

ABSTRACT

The ruins of Great Zimbabwe are a unique testimony to the Bantu civilization of the Shona between the 11th and 15th centuries (UNESCO, 2010). The study focuses on how the use of virtual environments can be applied to cultural heritage sites in the country as a way of increasing awareness and portraying the cultural diversity and significance of these sites. The 3D model developed by Heinz Ruther (2008) was used, with his permission, as the foundation for an interactive virtual tour of the Great Enclosure. As the model was drawn from range scanner data, the work entailed cleaning and repairing to remove redundant points and restore missing or deformed sections of the site. Texture maps were then developed and applied to dress the site resulting in a photorealistic approximation of the Great Enclosure. Various viewpoints and lighting were then placed in the site to facilitate navigation within the scene. However, limitations were realized in the hardware platform particularly with reference to the limited graphics card memory that acted as a bottleneck for the successful development of the 3D model as the number of polygons increased. Ideally, therefore, a hardware platform with higher specifications is therefore expected to give greater performance and better results. Additional work is therefore necessary to optimize the model, incorporate audio/visual cues and enhance the interactive nature of the resulting tool.

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ABBREVIATIONS

2D	Two dimensional
3D	Three Dimensional
CPU	Central Processing Unit
GB	Gigabits
GHz	Giga Hertz
ICT	Information and Communication Technology
NMMZ	National Museum and Monuments of Zimbabwe
NRC	National Research Council, Canada
UNESCO	United Nations Educational Scientific and Cultural Organization
VRML	Virtual Reality Modeling Language.
ISPRS	International Society for Photogrammetry and Remote Sensing.

CHAPTER 1. INTRODUCTION

1.1. Background

Humans have always perceived their environment through their senses, with vision being the most dominant component (Bishop & Lange 2005). The use of computer graphics has provided more exciting ways of visualizing the environment in three dimensions (3D). Some forms of visualizations include animation as the fourth dimension. Visualization of cultural heritage sites has been one important application of 3D technologies enabling preservation, reconstruction and virtual tours of some of the world's heritage sites. One of the most important heritage sites in Zimbabwe is the Great Zimbabwe National Monument because of its size and the creative craftsmanship behind the structure.

Cultural heritage forms a very significant part of a people. Dissemination of information or awareness of sites which hold rich cultural values is important for the preservation of these sites. A lot of effort has been put into publicizing the richness and diversity of the country's heritage. These efforts have included the use of radio and television stations as once off programs for listeners and viewers. They also include the use of pamphlets that disseminate information especially to the persons that visit these sites.

Additional public media such as newspapers occasionally highlight some key information about cultural heritage sites. Websites have also been used as tools for communicating information pertaining to these heritage sites. One of these is the website of the Ministry of Home Affairs, http://www.moha.gov.zw/nmmz_monu.php which includes the National Museums and Monuments of Zimbabwe (NMMZ). It provides an overview of the heritage sites in Zimbabwe.

One common attribute of most of these approaches is limited use of interactivity with the target audience. According to constructivism and recent studies, people understand and retain more through interaction with the focus area. Scholten (2001) revealed that usage of multimedia based instruction for speech pathology students resulted in significant increases in student outcomes. The Cognitive Theory for Multimedia Learning (Mayer, 1997) describes the way in which information is processed through the audio and visual channels for effective learning to take place. Figure 1 below gives a summary of the theory.

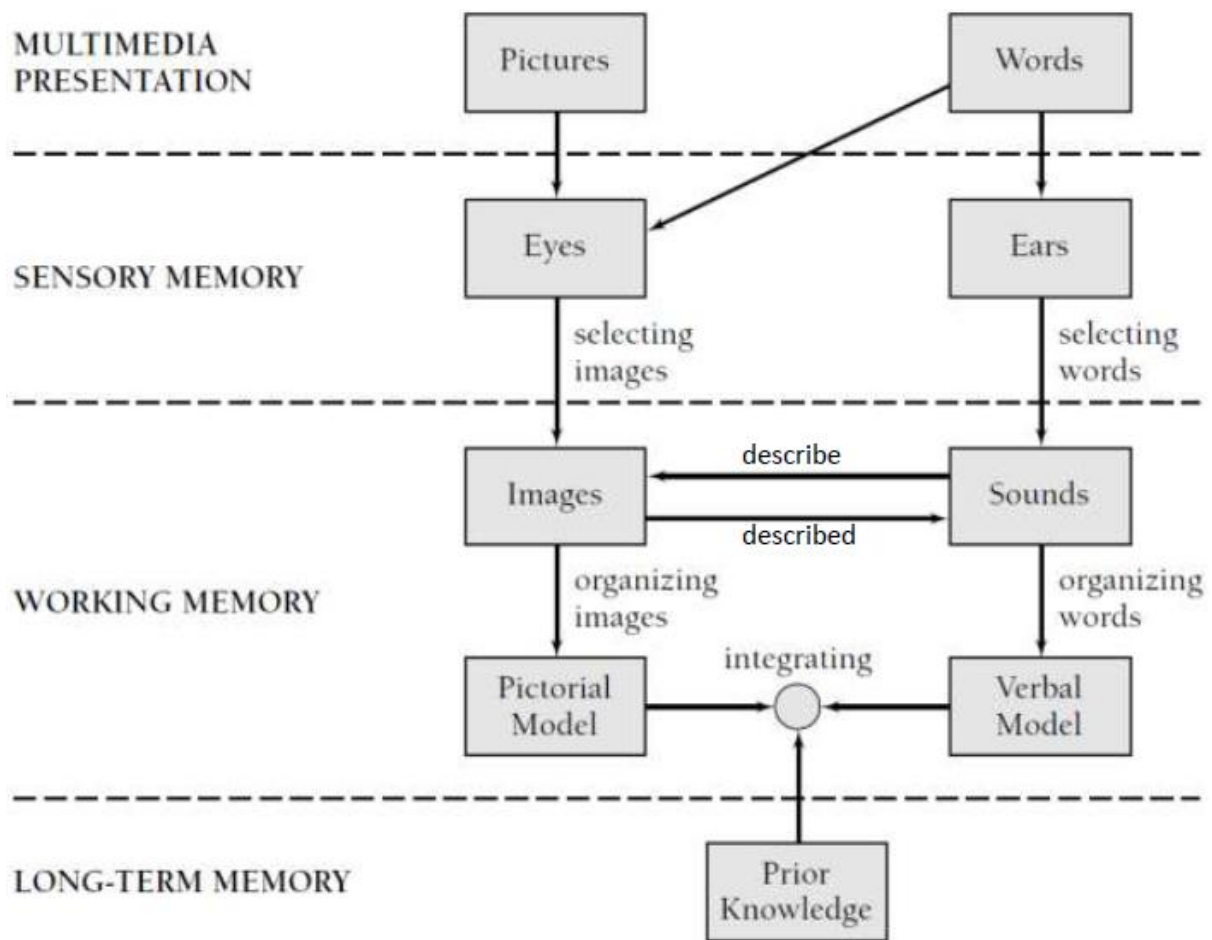


Figure 1: Cognitive Theory of multimedia learning (Mayer 1997)

A study on multimedia learning also indicated that the use of multimedia with appropriate visual cues resulted in higher retention scores (Tabbers, Martens & Merriënboer 2004). On the basis of this work, interactive multimedia environments have a great potential in the implementation of an effective campaign for increasing awareness of cultural heritage sites. There is therefore need for tools on cultural heritage which incorporate high levels of interactivity. In addition these tools should be publicly available.

Alternative ways of getting information about cultural heritage sites are therefore needed to capture the interest of the people and increase significantly the target population, particularly the younger generation.

This study looks at visualization of cultural heritage sites as a more interactive presentation of information about the cultural heritage of the country.

1.2. Research Focus

The study focuses on the development of virtual environments for cultural heritage sites in Zimbabwe as an interactive form of disseminating visual information about these sites with specific reference to the Great Zimbabwe National Monument.

1.3. Overall Research Aim and Individual Research Objectives

The main aim of the study is to develop a 3D interactive tour of the Great Zimbabwe National monument as a complementary approach to increasing awareness of the cultural heritage of the country.

In line with the aim of the research study, the specific objectives of this work are:

1. To translate 3D spatial data into a working 3D environment.
2. To develop and apply photorealistic textures to the 3D environment
3. Storyboarding virtual paths through the Great Enclosure
4. Embedding audio and visual cues for highlights in the scene
5. Publishing the completed work to the web using VRML
6. Publishing of a research paper on the work done

1.4. Value of this Research

The study builds upon already existing initiatives to document and increase awareness of cultural heritage sites in Africa (Ruther 2008). On the basis of collected 3D spatial data of the Great Enclosure, further work entails development and application of appropriate textures to the 3D scene of the site. In addition, the final result is then a virtual tour of the Great Enclosure. Virtual tours play a significant role in the visualization of cultural heritage. They present a more interactive dimension in the way in which cultural information is disseminated.

Virtual exploration of sites has the potential to capture and maintain the interest of public users as they interact with the site. As most of the senses are engaged in the process, this can contribute to more retention of disseminated information and therefore possibilities for greater understanding.

In conjunction with the National Museums and Monuments of Zimbabwe, the results of this study can be published on the internet for public access. The current drive by government over the past few years to ensure improved accessibility of information and communication technologies has resulted in generally more affordable ICT equipment for public consumers (The Herald, 2009). In addition to affordable ICT devices, technologies have also been integrated into the educational delivery system. The overall effect is wider access to online environments. The potential reach to an increased local population of the research results is thus ensured through the use of online environments. Wider visibility is therefore inherently possible, with the international community being able to gain an understanding and appreciation of the rich cultural heritage of the country.

