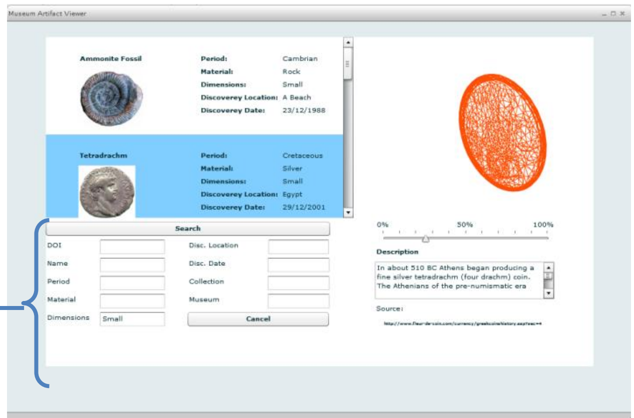

Figure 20 - V1.0 Simplified searching functionality

The information source is now included, allowing the user to verify the credibility of the information provided. Where the source used is an online journal or paper, the source will provide a direct link to it. This is current version of the system, but work is being done into texture mapping:

4.2.3.6 Version 1.1 – Textured Models (Current Version)

For a model to be correctly imported using Papervision3D, it must be a specific format: COLLADA 1.4. Any model using this format will be displayed in Adobe Air, however, Papervision3D loads in a model and an image file that represents its texture. Therefore, to include textured models a given COLLDA file must be associated with a .png or .jpeg image. To associate a COLLADA model with a texture image, Blender was first used to produce an unwrapped map of the model surface.

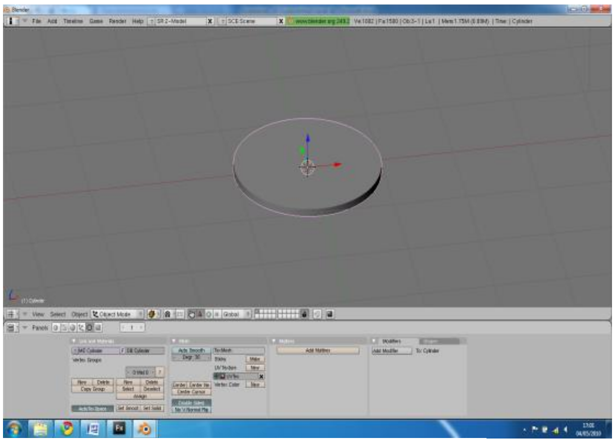

Figure 21 – Basic coin model loaded in Blender

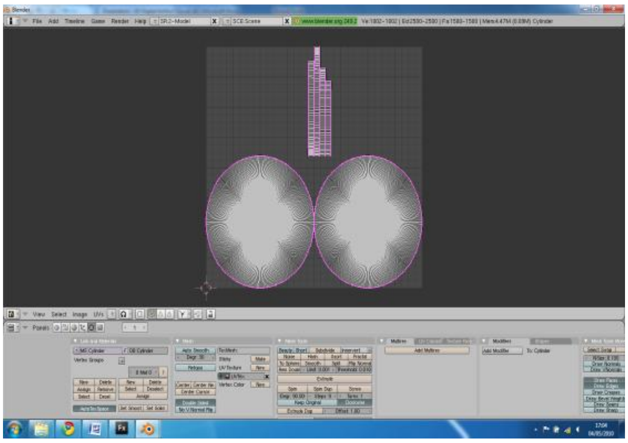

Figure 22 - Unwrapped surface map of coin model

The surface map of the model was then saved as a .tga file and loaded into Adobe Photoshop. After editing the surface map using Photoshop (Figure 25), the model is exported in the appropriate format using Blender. COLLADA files use a relative path to find an associate image. Thus, saving the image file in the same directory as the model allows the Papervison3D library to open and properly display a textured model (Figure 27).

At this stage in the development of the application, it is also worth noting that using Photoshop allows COLLADA models to be directly imported and edited with instant feedback as to the appearance of the textured 3D model (Figure 26).

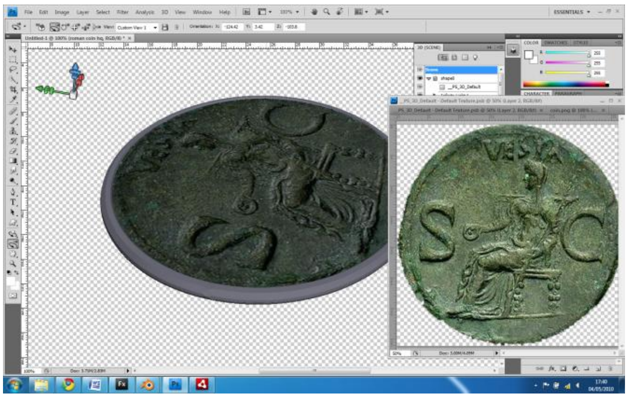

Figure 23 - Texture editing in Photoshop

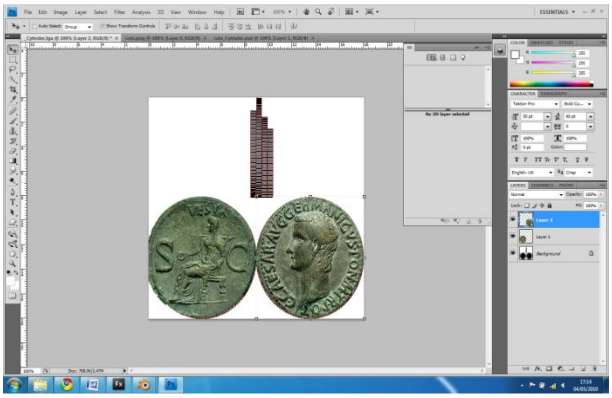

Figure 24 - 3D model texturing in Photoshop

Though successive versions were consistently reviewed to improve functionality, the application as a whole was tested to ensure it works in the way desired.