Virtualization of the Zimbabwe's cultural heritage sites can also be used as tool for marketing the diverse sites distributed all over the country. The country boasts of a total of five sites that have been inscribed as World Heritage Sites as shown in Table 1 (UNESCO 2010):

Table 1: World Heritage Sites in Zimbabwe

Site	Category	Inscription Date
Great Zimbabwe National Monument	Cultural	1986
Khami Ruins National Monument	Cultural	1986
Matobo Hills	Cultural	2003
Mana Pools National Park, Sapi and Chewore Safari Areas	Natural	1984
Mosi-oa-Tunya/Victoria Falls	Natural	1989

The results of the study can thus contribute to the tourism drive by the government and companies in the sector by offering a tool that can effectively reach a potentially wider market base.

In general, the targeted beneficiary is the local and the international population. Interactive tools for gaining an awareness of cultural heritage sites in the country can be made available as open resources. In particular, application of this study in the educational domain can provide students, or educational institutions with the unique ability to explore sites that they may not afford to visit due to cost, timing and logistical constraints. The same view can also apply to the general population as well.

1.5. Delimitations and Limitations of Study

The study will focus on the Great Enclosure, located within the Great Zimbabwe national monument. 3D spatial data of the site was taken by the Zamani group as part of a project to document Africa's heritage and the various landscapes. Laser scanning techniques were used to develop the 3D models which are available in three forms, high, medium and low resolution from Aluka. Aluka is an international, collaborative initiative building an online digital library of scholarly resources from and about Africa. The low resolution polygonal model has been selected for use in this study. The rationale behind the selection is the number of vertices contained in the polygonal model. In a feasibility exercise carried out with a laptop and desktop computer, the medium and high resolution models resulted severe performance degradation of these computers. The low resolution model did not have high memory footprint therefore making this model an effective alternative. For virtual simulation of the site, the low resolution model proved sufficient.

Various modeling techniques available within the 3D Studio Max environment will be utilized. Images from the internet of the site will be used to develop photorealistic textures to dress up the Great Enclosure 3D environment. Strict adherence to copyrights of such images will be followed.

1.6. Outline Structure

Chapter 1: Introduction

This chapter provides an introduction about Zimbabwe's cultural heritage sites and various ways in which information on these sites has been disseminated. Moreover, the chapter discusses 3D technologies as another form of disseminating information about cultural heritage sites, leveraging on how human perceive their environment through visual and audio channels. The focus of this study is highlighted and justified, and the overall research aim and specific objectives are clearly identified.

Chapter 2: Literature Review

This chapter gives a detailed look at the Great Zimbabwe National Monument, describing the architecture, background and historical significance of this site. Additionally, it explores an existing initiative on the development of a database with various African cultural heritage sites and landscapes under the Zamani Group. The chapter concludes by highlighting areas where contributions can be made to this initiative, and identifies how the use of virtual environments can be used to disseminate information about the local heritage sites.

Chapter 3: Research Methodology

This chapter presents the strategy to be adopted and provides supporting justification for the strategy. The process of data acquisition is also discussed, together with necessary development platform to be used as part of the study. A framework for the analysis of collected data is presented, and to conclude the chapter discusses some limitations and potential problems.

Chapter 4: Modeling of the Great Enclosure

This chapter takes the reader through the modeling process, starting from the cleaning of the model, and mesh reconstruction. Development and application of textures on the Great Enclosure is also discussed. Additionally, the chapter takes a look at the identification of viewpoints and setting up the navigation of the site. The chapter wraps up by looking at some challenges faced in the site development.

Chapter 5: Conclusions

This chapter reflects on the overall aim and specific objectives of the study. A summary of the findings in relation to the specific research objectives is given. The resulting conclusions from the research are derived and linked to the objectives. Additionally, limitations of the study are discussed and recommendations given thereafter. Clarification is then made on the type of contribution that has been made as a result of this study. The chapter concludes with a self reflection section which gives a personal perspective on the process undertaken to complete this work.

References

This section lists sources referred to in this work. Harvard system of referencing is used.

Appendix A: Glossary

This section describes some technical terms used in this study.

Appendix B: Criteria for selection of World Heritage sites

This is an extract from UNESCO (2010) detailing criteria used to select World Heritage site

CHAPTER 2. LITERATURE REVIEW

2.1. Application of 3D in Cultural heritage

3D technologies have for some time been applied to cultural heritage through the capturing creation and preservation of documentation for various artifacts, historical and archeological sites (National Research Council, 2010). Through the use of 3D tools, cultural heritage documentation can be availed for general public access. Presentation of cultural heritage information has become more attractive and interactive with the advances of 3D technologies, (Arnaoutoglou et al. 2003). Application of 3D in cultural heritage for public usage has predominantly come in the form of virtual environments as part museums or heritage archives.

The study presents a virtual educational environment for cultural heritage to complement awareness campaigns of cultural heritage in a country where 3D interactive environments are still to be applied as tools for visualizing heritage sites. Moreover, it discusses ways in which the country can benefit from advances being made in the application virtual environments to cultural heritage.

2.2. The Great Zimbabwe National Monument

The Great Zimbabwe monument is the most significant monument located south of the Egyptian Nile pyramids (Ampim 2004). The monument is the second largest site in sub-Saharan Africa, after the pyramid region of Egypt.

The site was adorned status as a World Heritage Site by United Nations Educational Scientific and Cultural Organization (UNESCO) in 1986 using criteria (i), (iii) and (vi). The criteria are explained as follows:

- – representation of a masterpiece of human creative genius;
- – to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;
- (vi) – to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance.

The monument is located about 30 kilometers from Masvingo, a town which is in the south-eastern part of Zimbabwe.

2.3. Historical Significance

Great Zimbabwe was built in the period between 12th and 15th centuries by ancestors of the Shona people (Ampim 2004). However, occupation of the area had already taken place before the building of the site as early as the fifth century (Chirikure and Pikirayi, 2008)

It is estimated that the site had as many as 18 000 inhabitants making it one of the largest cities of its time (Ampim 2004). It became a very powerful kingdom which lasted about three centuries (Chirikure and Pikirayi 2008) before its eventual decline. The causes for the decline are still not clear with scholars putting forward various theories ranging from disease to over-farming as possible explanations.

Evidence shows that Great Zimbabwe was part of a comprehensive trade network during the Medieval period (Ampim 2004), reaching as far as the Limpopo valley in South Africa, the southern Mozambique coast and to some extent, some parts of Zambia (Pwiti 1989).

2.4. Architecture of the Great Enclosure

The Great Zimbabwe was built out of large granite rocks as the bricks. The most amazing aspect about the walls is that they were not built with mortar to hold the bricks together. It has been viewed as the creative genius of civilization that made the site its home.

The Great Zimbabwe is composed of three architectural groups:

- Hill complex, which has the Eastern Enclosure in which the famous Zimbabwe Bird is believed to have been housed.
- Valley Complex, divided into Upper and Lower Valley Ruins
- Great Enclosure composed of an inner wall encircling various structures and a grand outer wall.

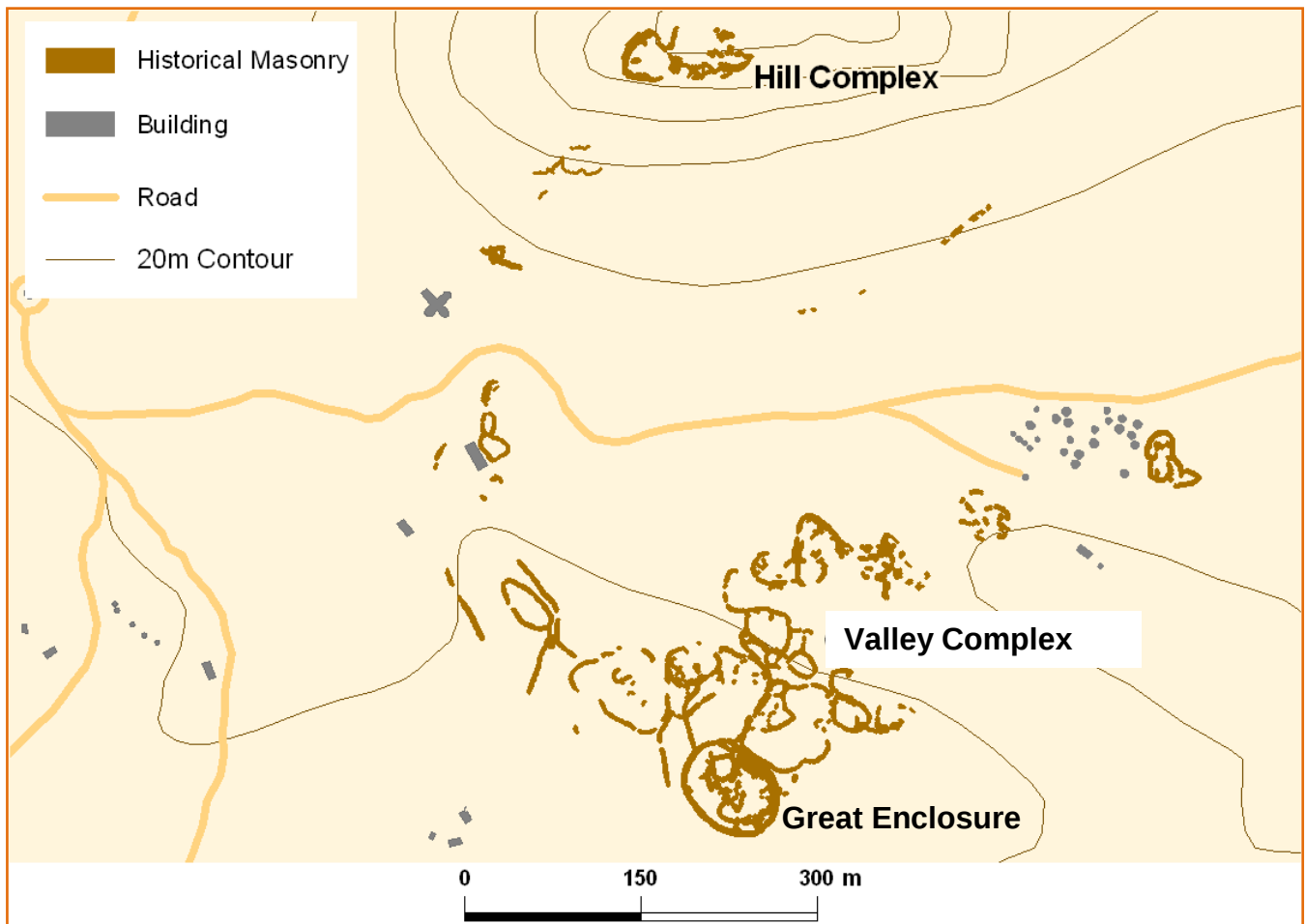


Figure 2: Map of the Great Zimbabwe showing the three architectural groups (Zamani Project 2008)

Of primary interest in the study is the Great Enclosure. The Great Enclosure is believed to have been focus of control due to the elaborate nature of the walls which surpasses that of the remaining parts of the Great Zimbabwe.

The walls of the Great enclosure are as high as 9.5 meters and the outer wall extending as much as 278 meters in length.

Figure 3 is a ground plan of the Great Enclosure illustrating its oval structure and the thickness of the walls.

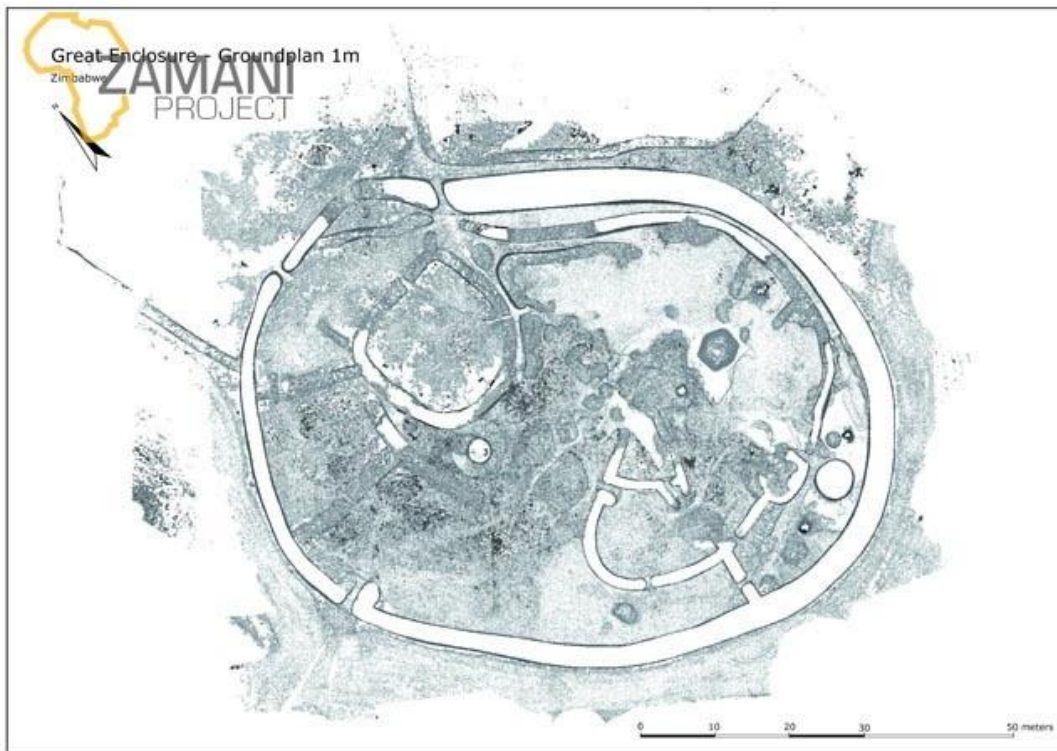


Figure 3: Ground Plan of the Great Enclosure - (Zamani Project 2008)



Figure 4: Aerial photo of the Great Enclosure taken from an aircraft (Koeller 2003)

2.5. 3D Visualization in Cultural Heritage

Visualization of cultural heritage sites and artifacts is an interdisciplinary approach bringing together history, archeology, photogrammetry and architecture (Botteri & Fangi 2002). In addition, there is an artistic dimension in the way in which the visualization is presented for various purposes.

2.5.1. Rationale behind 3D Visualization of Cultural Heritage Sites

3D spatial information of heritage sites has greatly assisted in the preservation and maintenance of cultural heritage sites and artifacts (Caprioli et al. 2007). Development of proper structural maintenance strategies has effectively been aided by the spatial information of sites. Damage to sites during maintenance exercises can be greatly reduced when the activities to be carried out and their effects are visualized prior to them being carried out.

Analysis of sites for possible reconstruction activities has been speeded up, providing possibilities of previewing changes prior to their undertaking. Visualization of sites before the degradation over time can reveal a lot more about the civilizations that occupied the site and their activities. Physical reconstruction of heritage sites can therefore be based on the virtual reconstruction of the same site.

Visualization of heritage has also facilitated academic explorations of sites from simple awareness applications to high resolution, in-depth site analysis by expert archeologists. 3D environments have given users a unique ability to walk through some of the existing cultural heritage sites. The benefits are twofold: (1) users who may not have had the opportunity to physically tour a site can experience it through a virtual application and learn about the site in the same environment, (2) pre-exploration of sites prior to visits and post-exploration to study more about the site.

2.5.2. The African Cultural Heritage and Landscape Database Project

The African Cultural Heritage and Landscape Database is a project managed by the Zamani Group. “Zamani” is a Swahili word signifying “the past”. The Zamani group dwells on the African context with the aim of exploring and developing a database of Africa’s cultural heritage and various landscapes.

Table 2 lists the team-members of the group.

Table 2: Zamani group team members.

Name	Team role
Heinz Ruther	Principal Investigator, Em. Professor of Geomatics
Christoph Held	Chief Scientific Officer
Roshan Bhurtha	Scientific Officer
Ralph Schroeder	Scientific Officer
Stephen Wessels	Scientific Officer

The rationale for the creation of the Zamani group was to document Africa's heritage on the following basis:

- Increase international awareness of Africa's heritage
- Provision of material that will be used in research studies
- Creation of accurate records of important sites to aid in the reconstruction and conservation process.

The project was born as part of the Geomatics Department at the University of Cape Town with funding from the Andrew W. Mellow Foundation. The spatial data developed as part of the project is meant to be used only for educational, scholarly, and other not-for-profit purposes.

Below are some of the sites that were completed using sophisticated tools to collect spatial data as part of the documentation project which spanned several countries across Africa.

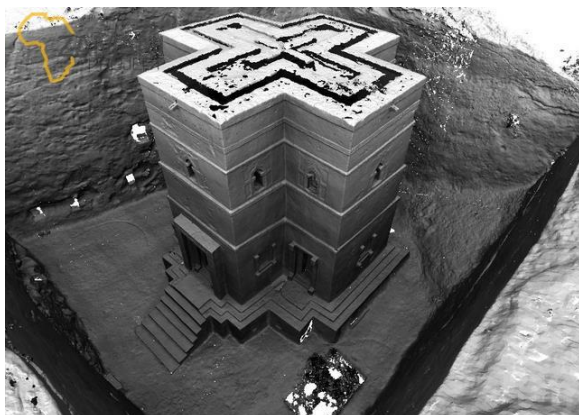


Figure 5: Biet Giorgis, Lalibela Ethiopia

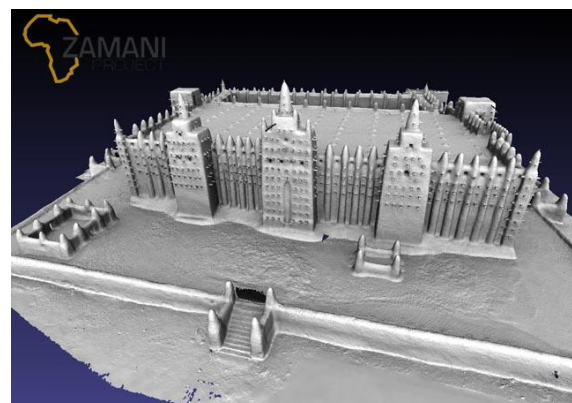


Figure 6: Djenne Mosque, Mali.



Figure 7: Elmina Castle, Ghana



Figure 8: Gede Palace, Kenya

The African Cultural Heritage and Landscape Database is an initiative driven under the guidance of Professor Heinz Ruther. This project continues to spread, with some sites still in progress, and others planned for exploration. The objective is the creation of a database of some of the most significant sites in Africa. Among other heritage sites forming part of the database is the Great Zimbabwe National Monument.