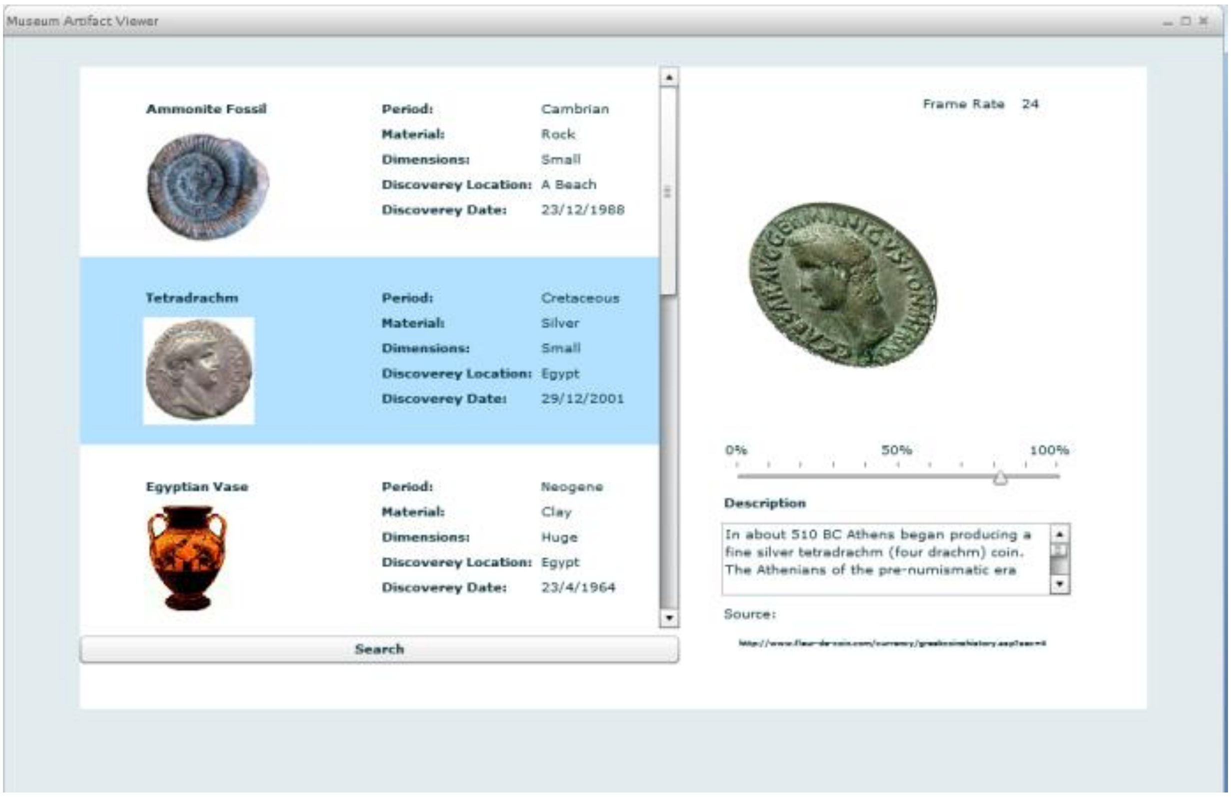

Figure 25 - V1.1 Displaying a textured model

4.4 Validation

Using black box testing, the system was treated as a single object and it was exposed to different use case scenarios. The areas the application was tested in are as follows:

- Data Integrity
- Environment Testing
- Performance Testing
- Load Testing
- Ease of use

4.4.1 Data Integrity

To ensure that information is downloaded and displayed accurately; an .xml file containing example information is read in by the application. The result of this is the information being displayed correctly on screen (Figure 22).

4.4.2 Environment Testing

Multi-platform support is an important aspect of this application. Being able to run consistently across multiple operations system increases the accessibility of the application. To test the applications robustness, it was installed and run on the systems shown in Table 4.

System Name	Mac Book Pro	Dell Inspiron 1720	Acer Aspire1
Operating System	Mac OSX (10.6.3)	Windows 7 Ultimate (6.1)	Linux: Ubuntu
RAM	2gb	2gb	512mb
Hard Drive Capacity	160gb	120gb	6gb (SSD)
Processor	Intel core 2 duo 2.4GHz	Intel core 2 duo 1.86GHz	Intel Atom 1.6 GHz
Graphics Card	NVIDIA 8600n GT 256mb	NVIDIA 8600m GT 1024mb	Mobile Intel 945GSE Express 8Mb

Table 4 - Systems used for testing the Application

The runtime environment Adobe Air successfully installed on these platforms thus there was no issue when installing the Digital Artefact Viewer application. When running, there was no difference in performance between the MacBook Pro and the Dell Inspiron. However, due to the low system specifications of the Acer Aspire 1 there was a reduction in performance. Though the application did correctly display 3D models, when interacting with the model there was noticeable lag between user input and models position being updated on screen. There was also a correlation between the applications performance and the quality of the model displayed. Because of this correlation the application was then tested to establish the relationship between model quality and system performance.

4.4.3 Performance Testing

Models included with the system must be of sufficient quality to facilitate historical research into the domain the artefact exists in. However, there is a direct correlation between application performance and model quality. Table 5 illustrates the performance of the system when displaying models of large file sizes and high polygon counts.

Models were stored client side and were imported and rendered at run-time using the Adobe Air runtime environment. The time taken from selecting a model to it being displayed on screen was recorded, showing the ability of Air to render 3D graphics in real-time. The application timed-out when loading models with 50 000 polygons and for those above 10 000 there was still a noticeable delay. Interacting with the models was slow, however after reducing the quality further the system ran at a consistent rate and responded to it user input in real time. The trade off with using lower polygon count models is the clear loss of geometric detail.

Model	Quality (Polygon Count)	File Size (MB)	System Performance (Average FPS)	Application Responsiveness	Memory Usage (MB)	CPU Usage (%)		Load Time (ms)
						Idle	User Input	
Figure 30	250000	20.03	-	None	217.81	~50	-	> 300000
Figure 29	50000	6.44	24	Slow	119.63	~50	~61	28614
Figure 28	10000	1.11	24	Immediate	45.57	~48	~59	1711
Figure 31	5000	0.59	24	Immediate	34.22	~46	~55	1120

Table 5 – Models Tested

Figure 29 - Coin 250000 polygons

Figure 28 - Coin 50000 Polygons

Figure 27 - Coin 10000 Polygons

Figure 26 - Coin 5000 Polygons

4.4.4 Load Testing

Downloading models is a key feature of this application; however, users of the system will have a various internet connection speeds. Similarly to system performance, there is a correlation between the speed in which a model can be loaded (load time) and the quality of the model (file size). Finding the right balance between these aspects was achieved by using models of various file sizes.