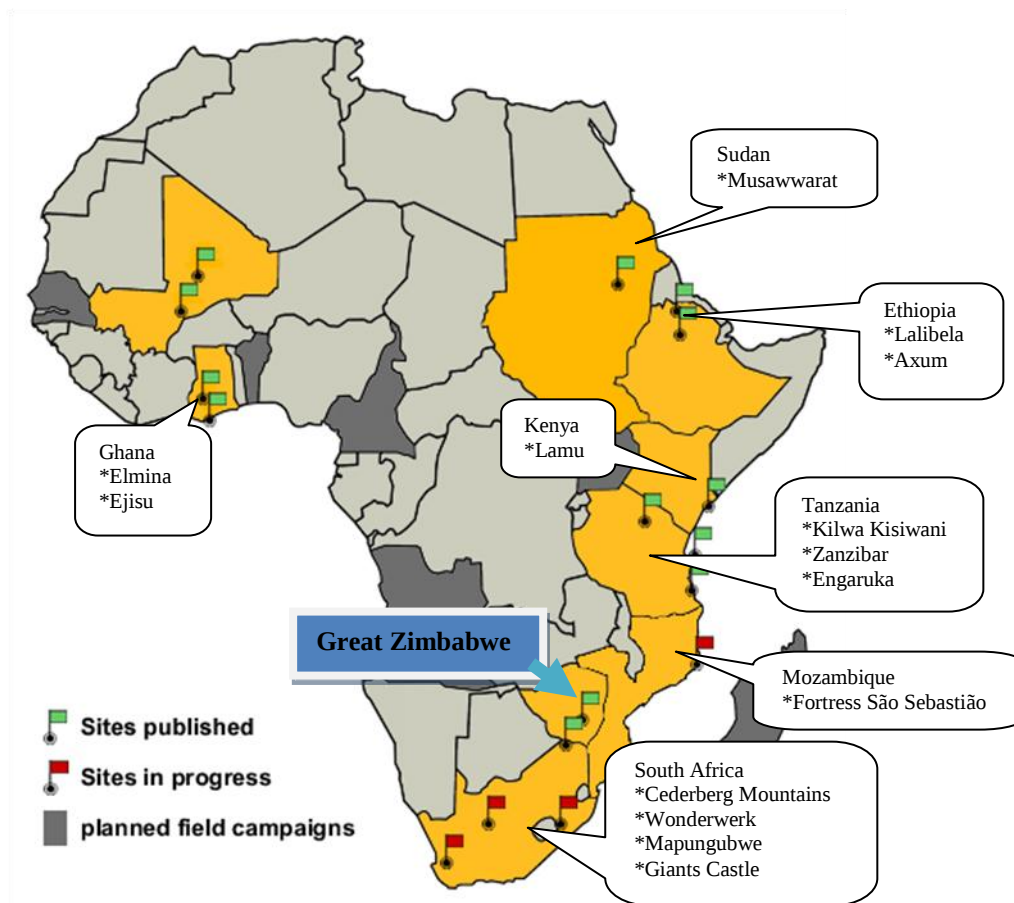


Figure 9: Map of Africa showing sites in different countries that are included in the Zamani Project

Digital documentation of the Great Enclosure was created with the use of terrestrial scanners for acquisition of spatial information of the site. The resulting high resolution models developed from the point clouds are shown in Figure 10 and Figure 11:



Figure 10: Close-up of the high resolution model of the Great Enclosure



Figure 11: Full view of the Great Enclosure

The 3D models developed through the project are an accurate representation of the project. On the basis of these developed models, the intention of the Zamani group is to further develop them into integrated and interactive environments.

Work on the Great Enclosure was completed successfully with various models being developed, ranging from the low resolution up to the high resolution models. However, full texturing and addition of interactivity still has to be carried out.

2.6. Summary: Emerging Issues and the need for additional research

The value of cultural heritage can never overemphasized, as revealed by the review of the literature. Zimbabwe has a rich collection of invaluable geographic locations which represent the cultural heritage of the country. Through the National Museums and Monument of Zimbabwe (NMMZ), the country has undertaken various activities to preserve, document and increase awareness of local cultural heritage sites. These have included joint efforts for restoration of the Great Zimbabwe National Monument (UNESCO 2010). This indicates the level of commitment the country has towards its cultural heritage.

In addition to activities of restoration, a drive for increasing awareness has necessitated the need for various forms of awareness campaigns. This has included local television program,

Madzinza eZimbabwe, which featured the expertise of historians covering backgrounds of various ethnical groups in the country, and the sites in which they lived. In addition, the NMMZ has used its website to provide information about the sites in the country.

The study of the relevant literature has revealed a gap in the implementation of awareness campaigns for cultural heritage, where 3D virtual environments have not yet been adopted for cultural heritage sites in Zimbabwe. In as much as different approaches have been taken to publicize heritage information, there is another alternative that is still to be tried and implemented in the country. Interactive visualization of cultural information in 3D is a possible alternative that is still to be utilized as an approach to generate potentially high levels of interest in cultural heritage sites. The study therefore embarks on introducing interactive virtual environments for heritage sites in the country, with the Great Zimbabwe National Monument as a reference.

The research attempts to capture the Great Enclosure, which forms part of the Great Zimbabwe National Monument, giving it a realistic look and feel thereby immersing the target audience into the virtual world and encouraging them to explore. The work done by Professor H. Ruther forms a critical basis for this study as it builds up on the 3D spatial data that forms part of the African Cultural Heritage and Landscape database. Additional work is on the application of realistic textures and bringing the whole 3D world to life. The steps taken to carry out these tasks are highlighted in the next chapter, Research Methodology.

CHAPTER 3. RESEARCH METHODOLOGY

3.1. Introduction

This section focuses on specifying the research methodology adopted to address the research issues highlighted above, further giving details on the approaches taken to collect relevant data. A framework for analyzing and making use of the data is then highlighted including the limitations and potential problems that may be faced.

3.2. Research Strategy

The study, by nature, is qualitative as it seeks to explore phenomena of virtualization and how it can be applied in the context of a specific location, in this case. The empirical research in the study seeks to investigate and introduce interactive virtualization as awareness tools in the context of cultural heritage through a collection of interrelated objectives.

Action research has been adopted as the key strategy for the study. Action research can be described as a flexible research methodology uniquely suited to researching and supporting change (Given, 2008). The diagram below indicates the model of action research.

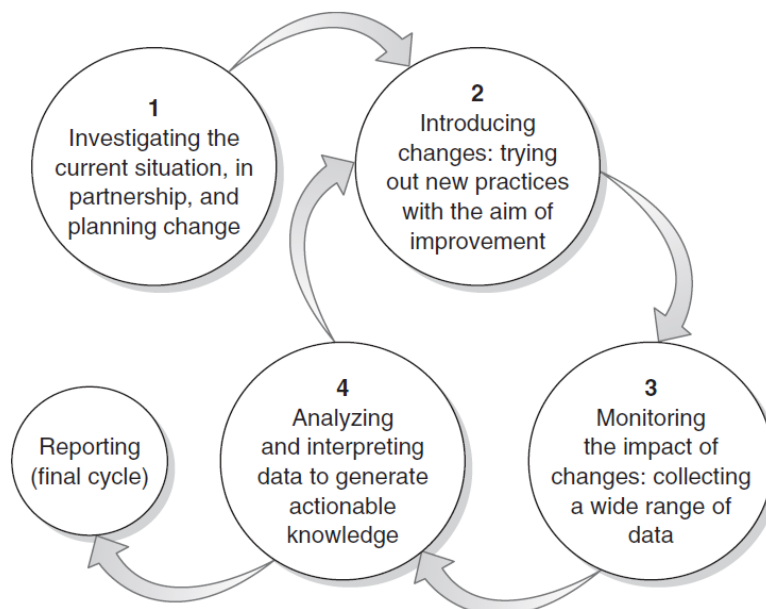


Figure 12: Model of Action Research

Action research generally involves fluid overlapping cycles of investigation, action planning, piloting of new practices and evaluation of outcomes.

The outcomes of action research are therefore theoretical and practical providing a solution within the given context. Al-Hakim and Cater-Steel (2009:21) highlight the aim of action research as:

“...to contribute to both the practical concerns of people in an immediate problematic situation, and to the goals of science by the joint collaboration of the researcher and practitioner within a mutually acceptable ethical framework.”

Action research, as an outcome produces new knowledge that is of direct practical value and relevance to professionals involved (Al-Hakim & Cater-Steel 2009). The study investigates and applies existing knowledge with a view to improve the ways in which cultural information disseminated. On the basis of objective 5, the main outcome is thus the delivery of a practical technological solution that can be directly applied in the context of cultural heritage.

3.3. Data Acquisition

3.3.1. Site Selection

The selection of the site was done on the basis of existing efforts to develop virtual environments of cultural heritage sites in Zimbabwe. Thus, the Great Enclosure which forms part of the Great Zimbabwe National Monument was chosen as a site for the study for the following reasons:

- There is already an existing raw 3D model of the site
- Additional tasks need to be carried out to complement existing work on the model

The Great Zimbabwe National Monument has, and continues to be one of the most significant cultural icons for the country.

3.3.2. Development Platform

The platform used for working in the 3D environment is a consumer computer with the following specifications:

Table 3: Development platform specifications.

Property	Value
Processor	Intel® Core™ Duo CPU T5870 @ 2.00GHz, 2.00GHz
Memory	2GB
System Type	32 Bit
Operating System	Windows 7, Professional
3D Software	3D Studio Max 2010, 32 bit

3D studio Max 2010 has been selected as the software platform for use in the study as a high ranking, industry standard platform for modeling. Even though it has been around for a number of years, it has maintained its spot as the most preferred program by 3D artists mainly because of its robustness.

3.3.3. Texture Development

Texturing the model requires photorealistic maps to be developed. 2D images sourced from the internet form the basis for development of texture maps to give the model a realistic appearance. Images used are distributed under the creative commons copyright therefore easily editable and incorporated into the texture maps for the model.

3.4. Framework for Data Analysis

The development of a virtual tool for visualization of cultural heritage transforms a raw 3D scene as created from range scanner data, into an interactive virtual world enabling tours with user controlled navigation. Figure 13 outlines the steps taken to carry out this transformation.