4.4.5 Ease of Use

Analysing the applications ease of use was done through asking users to perform specific actions on the system, averaging the time taken and allowing users to provide feedback. The results of the user testing can be seen in Table 6 - User Testing Results

Action Performed	Expected User Behaviour	Average Time Taken	Overview of User Comments
Search for and select Tetradrachm coin	Click the search button and search for Tetradrachm	<30 seconds	Was obvious how and easy to search
Zoom in fully	Move the scroll bar fully right	<10 seconds	The zoom bar was immediately apparent and easy to use
Zoom out fully	Move the scroll bar fully left	<10 seconds	The zoom bar was immediately apparent and easy to use
Move the coin to the top left of the screen	Press UP and LEFT on keyboard	< 120 seconds	Model moved too slowly, felt tedious
Centre the coin	Press DOWN and RIGHT on keyboard	< 120 seconds	Model moved too slowly, felt tedious
Rotate coin until the underside is face up	Click mouse on model and drag to the left	> 120 seconds	Coin did not rotate in the expected way, felt awkward trying to position it
Rotate coin to original position	Click mouse on model and drag to the right	> 120 seconds	Coin did not rotate in the expected way, felt awkward trying to position it

Table 6 - User Testing Results

When testing the user interface, a few users had to be prompted to use the keyboard to move a model; this implies that moving the model is not as intuitive as it could be. This can easily be fixed, however, by including on screen instructions regarding positioning a model. The main concern raised during user testing was the rate at which the models position was updated in respect to user input. Rotating and moving was regarded as tedious due to the slow update rate, and the act of rotating the model was not *'smooth'*. Smoothness refers to how accurately the models position changes. When rotating the model the majority of users could not execute complete control. For example when asked to rotate the coin so that the underside was facing the user, the model would rotate on both axis.

Adding the functionality to automatically centre a model was also suggested when users were asked to move and rotate the coin back to its original position.

4.4.6 Validation Summary

From the results procured when validating the application, it has been established that the application performs has met the necessary requirements and performs in the desired way. Though there were some issues regarding the applications ease of use, a full analysis of the results obtained occurred when evaluating the software engineering process that resulted in its creation.

5 Evaluation

Having developed the application it's vital to evaluate the process that resulted in its creation. This evaluation will provide insight into its benefits and ways in which it can be improved. Each section of this dissertation will be retrospectively scrutinized with the purpose of establishing the following:

- Was the result of a given section enough to satisfy the intended outcome?
- The merits of the approaches / techniques used.
- The limitations of each approach?
  - Including how it can be improved.
- Which of the goals each stage applied to.
  - Was the goal fully satisfied?

This dissertation will then be evaluated as a whole determining whether the original aim was fully met including the feasibility of the continuous development and implementation of the system produced.

5.1 Summary of Research

5.1.1 Background Research

Regarding background research several areas were looked into. The intended outcome was to establish how different technology implementations can be used to further the purpose behind a museum. This purpose applies to several different areas including education and collaboration the goal of the background research was to find the links between technology and the individual areas of a museums purpose. These relationships can be seen below:

- Information Digitization – Accessibility, Preservation
  - Digitizing collections provides digital copies which can be disseminated online or act as digital back-ups, with real world objects containing the same information as their virtual doppelgangers.
- Technology Implementation in Museums – Education, Accessibility, Interaction
  - The amalgamation of archaic museum collections and modern day technology provides greater opportunities for people to assimilate information and engage with the past.
- 3D Modelling & Scanning Technologies – Accessibility, Preservation, Interaction
  - 3D models representing artefacts can be stored in the public domain, allowing information to shared across, practically, unlimited spatial and temporal distances.
- Development of Rich Internet Applications – Accessibility, Interaction
  - With the implementation of RIAs, models can be streamed or downloaded; manipulated in real time; and used by anyone for their own purpose.

For each research area different research techniques were employed; including:

- Background reading:
  - This technique was used to give general background knowledge on each of the research areas. There was a plethora of research & similar projects available so

finding research in area was straightforward. Although, it was difficult to find information directly related to the indivudal goals of this dissertation.

- Interviewing:
    - Realising that a museums had an educational role within society, it was decided to include research into the role of technology in education. To gain insight into this new field I interviewed a cross section of staff at the Institute of Technology in Education at the Open University. This provided first hand information into the most up to date research currently being undetaken. However, the information procured did not directly relate to my original aims and goals, due to research relating to technology use in education.
- Practical investigation:
    - Determing the quality of 3D models produced by different scanning techniques proved difficult. Due to to the variation of the objects that can be scanned and the expense and limited availability of the equipment, it was challenging to ascertain consistent / useful results. To provide relevant information a selection of example artefacts were scanned using a Roland MDX40 and VI-9i scanner at Newcastle University and the Open University respectively. This provided some insight into the skills needed to operate the machine and the appropriateness of the equipment for the domain this dissertation researched into.

The goals of this section were to:

- *Research 3D technologies that are currently being utilized, focusing on availability, quality and distribution methods.*
- *Analyse current historical researching methodologies, including resources used and establish which information is commonly sought after.*

The information procured from research has fully satisfied the first goal. However, the scope of the research undertaken was broadened to include areas that are related to the purpose of museums. Originally it was the intention of this section to meet both goals, though it only partially fulfilled the second goal. However, the elicitation stage of the software development process involved more research which when combined with the previous section; fully fullfilled this goal.

5.1.2 Elicitation

The purpose of the elicitation stage was to provide bespoke research into the domain in which the system would exist. Therefore the intended outcome of this section was a set of elicitation notes. These notes were expected to include:

- Research into:
    - Which information is expected to be included within museum collections?
    - What sources are used to pull this information from?
    - Raw requirements that the developed system, ideally, will include.
    - Behavioural constraints that the system must adhere to.

To procure this information, the following techniques were used:

- Background Reading:
  - Reading was done into the code of ethics that museums abide by. Ensuring that the raw requirements and behavioural constraints of the application could be directly applied to the domain in which it would exist. Due to the openness of information that a museum exhibits, there was an abundance of information to go by. However, the volume of information that is available meant that it was difficult to ascertain which of the purposes elicited applied to all museums. This issue was circumvented through cross-referencing of multiple codes to determine which areas were most important.
- Questionnaires:
  - Using questionnaires provided quantitative research which made it easier to establish the most popular research methods; which information is widely used etc. The investigation provided valuable insight which was included with the elicitation notes. However, the value of the information procured is questionable, due to the limited number of responses received. Though, questionnaires were only disseminated to those whose work is related to museums, the lack of responses is therefore offset by the relevance of the results obtained.

- *Analyse current historical researching methodologies, including resources used and establish which information is commonly sought after.*
- *Elicit raw requirements from potential users and use information gathered from research to establish a set of requirements.*

As previously mentioned the second goal of this dissertation was only partially satisfied by the background research section. However, the elicitation stage of the software development process produced valuable results explicitly showing the most important information and establishing the most common research sources. User requirements were established in this stage, though they had not yet been formed into coherent, specific requirements around which the application was designed.