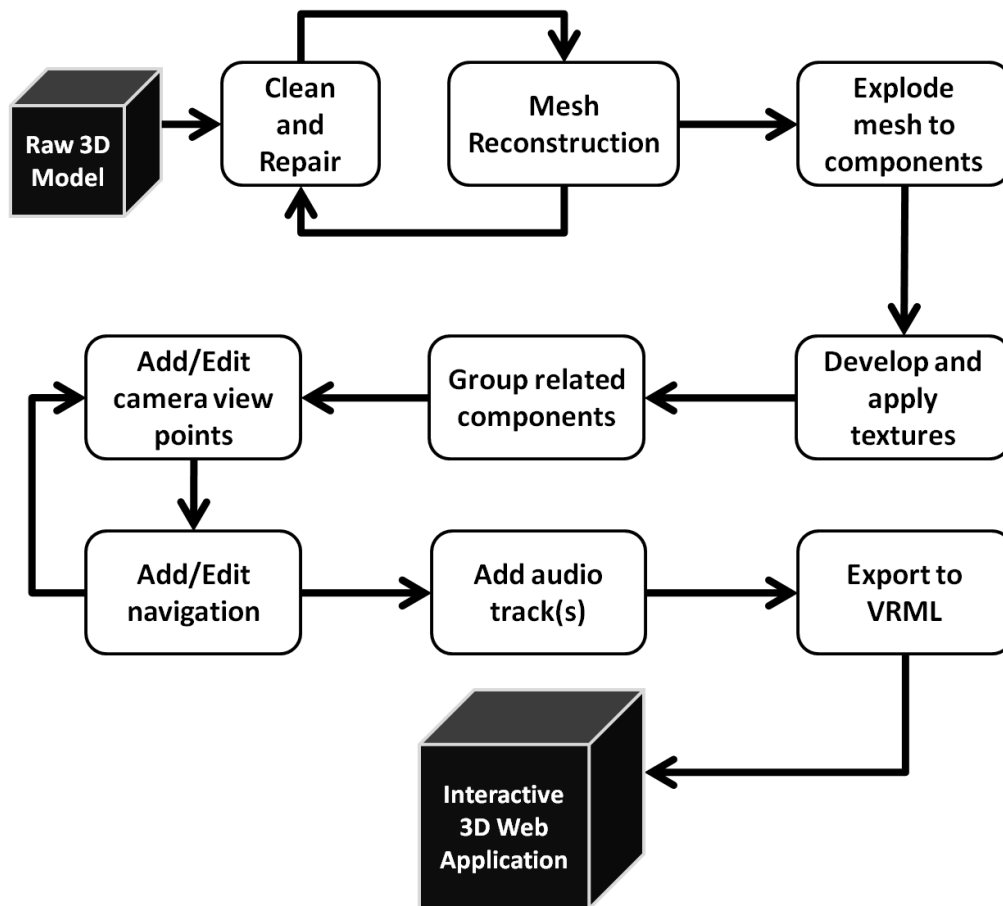


Figure 13: Transforming a raw 3D scene into a virtual interactive world.

As with any typical raw data, the 3D model has to go through a rigorous set of cleaning and repairing processes to remove vertices and faces which can potentially cause problems in the processing of the 3D model. Duplicated vertices, as an example, significantly increase the number of points to be processed. At face value, this may not necessarily appear as problem, however, the performance of various computations during the manipulation of the 3D model has the potential to decrease especially when viewed also in the context of the processing power of the computer on which a 3D application is running. Outlined in Figure 13, are some of the major activities that are used to effectively clean the 3D model, in the process coming up with a refined model.

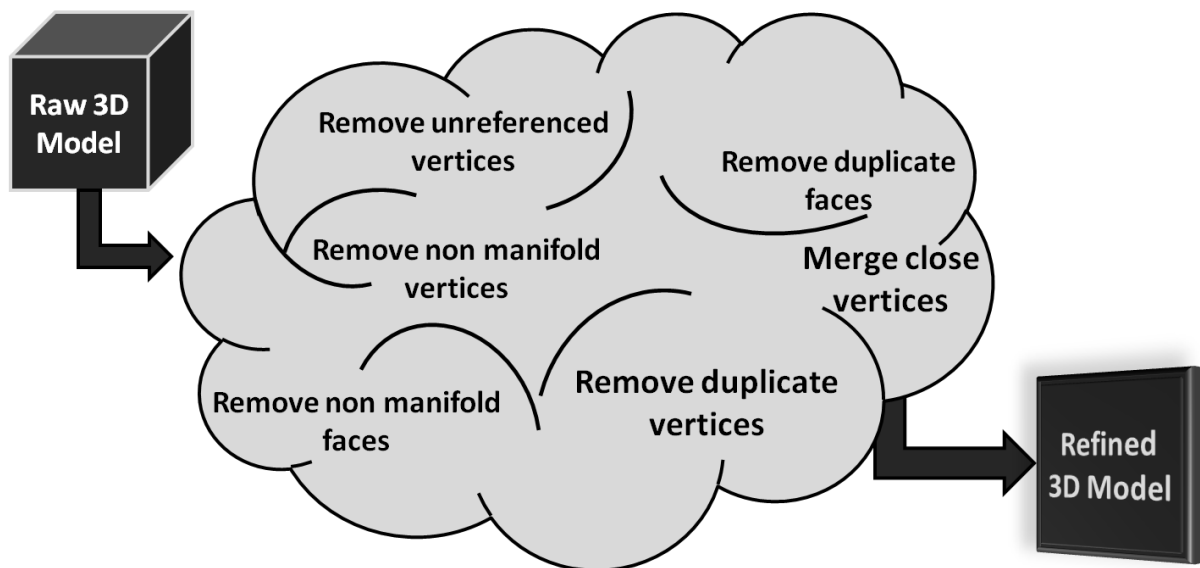


Figure 14: Cleaning and repairing the 3D model.

Unreferenced vertices are those points in the scene that are not linked to any other point in the same scene. In some cases, when a 3D model is taken directly from scan data, there is often a large proportion of unreferenced vertices that come as part of the model.

The possibility of duplicated vertices and faces is also inherent in models derived from scan data. They, also have a significant performance impediment in various computations or processes used in the development of the model. The direct consequence is large memory footprint.

Non manifold vertices and faces do not conform to the Euler Poincare equation that states that:

$$E + 2 = V + F$$

Where E is the total number of edges, V is the number of vertices and F is the number of faces. Objects which do not satisfy this equation do not exist in the real world (Kfourmetrics, 2008). A clear example of non manifold objects is self-intersecting faces.

3.5. Limitations and Potential Problems

The study, though it generally attempts to introduce virtual tours of cultural heritage sites in Zimbabwe, is limited by the fact that the specific results obtained cannot be necessarily

extended to the wider research community. Even in the national context, it would be difficult to make generalizations as each cultural heritage site has its own level of complexity and various challenges that may need to be addressed.

Basically, within the context of action research, the purpose of the study is to provide interactive means of visualizing cultural heritage sites using 3D environments. The study therefore focuses on depth, with the intention of improving the way in which cultural heritage sites are visualized, rather than generalization.

The study bases itself on existing work about cultural heritage sites in Africa. However, the extent of development of the interactive environment is bounded by the software and hardware platforms to be used, and the size of the model that can be supported by these platforms. 3D Studio Max 2010 was selected as the main development environment for the 3D model, with the assistance of Meshlab on the cleaning and repair process for the initial 3D model. Hence all activities on the 3D model are limited to the tools available from these software platforms. However, care is taken to maintain the stability of the site during the development in order to deliver a working, interactive 3D model of the Great Enclosure. The cleaning and repairing process would be able to remove most of the redundant vertices, faces and non-manifold geometry. Therefore, any operations on the geometry of the model would not include any of these points.

This chapter has therefore provided details on the research strategy used in this study, and has additionally addressed limitations of the study. The next chapter, Modeling of the Great Enclosure, demonstrates the development of the interactive 3D model of the site, describing the challenges faced and some approaches taken to overcome those challenges.

CHAPTER 4. MODELING OF THE GREAT ENCLOSURE

4.1. Introduction

The chapter gives an insight into the study described in Chapter 3, Research Methodology. Figure 15 shows the raw 3D model with an initial 56, 256 vertices and a total of 99, 999 faces. The next few sections discuss the various stages that were gone through in the transformation of the model to a workable interactive world.

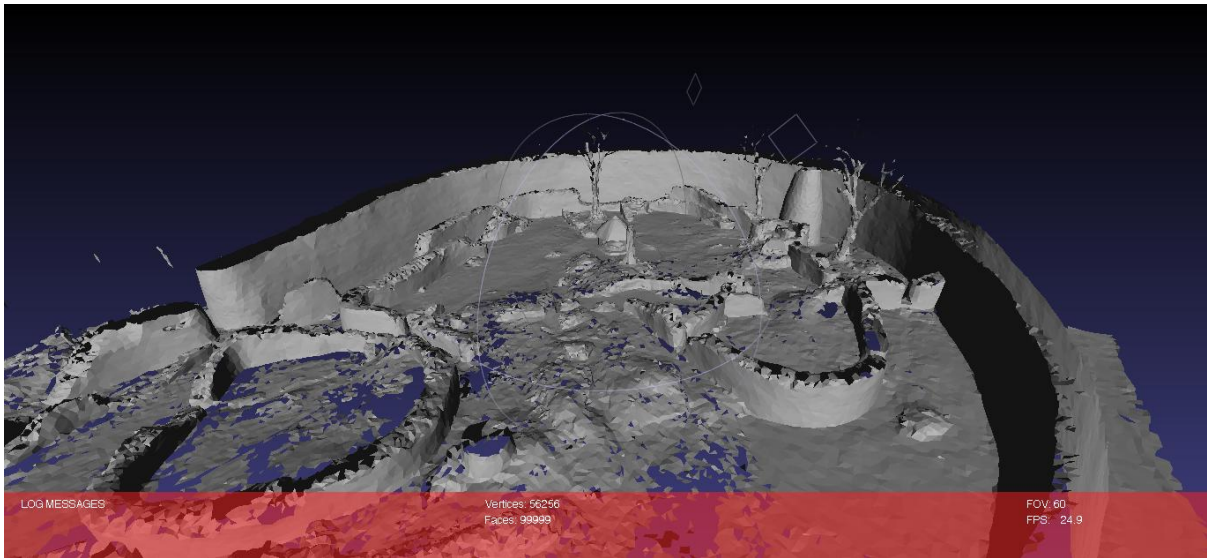


Figure 15: Raw 3D Model showing the initial number of faces and vertices.

4.2. Cleaning the 3D Model

The cleaning and repairing process took on the unstructured model given in Figure 14 which involved continuous iterations on the following process until the model was largely stable with no further changes taking place:

- Removal of:
 - Unreferenced vertices
 - Non manifold vertices and faces: these do not conform to
 - Duplicate faces
 - Non manifold faces
 - Isolated pieces with respect to number of connections
- Merging of vertices that were too close together.

The table below summarizes the results of the various processes that were used to clean and repair the model.