5.2 Analysis

5.2.1 Requirements Analysis

The purpose of this stage of the software engineering process was to provide a specific focus for the design, and therefore, the development of the application. Thus, the intended outcome of this stage was to produce a model of the existing domain and set of functional and non-functional requirements.

A museums role in society is to store information (their collections) for the benefit of the society. Thus a data flow diagram was produced (Figure 9) to model the flow of information between the museum, the collection it contains and the public. Though, this is an effective way of modelling the flow of information the current model is not comprehensive. Ideally, the DFD should show the flow of information between:

- Museums and other museums;
- Other institutions and museums;
    - E.g. Universities, schools, governmental institutions;

There also needs to be a clear distinction between members of the public, as individuals will have different reasons for visiting a museum. For example a school teacher on a school field trip will want information that is easily digestible by her pupils, whereas a Professor of Archaeology writing a research paper will want highly detailed information.

An Entity Relationship Diagram was used to represent the different beings, objects and institutions that regularly interact with museums. This shows the relationships between collections, museums and visitors; with visitors split into the general public and researchers. However, this diagram fails to acknowledge the relationships with other institutions i.e. a museum may collaborate with other museums & institutions and a credible researcher will be associated with an institution.

As previously mentioned the following goal was only partially satisfied during the elicitation stage:

- *Elicit raw requirements from potential users and use information gathered from research to establish a set of requirements.*

Through the establishment of the existing domain, using the raw requirements and system constraints a set of specific functional and non-functional requirements was established. These requirements were then used in the design and specification of the final system.

5.2.2 System Specification

From this stage, the intended result was a clear and specific set of designs upon which the system would be developed. The design of the new system was separated into:

Data Flow Diagrams (DFD)

The DFD shows the flow of information in the new system. Using this technique to model both the current domain and the developed application, allowing the flow of information to be compared. However, similar to DFD of the current domain, the system's DFD does not differentiate between average members of the public or researchers, nor does it include the relation between museums and other institutions.

Database Design

The database design stated specifically the information that will be included within the system. The current database design shows that a database contains a link to a model, rather than storing the model itself. The design of the database is based on which information should be included within the system. Therefore this design ensures that the final system contains all the necessary information set in the functional requirements.

Screen Designs

Several GUI mock-ups identified the layout of the application user interface and acted as a basis for its implementation. Though the designs did provide a base there was a dramatic change of the user interface between initial design and subsequent versions of the application.

Hardware & Software Interface Design

This design explained the different hardware and software used and how they are integrated together. This provided a visual explanation of the entire digitization process from scanning an artifact to the finished digital model being displayed on screen. Using this diagram provides a simple, easily understandable way to represent the system. However, some of the lower-level, technical details are lost.

Although this stage did not directly satisfy any of the goals previously stated it acted as a bridge between requirements analysis and system implementation. With this stage, the requirements were expanded to include the technical aspects of implementing the system thereby providing a logical structure for developing the application.

5.3 Implementation

5.3.2 Application Creation

The culmination of the background reading, information elicitation and analysis, the outcome of this stage was the application that met the requirements established. During development, requirements were separated so that progressive versions of the system could be created. Doing this meant that the system was created in a logical order, with the basic requirements met first and the advanced requirements met in later versions. The structure of the applications creation, and the requirements each version met are as follows:

Version 0.1 – Initial Development

Created the initial Rich Internet Application including a basic user interface that displayed information, satisfying:

- **NFR2** - Relevant information pertaining to collections will be included with 3D models.
    - **FR1** – Relevant Information:
        - Unique Identifier (DOI)
        - Name
        - Period of Origin
        - Description, including:
            - Information with the same level of detail as the records displayed with museum collections.
        - Date & Location of discovery
        - Dimensions
        - Material
        - Age
- **NFR4** - The application will utilize web technologies ensuring models are accessible online.
    - **FR5** - Adobe Flex will be used as the framework for the application utilizing: PHP, CSS & HTML
- **NFR5** - The application will run on across multiple platforms.
    - **FR6** – The final application will be compiled to .air format utilising the Adobe Air runtime environment

Version 0.3 & 0.4 - Ability to Search

Added the functionality that allows a user to find and view information pertaining to a specific artifact though not directly meeting any requirements, it was still a major improvement to the application.

Versions 0.5 to 0.8 – Inclusion of 3D models

Developed the user interface allowing users to view a 3D model, with later versions adding greater interactivity with the model, satisfying:

-
    - **FR3 –** (Including) Digital images and 3D models representing an artifact
- **NFR9** - Users will be able to view models from different angles and from different distances.
    - **FR10** - Models can be rotated through 360 degrees around the x, y & z axis
- **FR11** – Users will be able to view a model from a translated range of 1mm to 1m.

Version 0.9 – Database Integration

Connected the application to a mySQL database; allowing for more efficient data storage and searching. Again not directly satisfying any requirements, thought it ensured the application was more efficient.

Version 1.0 – User Interface Redesign

Tweaked the user-interface promoting ease of use, including more detailed information with a link to the source of the information displayed.

-
    - **FR2 –** (Including) A link to the credible source of the information included.
- **NFR10** - Anyone with access to a PC will be able to use the application.

- **FR12** - The application will provide instant feedback to user input.
- **FR13 –** The application will have an intuitive user interface

Version 1.1 – Textured Models
This was done to ensure that the following requirement was fully met:

- **FR3 –** (Including) Digital images and 3D models representing an artefact

This progressive development of the system allowed for clear definition of each addition and modification, making it easier to see the requirements already met. This phased release strategy allowed future versions discussed, including which requirements they'll meet or how they'll add to the overall performance of the system.

When establishing the requirements, it makes sense to list the requirements in the same order that they are intended to be met by the system. Not providing a logical order to the requirements did not degrade the development of the system, thought it did mean that it was difficult to determine which requirements should take precedent. For example, **FR10** was met before **FR2**, even though the latter had more importance regarding the aim of this dissertation. With version 1.1 being the latest development of the application, it should have satisfied the following goals:

- *Create a Rich Internet Application (RIA) that allows users to view information pertaining to a specific collection.*
- *Develop the RIA so that users have the ability to stream 3D models or download and store them for offline use.*
- *Evaluate the system and determine whether it meets the elicited requirements and determine a compilation of advancements for the system*

The functionality to allow users to view information pertaining to a specific collection was added in the earlier versions of the system, ensuring that this goal was met very early on the application development. Regarding including 3D models in the system, that can be downloaded or streamed was only partially achieved. Users can stream models, and they can be downloaded and stored in cache memory.

With version 1.1 being the latest version of the system, it was important to test the system. Testing ensures that not only the requirements are met, but that the system is also suitable for implementation in its intended domain.