Table 4: Activities of the cleaning process and their results

ACTIVITY	NUMBER OF FACES	NUMBER OF VERTICES
Removed duplicate faces	570	
Remove non-manifold faces	953	
Remove non-manifold vertex		1338
Merge close vertices		151
Remove unreferenced vertices		2185
Remove isolated pieces	560	
Totals	2083	3674

4.3. Mesh Reconstruction

The original model contains lots of gaps (holes) which are sections of the site that the range scanner could not effectively articulate. It is important that these holes get filled in for additional tasks that include texturing to take place.

4.3.1. Closing Holes in MeshLab

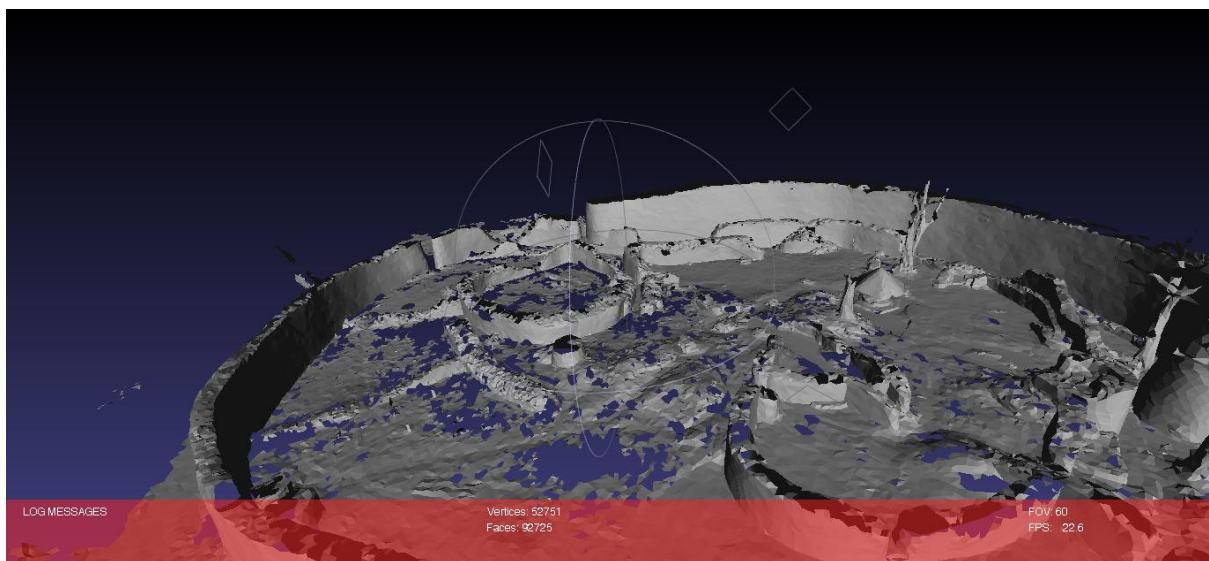


Figure 16: Model after going through the cleaning process.

As can be seen in the model, there is a significant number of patches inside the model, with different sizes ranging from very small to very large. The first step in the reconstruction involved the closing of holes under a minimum threshold according to the world unit.

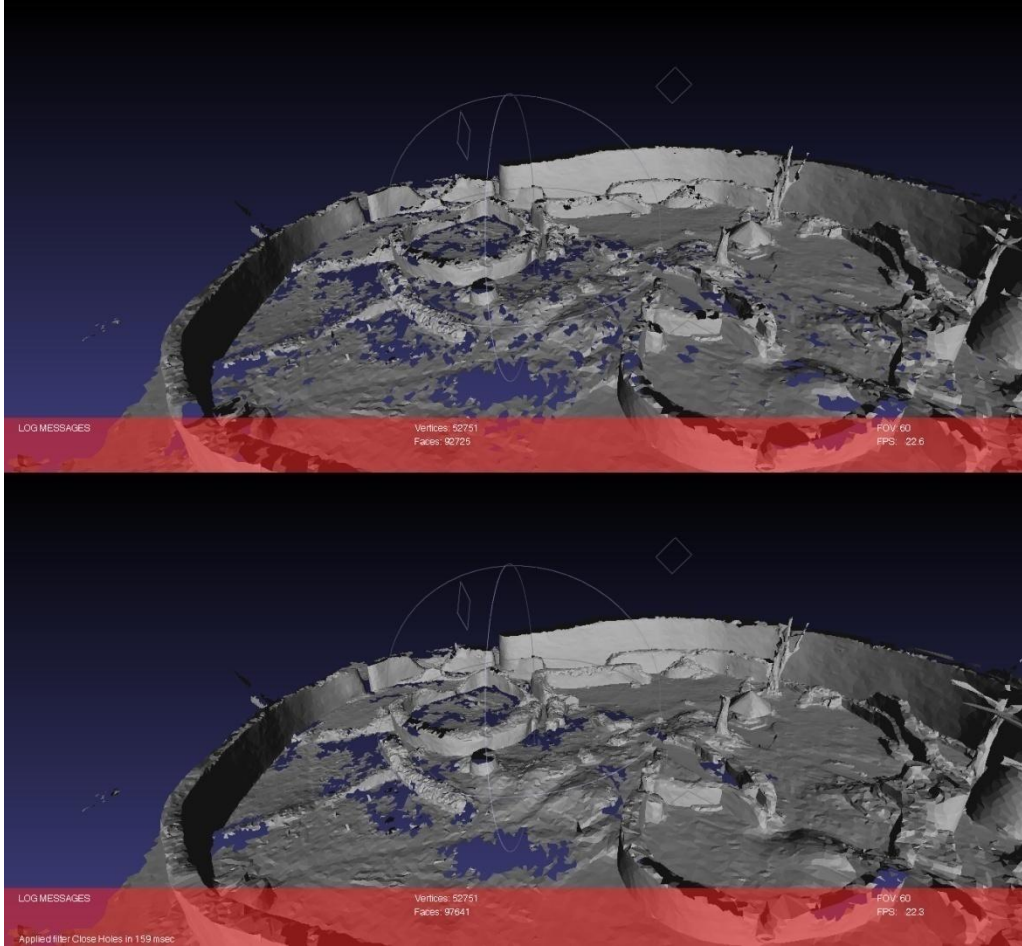


Figure 17: A comparison of the model before closing holes(top) and after(bottom)

The algorithm used for filling holes in MeshLab is based on the work by Peter Liepa (Cignoni et al. 2008). Instead of only using a weightset based on area ($L_{\text{area}} = [0, \infty)$, with $0_{L_{\text{area}}} = 0$), the algorithm (Liepa 2003) uses a modified weightset in which each weight is an ordered pair of (angle, area) The algorithm states that, given a sequence of vertices bounding the hole, $V = \{v_0, v_1, \dots, v_{n-1}\}$, $v_i \in \mathbb{R}^3$,

let $P = (v_0, v_1, \dots, v_{n-1})$ be the associated 3D polygon that covers the hole.

Define a weight function $\Omega_{\text{angle}}: V^3 \rightarrow L_{\text{angle}}$,

$$\Omega_{\text{angle}}(v_i, v_m, v_k) = (\mu(v_i, v_m, v_k), \Omega_{\text{area}}(v_i, v_m, v_k))$$

where

L_{angle} (defined as $L_{\text{angle}} = [0, \pi] \times [0, \infty)$, with $0_{L_{\text{angle}}} = 0$) is a weightset,

Ω_{angle} assigns a weight to each triangle whose vertices are in V ,

$\mu(v_i, v_m, v_k)$ is the maximum dihedral angle between (v_i, v_m, v_k) and existing adjacent triangles, and

$\Omega_{\text{area}}(v_i, v_m, v_k) = \text{Area of } (v_i, v_m, v_k)$ (note: when this weight function is used in the Triangulation Algorithm it will yield a minimum area triangulation).

For $0 \leq i \leq j < n$, let $W_{i,j}$ be the weight of the minimum-weight triangulation of the subpolygon $(v_i, \dots, v_j)$. We calculate minimum weights for polygons with increasing numbers of vertices, starting from polygons of 3 vertices (i.e. triangles) using the following **Triangulation Algorithm**.

1. For $i = 0, 1, \dots, n-2$, let $W_{i,i+1} \leftarrow 0_L$ and for

$i = 0, 1, \dots, n-3$, let $W_{i,i+2} \leftarrow \Omega_{\text{angle}}(i, i+1, i+2)$. Set

$j \leftarrow 2$.

2. Put $j \leftarrow j+1$. For $i = 0, 1, \dots, n-j-1$ and

$k \leftarrow i+j$, compute

$$W_{i,k} \leftarrow \min_{i < m < k} [W_{i,m} + W_{m,k} + \Omega_{\text{angle}}(v_i, v_m, v_k)]$$

Record the index m where the minimum is achieved as $\lambda_{i,k}$.

3. If $j < n-1$, go back to step 2. Otherwise the weight of the minimum-weight triangulation is $W_{0,n-1}$.

4. Recover the triangulation using the $\lambda_{i,k}$ values recorded in step 2

4.3.2. From MeshLab to 3Ds Max

The mesh reconstruction was taken to 3Ds Max to effectively work on the larger holes, capping them to reflect the structure of the site, the Great Enclosure. The original model was

in polygonal format (*.ply) which is not supported by 3Ds Max. However, a library was made available as a plugin for 3Ds Max to support these files.