5.3.3 Validation
Testing the latest version of the system provided a specific set of results that were used to determine the appropriateness of the system. Results were formed by applying a variety of test-scenarios designed to test specific areas of the system,

Testing Area	Test-Scenario(s)	Results
Data Integrity	Example information pertaining to a collection of artefacts was downloaded by the application.	Information was displayed correctly, without degradation or loss. (Figure 22)
Environment Testing	The application was run on multiple systems, with various specifications and operating systems.	The application installed and ran correctly across all platforms.
Performance Testing	Models of various qualities (polygon counts) were downloaded and displayed by the application.	There is a direct correlation between polygon count and system performance.
Load Testing	Models of various qualities (polygon counts) were downloaded by the application.	There is a direct correlation between polygon count and time taken to download and display the model.
User Interface	A collection of users were asked to perform actions and provide feedback on its ease of use.	Overall, the application was rated very easy to use; though interacting with the 3D model was described as tedious.

From the testing performed on the system, it was clear that the following values in the system are interrelated:

- Model Polygon Count
- Model File size
- Application Responsiveness
- Resources Used
- Input Latency

To ensure that the system does not degrade in performance to such an extent that it interferes with the user experience; the following values have been established:

- Polygon Count: <50000
- File Size: <7 mb
- Application Frame Rate: 24

These values will provide a consistent user experience across all platforms. Overall, the results from the systems validation have shown that it can potentially fit in the proposed domain, however further analysis of this feasibility was required.

5.3.4 Feasibility Analysis

As discussed in the background research, there was a limitation as to the currently available scanning methods, especially considering the process of digitations must not degrade an artefact. Requiring a low user skill level, 3D scanners are a solution to creating digital models, however currently this technology is not readily available with a high resolution scanner costing upwards of £50000. The other financial aspect of the application is that high quality digital models will need to be stored, ensuring the continuous preservation of the information they represent, incurring an initial set-up cost as well as a continuous cost for maintenance.

Assuming a museum is able to justify the costs discussed, there is a plethora of 3D modelling software available. Allowing models to be edited and tweaked so that they can be considered highly accurate representations. The use of Blender and Adobe Photoshop in this dissertation meant that the geometry and texture of the model can be edited in a suitable software package. It was shown that hosting these models using a rich internet application was counter-productive as the polygon count of a model had to be reduced so the applications performance was not degraded. Models featured in the system may not be described as highly accurate; however, they can be seen as very close approximations to the real thing. [4.2.1]

Therefore, allowing for the current high cost of producing the models, then the software can be implemented to further the purpose of museums to improve accessibility. Though models are not as detailed as initially anticipated, the development of rich internet applications and 3D scanning technology will see greater availability and accurate model representation and brings down costs.

5.4 Overall Evaluation

Reflecting back on the software engineering process that resulted in the creation of the system there were merits to, and potential improvements in the approaches used in each stage. They are as follows:

5.4.1 Research:

- Merits:
    - Background reading provided a valuable overview of the current technologies in place, and proved useful when discussing the potential benefits of the use of technologies within museums.
    - Elicited research allowed the development of the application to be focussed towards the museums domain.
- Improvements:
    - The research done can be broadened to include other areas:
        - The Educational role of Museums
        - Technology use in Education

        - Human Computer Interaction
        - 3D Printing Technology

5.4.2 Analysis

- Merits:
    - The use of dataflow diagrams (Figure 9) allowed the flow of information to be accurately modelled in the current domain. Relationships between museums, their collections and the public are depicted by means of entity relationship diagrams (Figure 10). This along with information gathered during the elicitation stage provided a valuable source when establishing the requirements.
- Improvements:
    - The current requirements of the system can be expanded to include:
        - Clear differentiation between different members of the public
        - Ways in which the system can be more interactive
        - How the system can be developed to be an educational resource

5.4.3 Specification

- Merits:
    - The database designs and DFD showing the new system provided a good reference for establishing the structure of the systems database. Combined with screen mock-ups and the hardware-software diagram effectively illustrated how new collections are added to the system and how information pertaining to them is displayed and distributed
- Improvements:
    - Constant reviewing of the system design will allow the specification to be updated as the system develops.
    - Gather user feedback on the systems designs, ensuring that no requirements were missed

5.4.4 Development

- Merits:
    - Separating the creation of the system into different versions provided a methodical structure for the systems development. Each version clearly shows which requirements have already been met, whilst providing a base for the further expansion of the application
- Improvements:
    - Throw-away prototyping will allow for the methodical development of the system with the most current version not being influenced by older versions.
    - Feedback can be gathered from potential users regarding the latest prototype, providing ideas for the further development of the system.

5.4.5 Validation

- Merits:
    - The system was comprehensively tested and the techniques employed allowed the establishment for the optimum model quality and file size whilst ensuring the applications performance did not degrade.
- Improvements:
    - Further testing of the user interface can be done to ensure the application is usable by a range of people. Ensuring that the system is suitable for the different purposes of distinct users.
    - Give end users more visibility of the prototype and early version releases.

6 Conclusion

Having created the system and evaluated the process that resulted in it, this section will now look back and determine whether the original aim and objectives were met. Including a reflective look at my own performance in achieving these objectives, along with a review into the technical knowledge I've acquired. Using the research procured in this dissertation the future developments in these areas can be determined; therefore providing a reference to the ways in which the system can be expanded. Using my self-evaluation in combination with the research into future developments I'll ascertain the most useful technical knowledge for myself to develop.

6.1 Original Aim & Objectives

The original focus of this dissertation was *"To develop a system that improves the accessibility of museums artefacts for universities, to benefit historical research."* To accomplish this aim a set of goals were produced breaking down this task into several areas of research and development. The extent to which these goals were achieved can be seen in **Error! Reference source not found.** explaining how they were met, any obstacles presented, how they were overcome and future expansions.

To accomplish this aim a rich internet application was produced that allows users to interact with 3D models. Information pertaining to museum collections can be accessed by anyone online and through the use of 3D scanning technology high quality digital representations of artefacts can be produced. However, the use of a rich internet application imposed a limitation on the quality of the 3D models that can be distributed online.

It was demonstrated that there is limited support for 3D graphics with rich internet applications. Created with Adobe Air, 3D models can be included with the system through the use of other the additional library Papervision3D. System performance degraded as the polygon count of a model increases. This introduced a balance between model quality and the rate at which the models position is updated as a user interacts with it. Therefore, to ensure the system performs at an acceptable rate (24 frames per second), there is a polygon limit on models (<50000) polygons, based on the target software environment (or domain) defined previously.

Digital artefacts produced are only close approximations and whether they are of sufficient quality to facilitate historical research is debateable. However, information pertaining to the artefact is still highly accessible. Therefore, this aim can be considered partially met and as rich internet applications continue to develop, the sophistication of 3D graphics supported by internet enabled will increase.

Goal	Outcome	Explanation	Further Development
Research 3D technologies that are currently being utilized, focusing on availability, quality and distribution methods.	Partially Achieved	The background research done was comprehensive enough to provide a broad overview of use of 3D technologies. Though due to the majority of 3D technologies being state of the art, there was a limitation on the amount of bespoke / hands on research that could be done.	Look into 3D scanning that has low entry barriers i.e. low user technical requirements and set-up costs.
Analyse current historical researching methodologies, including resources used and establish which information is commonly sought after.	Achieved	During the elicitation stage of the software development process utilized sufficient information was drawn out of the domain to establish information and resources used in historical research.	Expand the system to include other resources, which relate to the collections displayed.
Elicit raw requirements from potential users and use information gathered from research to establish a set of requirements.	Partially Achieved	Eliciting information from the domain provided a sufficient set of requirements upon which the system was developed. However, if this elicitation continued throughout the systems development then the requirements could continuously be updated and tweaked improving the development of the system.	Have a dynamic set of requirements that are constantly updated in regards to developments in technology and the needs of people within the current domain.
Create a Rich Internet Application (RIA) that allows users to view information pertaining to a specific collection.	Partially Achieved	Earlier versions of the system showed information regarding a collection. However, information shown only related to a specific artefact, rather than the collection it belonged to. This was due to the complexity involved in displaying a model that represented an artefact.	Expand the system to display artefacts in multiple categories i.e. which collection or museum they belong to.
Develop the RIA so that users have the ability to stream 3D models or download and store them for offline use.	Partially Achieved	Due to the limitations posed by the current generation of RIA, including 3D models within the system was only achieved through the use of additional libraries. Though these 3D models are accessible online and are downloaded and stored locally, users are not given the explicit option to do so.	Give users of the system the option to download and store their favourite collections, and view them without the need to connect to the internet.
Evaluate the system and determine whether it meets the elicited requirements and determine a compilation of advancements for the system.	Achieved	Analysis of the system regarding the initial requirements can be seen section 6.3. This showed that the initial requirements of the system were met through different versions of the system.	Ensure the compilation of advancements furthers the purpose of museums in society.

Table 7 - Critical Evaluation of original Aim & Goals

6.2 Skills Learnt

When researching into and developing the application, the concepts and technology discussed are state of the art. Given this I had limited starting background knowledge and little or no experience with the technologies utilised. With the scope of this dissertation my understanding of several innovative areas of technology has developed. However my level of comprehension in these areas is not consistent due to the limited availability of equipment required and technical support.

When researching into 3D scanning technology, I was unable to gain practical experience of a range of 3D scanning techniques. However I was able to use a contact scanner available at Newcastle University and was able interact with a range of laser scanners at the Open University (Table 1). This provided excellent knowledge of the operation and specifications of these machines. Including the 3D models produced and the models used for testing in the application was the biggest technical obstacle when developing the system.

Only 3D models stored in the COLLADA file format can be displayed using Adobe Flex and Papervision3D. Therefore when importing models into the application they first had to be loaded up in Blender. After becoming familiar with the 3D modelling software I was able to edit the geometry of a loaded model, reduce the polygon count and export it to COLLADA format. To improve the realism of a model, a COLLADA file is associated with an image file as a stream input and uses this as the models surface map.

To create the textures for a model, they were imported into Adobe Photoshop. Working with Photoshop I was able to create and edit textures and instantly see how they would look on the model. These models with an associated texture image were used when creating the application in Adobe Flex.

Using Adobe Flex I gained excellent experience programming in ActionScript 3.0 and MXML. Learning MXML allowed to declaratively set the interface for the application. Understanding how the scripting language ActionScript worked with a declarative language was fundamental in developing the application that effectively displayed information and provided the functionality established in the requirements. Storing and publishing information was done through the use of PHP and XML which is supported natively by Adobe Flex. Though, due to the limited support for 3D modelling in Adobe Flex, I took it upon myself to include the additional library Papervision3D.

The Papervision3D library was vital when developing the system to display COLLADA models, however, there was limited online support explaining its use. When learning how to incorporate Papervision3D there were a lot of hit and miss attempts at displaying a 3D model. Once the additional library was included in the system, and a model was correctly being displayed, I found that it was easy to work with when programming in ActionScript 3.0.

Reflecting back on the skills I've learnt and taking into the account the future developments of the areas I've researched into I'll be expanding my current background knowledge and skills in the following domains:

- Rich Internet Application Development in JavaFX and HTML
- Accessible 3D Scanning Methods
- Human Computer Interaction
- Technology in Education

6.3 Future Developments for the Application

After researching into a museums purpose and developing an understanding of the technologies available I've found that the scope for the system can be expanded. For example, it is a museums role to be an education asset to society, and the amalgamation between technology and education is continuing. Using the knowledge and experience I've gained from this dissertation the following collection of improvements below have been compiled. Each of these has been established to further the role of museums in society:

Education

- Provide different interfaces tailored to the intentions of the user:
    - Researchers require higher-level information including links to a selection of other online resources
        - Researchers can be associated with an online resource whether they wrote it or they think the research contained within a resource is of value.
        - Providing wikis for researchers to collaborate together for research into a specific collection or artefact
- Teachers will want to customise the information displayed, based on the age group the information is intended for.
    - Taking in other inputs from users e.g. human interface devices [HID], will promote interaction and user engagement

Accessibility

- Further developing the system so it works on mobile platforms
- Allow users to organise their favourite collections and download them for improved offline support
- Generating metadata for museum collections so that they can be further organised and sub-categorized, e.g. including the purpose of an artefact and the domain of society it existed in will add context and making information easily digestible for non-historical professionals

Preservation

- Storing models in the maximum possible detail will mean information is not lost in the digitization process.

- Distributing simpler versions of models allows users to download models that are of suitable quality for their needs. I.e. a researcher will need a highly detailed model whereas a close approximate is good enough for other users.

Interaction

- Other interaction methods can be employed to improve the degree in which a user can manipulate a model e.g. data gloves, computer vision.

As to the technology that should be used for any developments of the system, though Adobe Air rich internet applications are the only platform that support 3D graphics, JavaFX has announced it will support it in the future. However, if JavaFX was used for the further improvements to the application then it is likely that this will be superseded by HTML5 after its introduction. Since JavaFX is based around Java, which has better performance when handling 3D graphics, I'd recommend the application is created using this. Ensuring the application furthers the purpose of museums in society will require further research into the principles of their existence.