Figure 22 below shows the model in the 3DsMax environment. In this environment, reconstruction work focused on the capping of large holes with the following complementary activities:

- Adding polygons
- Merging vertices
- Connecting vertices
- Unifying edges\

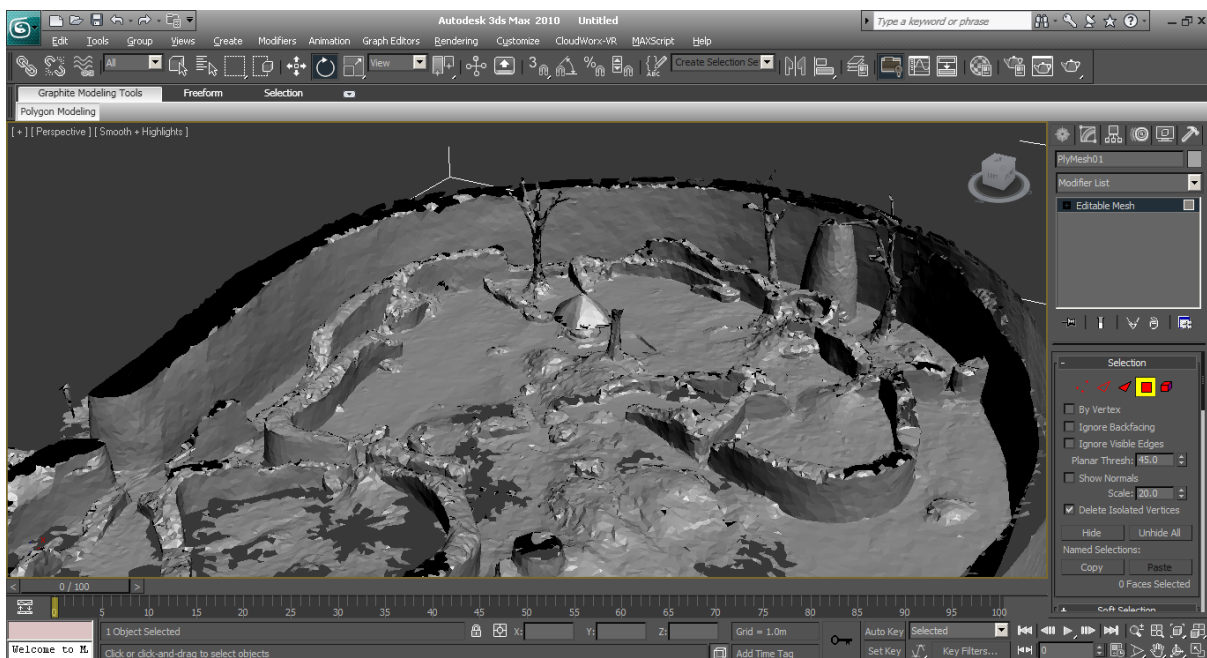


Figure 18: Model exported to 3D Studio Max 2010

The complex nature of the holes made it difficult to carry-out the capping of holes in a single step. The holes, being in more than one plane, required careful analysis especially considering the height component in the Z-axis if the hole was predominantly in the XY-axis. Points in the same hole sometimes varied significantly with respect to their positioning in the Z-axis.

The diagram below shows an example of a hole encountered that started from the ground and extending into one of the walls.

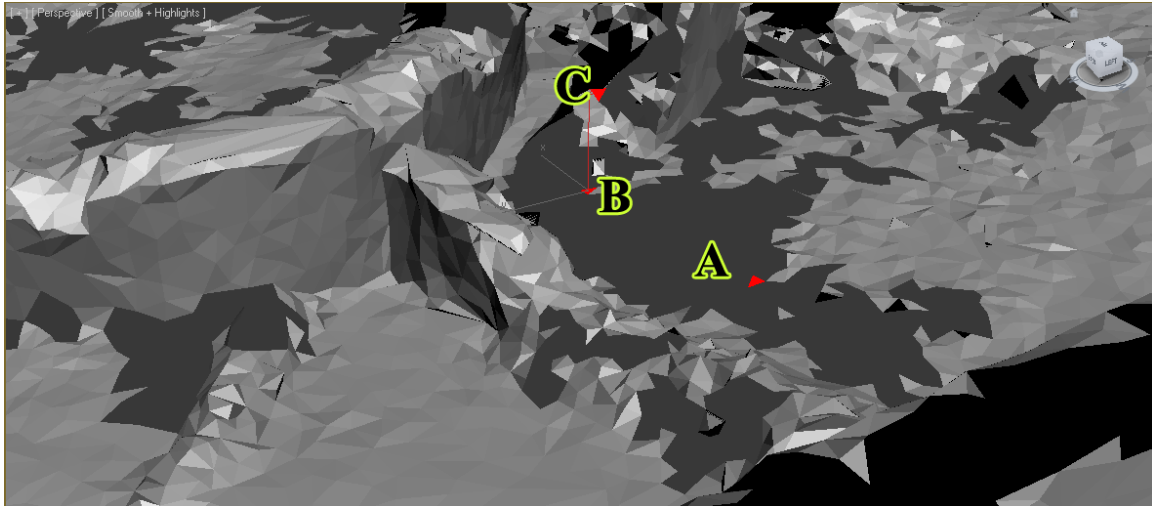


Figure 19: Section of the model indicating a hole stretching from the ground and into the wall.

The faces A and B are part of the ground, however C is part of the wall. Capping this hole resulted in Figure 24 below.

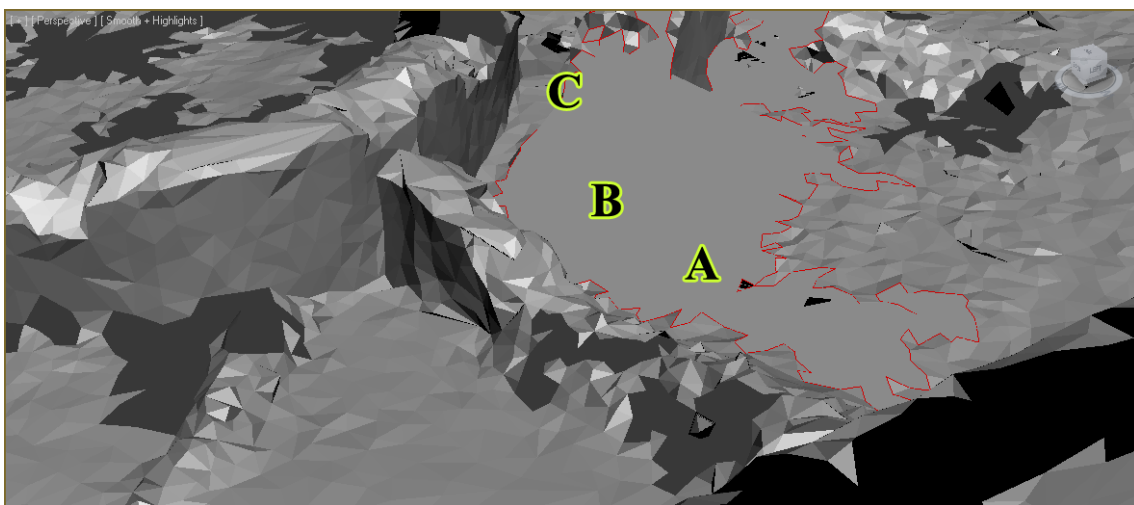


Figure 20: Capped hole with A, B and C totally covered by the cap.

The cap, in this case, is one large face made up of several bounding edges. However, in interactive environments triangulated meshed are processed with great ease than this type of face. The cap was next converted into a triangulated patch as highlighted in Figure 25.

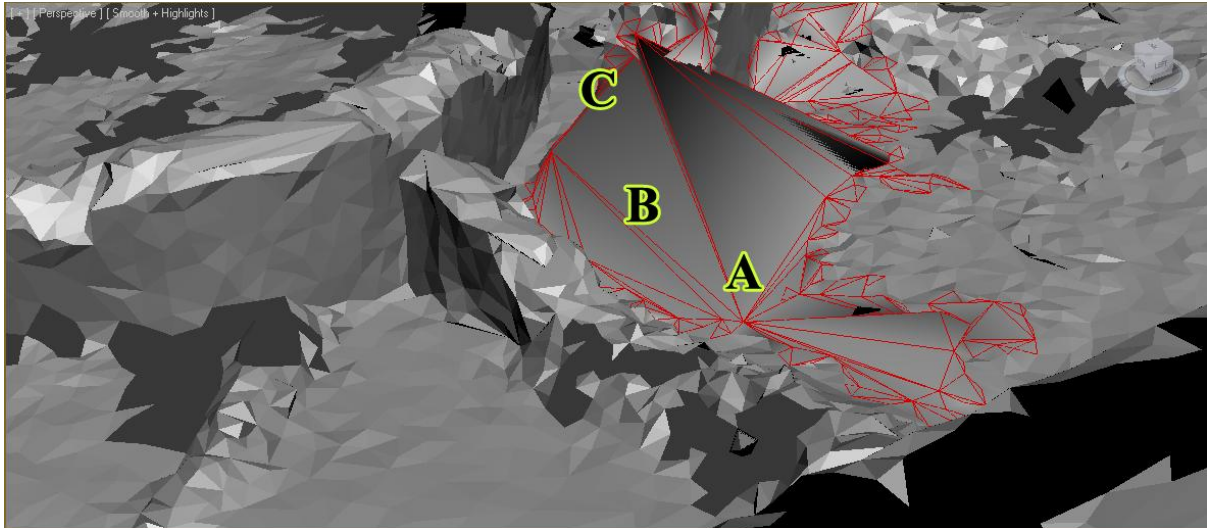


Figure 21: Triangulated cap covering hole.

The hole, due to its complex nature, has resulted in a distortion of the mesh after it was capped. For this reason, an analysis of the structure of the hole was made before capping took place. Manual bridging of selected edges successfully split the large holes into smaller manageable pieces that were then capped without significant changes to the structure of the mesh in comparison with images of the same location.

4.3.3. Exploding the Mesh

The resulting model after capping holes and re-meshing selected sections, was then broken into multiple elements based on the angles of its edges. This process, in the 3Ds Max environment is known as exploding.

Breaking the mesh into elements then facilitates the texturing of the model. The result of the explode depended on the angle specified. When the angle of 900 was used, the mesh still remained as it was before. Therefore, after experimenting with various angles, an angle of 250 was found to be most suitable as it effectively split the mesh into its various walls, raised sections and the ground.