6.4 Future Research

Taking the research areas and principles already discussed forward, this section will now look at the other technological domains that can be looked into to further the aim of this dissertation and the role of museums in society.

With the introduction of 3D scanning technology, there was a obvious step forward towards 3D printing. Mostly using lasers to melt and shape plastic, 3D printers work to similar principles as normal printers. One such printer recently went on display at the Science Museum, allowing visitors to create their own pens and other simple objects [TELE]. The inventors of the machine hope that one day, printers such as this will be common place, and citing Moore's law we can safely assume that, eventually, 3D scanners and 3D printers be a feature of every home.

Given that the technology for reproducing 3D models currently exists digitizing artefacts allows for physical replicas to be produced. A recent study found that children could recall large-scale exhibits, with their recollections associated with "*kinaesthetic experiences*". [CHILD] For a museum to continue their role as an educational asset to society, they can incorporate 3D printers and other technologies.

Recently an Ofsted report stated that the use of virtual learning in an educational environment has been *"slow to take off"*[OFST]. Though, there are countless examples of the use of games in education. Consider the following description of a game; a player perceives tasks to be completed and progress to be made, whilst realigning experiences based on each exploration and interaction. Through using interactive technologies, this description of a game can be used to the same effect as a student in a classroom.

As computing power has increased so have the ways in which people can interact with them. Based on the latest developments in neurotechnology, a new generation of digital neural interface have been created. Epoc went on sale in December 2009 and is the first commercially aware games controller that allows uses brainwaves to control in game actions.[SHER]

6.5 Final Thoughts

Looking back on the topics discussed in this dissertation, there is a definite trend of technology becoming intertwined with every facet of society. As the virtual domain expands it is irrevocably binding with the day to day lives of people. Currently 76% of UK now has access to the internet, with 50% of Facebook users logging in every day. As 3D technology develops the way in which people interact with the virtual world will evolve. Futurists predict that within a few years, 70-80% [WOOD] of business and internet users will have a 3D virtual presence. This future prevalence of online 3D virtual environments, in combination with brain computer interaction will allow the direct interaction with virtual environments providing instant sensory feedback.

Speculating on the future of 3D virtual environments raises the issue of, if the environment is of such quality it and the interactions involved with it are so accurate, this could see the line of the virtual and real domain blur. Also, if the world in which we live was created by a grand designer, then it can be said that we, as a species, are the grand designers behind the virtual world. Having said this, then the virtual world we have created will be a direct reflection of human society and culture.

References

[APAC] Apache Software Foundation. (2004). *The Apache License, Version 2.0.* Available: http://httpd.apache.org/docs/2.2/license.html. Last accessed January 2010.

[CHILD] Anderson, D., et all (2002). *Children's museum experiences: Identifying powerful mediators of learning*. *Curator*, *45*(3), 213 - 231.

[COX] Cox, Dr J (2010). *Explore the Natural History Museum in 3D in Bath.* Available: http://www.bath.ac.uk/news/2010/02/25/abe/. Last accessed May 2010.

[GOSK] Goskar, T. (2007). *The Stonehenge Landscape in 3D.*Available: http://www.wessexarch.co.uk/blogs/computing/2007/11/15/stonehenge-landscape-3d. Last accessed November 2009.

[ICOM] International Community of Museums (2006). *ICOM Code of Ethics.* Available: http://icom.museum/ethics.html. Last accessed February 2010.

[JAVA] Sun. (2009). *JavaFX Tools.* Available: http://www.oracle.com/us/products/tools/050854.html. Last accessed January 2010.

[LEE] LEE, A. (2008). *The BBC Television Archive.* Available: http://www.bbc.co.uk/archive/tv_archive.shtml. Last accessed April 2010.

[LIN] Lin, A., Gregor, S (2006). *Designing Websites for Learning and Enjoyment: A study of museum experiences*. The International Review of Research in Open and Distance Learning. 7 (6), p33-37.

[MA] Museum Association (1889). *MA Code of Ethics.* Available: http://www.museumsassociation.org/publications/code-of-ethics. Last accessed November 2009.

[MAIL] Mail Foreign Service (November 2009). *Google puts thousands of ancient artefacts from Iraq museum online* .Available: http://www.dailymail.co.uk/sciencetech/article-1230623/Google-puts-thousands-ancient-artefacts-Iraq-museum-online.html. Last accessed November 2009.

[MAIO] Miao, J., Jullien V. (2000). *Press Release: Dot-Museum Named as Winner.* Available: http://icom.museum/release.museum2.html. Last accessed April 2010.

[MICRO] Microsoft (2007) *Microsoft Silverlight*. Available: http://www.microsoft.com/silverlight/

[MOZI] Mozilla. (2004). *Mozilla Code Licensing.* Available: http://www.mozilla.org/MPL/. Last accessed January 2010.

[OFST] BBC. (January 2009). *Virtual learning 'slow starter'.* Available: http://news.bbc.co.uk/1/hi/education/7824736.stm. Last accessed May 2010.

[OLIV] Oliver, P (August 2008). *JavaFX script vs ActionScript Performance.* Available: http://www.javaworld.com/community/node/1268. Last accessed January 2010.

[PAN] Pan, Q et al (2009) *ProFORMA: Probabilistic Feature-based On-line Rapid Model Acquisition***.** University of Cambridge

[PAPE] Papervision3D. (July 2007). *Papervision3D Development Blog.* Available: http://blog.papervision3d.org/. Last accessed May 2010.

[PETRI] Petridis, P et al (2008) *Exploring and Interacting with Virtual Museums***.** University of Sussex, Department of Informatics

[ROME] Agarwal, S et al (2009) *Building Rome in a Day*. University of Washington

[SAIN] Saino, S., Bartoli, L (2006). *Non-Destructive Investigation of Bronze Artefacts from the Marches National Museum of Archaeology using Neutron Diffraction*. *Archaeometry*. 48 (1), 77-96.

[SCHO] Schoenherr, S (July 2005). *The Digital Revolution.* Available: http://history.sandiego.edu/gen/recording/digital.html. Last accessed April 2010.

[SHER] Sherstyuk, A et al *Toward Natural Selection in Virtual Reality,* IEEE Computer Graphics and Applications, vol. 30, no. 2, pp. 93-96,C3, Mar./Apr. 2010,

[SUN] Sun. (February 2009). *License Agreement for Java SE Development Kit with JavaFX* . Available: https://cds.sun.com/is-bin/INTERSHOP.enfinity/WFS/CDS-CDS_Developer-Site/en_US/-/USD/ViewLicense-Start?LicenseUUID=1r9IBe.pkAYAAAEhCOwP5nUC&ProductUUID=wzdIBe.nIAMAAAEhLxhpOsXz&cnum=&evsref=&sln=. Last accessed January 2010.

[TELE] The Telegraph. (August 2009). *Three-dimensional printer allows Science Museum visitors to create their own objects.* Available: http://www.telegraph.co.uk/technology/news/6088323/Three-dimensional-printer-allows-Science-Museum-visitors-to-create-their-own-objects.html. Last accessed April 2010.

[TLC] The Library of Congress. (2000). *American Memory.* Available: http://memory.loc.gov/ammem/about/index.html. Last accessed January 2010.

[W3C] W3C. (May 2010). *A vocabulary and associated APIs for HTML and XHTML Editor's Draft.* Available: http://dev.w3.org/html5/spec/Overview.html. Last accessed May 2010.

[WOOD] Wood, D., Hopkins, H (2008) *3D virtual environments.* Australasian Society for Computers in Learning and Tertiary Education

Bibliography

[ANDE] Anderson, C., Maxwell, D. (2004) *Starting a Digitization Center.* Abington, Cambridge ISBN: 1843340735

[BENN] Bennett, T (1999). *The Birth of the Museum: History, Theory, Politics.* Florence, Kentucky: Routledge. 278. ISBN: 0415053889

[COST] Costello, P.J. (1997) *3D Model Databases: The Availability of 3D Models on the World Wide Web*, Advisory Group on Computer Graphics, no.36

[EARN] Earnshaw, R., Vince, J. (2001). *Digital Content Creation.* London: Springer. ISBN: 1852333790

[GLAD] Gladney, H. M. (2007). *Preserving Digital Information.* London: Springer, 2007. ISBN: 1843340739

[MITCH] Mitchell, W. (2000). *The Body and the Machine*. In: *The Digital Dialect*. Cumberland: MIT Press. 68-112. ISBN: 022621371

Appendices

Appendix A - Questionnaire

Museum Artefact System

The proposed system will feature 3D high definitation representations of museum artefacts. The system will also allow the user to zoom and rotate each artefact and will include comprehensive information on each artefact. This system will assist with historical research by improving accessibility to museum artefacts and relevant information.

All fields marked * are mandatory.

Title:

- ○ Miss
- ○ Mrs
- ○ Mr
- ○ Ms
- ○ Dr
- ○ Professor

Name

First ______ Last ______

Which of the following resources do you use for your work or research? *

(You may select multiple resources)

- ☐ Research Papers
- ☐ Field Work
- ☐ Internet
- ☐ Museums
- ☐ Textbooks
- ☐ Oral Histories

Other Resources

(Any other resources you use)

______

How regularly do you visit museums, to view artefacts for work / research? *

(If you are currently working within a museum, please select how often you visit other museums).

- Yearly
- Monthly
- Weekly
- Daily
- Never

If you have selected never to the previous question, please select the option which best describes why.

(If you are currently working within a museum, please select how often you visit other musuems).

- Too costly
- Travelling distance
- Having to book exhibits in advance
- Other

Other

(Any other reasons you have for not viewing artefacts first hand)

What information do you feel is important when you are working with an artefact? *

(You may select multiple information types)

- Unique ID Number
- Classification
- Description
- Period
- Age
- Material
- Condition
- Dimensions
- Where it was discovered
- When it was discovered

Other Information

(Any other information you feel is important)

Samples

Title:	-
Name	-
Which of the following resources do you use for your work or research?	- Research Papers - Field Work - Internet - Museums - Textbooks
Other Resources	Local, national and international journals
How regularly do you visit museums, to view artefacts for work / research?	Yearly
What information do you feel is important when you are working with an artefact?	- Unique ID Number - Description - Period - Material - Dimensions - Where it was discovered - When it was discovered
Other Information	If, and where, it has been published

Title:	-
Name	-
Which of the following resources do you use for your work or research?	- Research Papers - Internet - Textbooks
Other Resources	
How regularly do you visit museums, to view artefacts for work / research?	Weekly
What information do you feel is important when you are working with an artefact?	- Unique ID Number - Description - Period - Material - Condition - Dimensions - Where it was discovered - When it was discovered
Other Information	

Appendix B - User Interface Testing

Digital Collection Viewer Usability Survey

Please complete the following tasks, rating how easy they were to complete and provide a comment were necessary.

Task 1: Search for and find the Tetradrachm Coin

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Task 2: Zoom in fully on the coin

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Task 3: Zoom out fully on the Coin

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Task 4: Move the coin to the top left of the screen

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Task 5: Move the coin back to the centre of the screen

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Task 6: Rotate the coin so that the underside is face up

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Task 7: Rotate the coin to its original position

Time Taken (Seconds):

☐ **<10** ☐ **<30** ☐ **<60** ☐ **<120** ☐ **>120**

Difficulty:

☐ **1 - Easy** ☐ **2** ☐ **3** ☐ **4** ☐ **5 - Hard**

Comments:

Results

	Test User 1		Test User 2		Test User 3		Test User 4		Test User 5	
	Time Taken	Difficulty	Time Taken	Difficulty	Time Taken	Difficulty	Time Taken	Difficulty	Time Taken	Difficulty
Task 1	<30	1	<30	1	<30	1	<30	1	<60	3
Task 2	<10	1	<10	1	<30	1	<10	1	<10	1
Task 3	<10	1	<10	1	<30	1	<10	1	<10	1
Task 4	<120	2	<120	3	<120	1	<120	3	<120	4
Task 5	<120	2	<120	3	<120	1	<120	3	<120	2
Task 6	>120	4	>120	5	>120	4	>120	5	>120	4
Task 7	>120	4	>120	5	>120	4	>120	5	>120	5

	Test User 6		Test User 7		Test User 8		Test User 9		Test User 10	
	Time Taken	Difficulty	Time Taken	Difficulty	Time Taken	Difficulty	Time Taken	Difficulty	Time Taken	Difficulty
Task 1	<30	1	<30	1	<30	1	<60	2	<30	1
Task 2	<10	1	<10	1	<10	1	<10	1	<10	1
Task 3	<10	1	<10	1	<10	1	<10	1	<10	1
Task 4	<120	2	<120	1	>120	2	>120	2	>120	2
Task 5	<120	1	<120	1	<120	1	<120	2	>120	2
Task 6	>120	5	>120	3	>120	4	>120	3	>120	4
Task 7	>120	4	>120	5	>120	5	>120	5	>120	5