4.4. Texture Development

The development of textures commenced with the downloading of site images from which sample textures were collected and later prepared in the Adobe Photoshop environment. The rational was the creation of seamless textures to be applied without any noticeable breaks in the rendered model.

Texturing started with the main wall and subsequently the other parts of the wall. Below is the wall texture used for all the walls.



Figure 22: Texture for the Great Enclosure walls

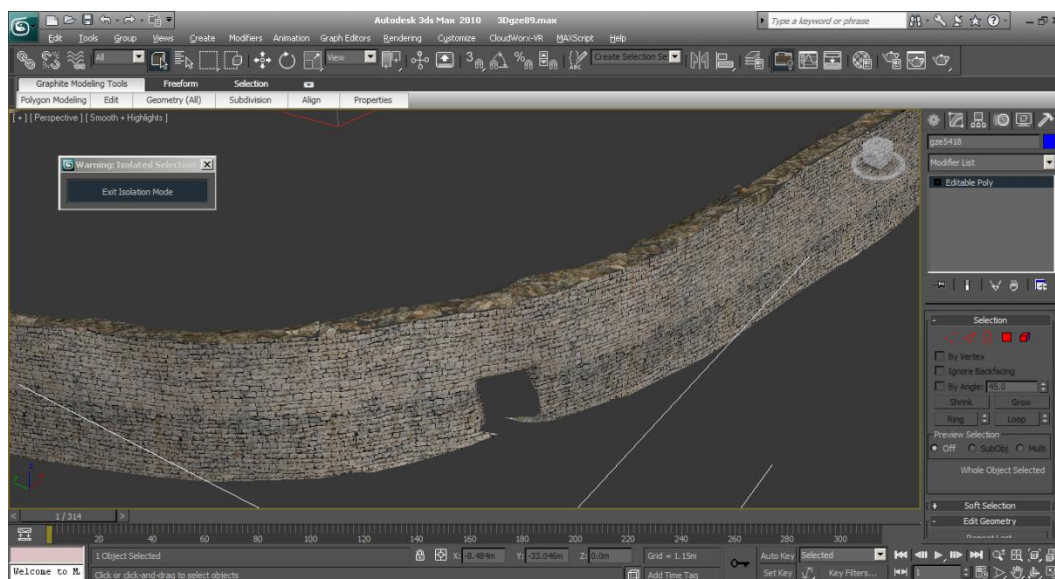


Figure 23: Main wall of the great enclosure with the texture applied.

The top part of the wall used a different texture to simulate a rubble-like feel of the that part of the wall.



Figure 24: Texture developed for rubble and other rough, stony surfaces.

In Figure 29 below, the close-up shows how the texture was used on the main wall, with the intention of giving a realistic look of the wall

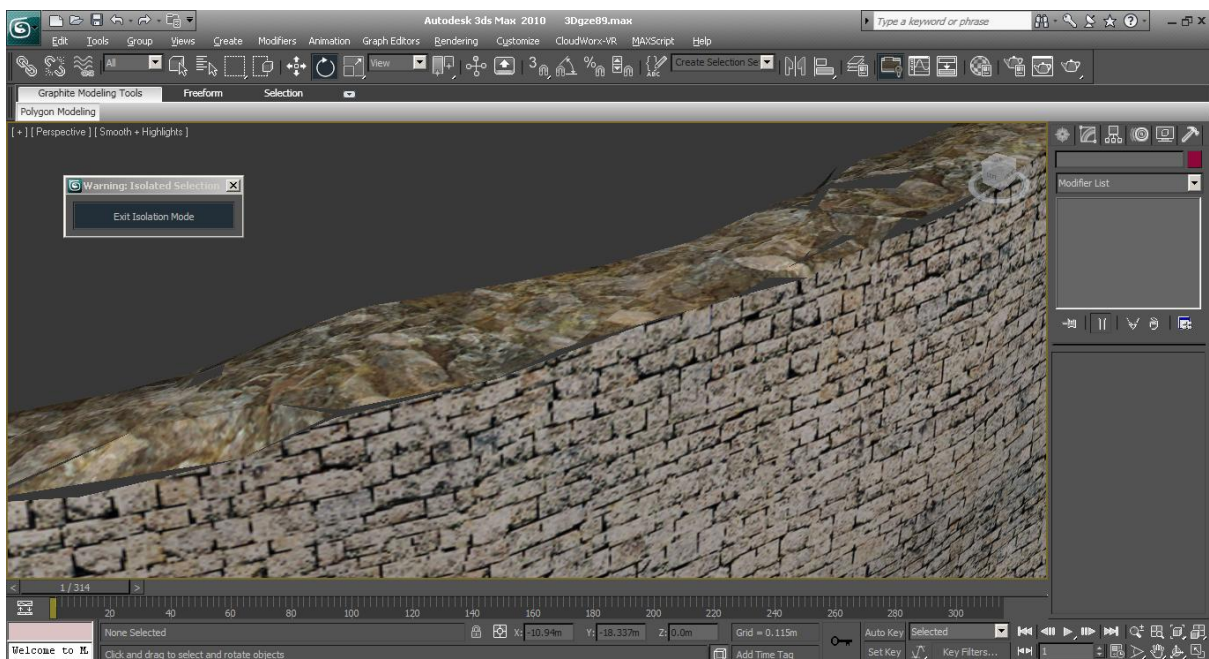


Figure 25: A close-up of the main wall showing the rubble texture applied

Additional textures were developed applied to various parts of the model which include the ground that had green grass, sandy and rocky sections applied to it. A collection of textures developed for use in the model is indicated in the figures below.



Figure 26:Original grass texture (Adnin & Smith, Mayang's Free Textures 2003)



Figure 27: Modified texture approximating a sandy-grassy texture.



Figure 28: Tree bark texture developed from a texture by Adnin Smith (2003).



Figure 29: Sandy Texture (Adnin & Smith, Mayang's Free Textures, 2005)



Figure 30: The Conical Tower showing the various textures applied.

Related components were then grouped for ease of manipulation as a single entity. Example include

- The tress and their leaves
- Walls
- Stone rubble

4.4.1. Texturing Challenges

Photorealistic textures were developed from existing images resulting in seamless mapping on the site. However, there were some exceptions. The texture map for the walls, though seamlessly tiled in the scene gives some kind of pattern where the middle part of the wall appears to be darker than the rest of the wall.

This is a slight detail that may then need to be revisited and corrected to result in a closer approximation of the wall compared with the original.

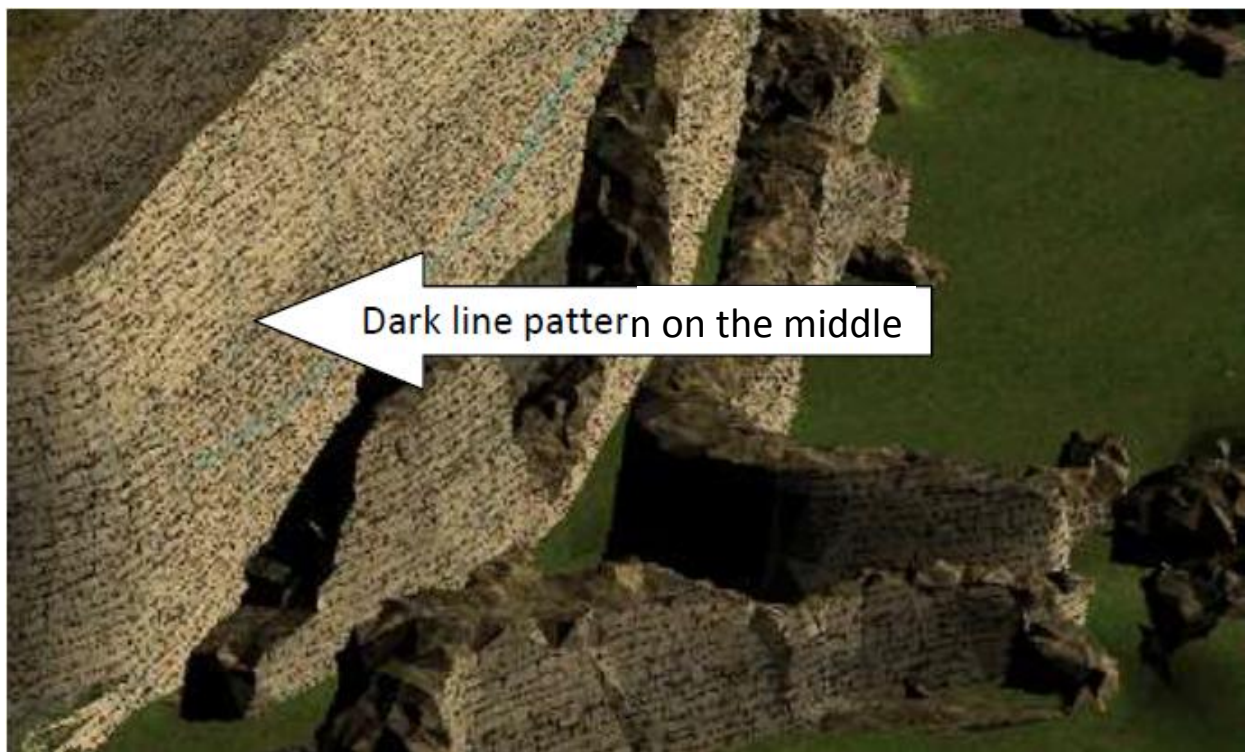


Figure 31: Section of wall showing the unwanted pattern appearing on the walls.

Moreover, in some cases where sandy patches meet up with grassy patches, there is a distinct separation between the two. Naturally, these would be seamlessly integrated. Therefore, there is need to work in transitional texture maps where two very different texture maps meet.



Figure 32: Different textures applied to a surface with a diagonal seam where they meet.

4.5. View Points and Navigation

On completion of the textured model, viewpoints were set up together with navigation for a virtual tour. 16 free cameras were set up in the scene signifying the various viewpoints for selection by the visitor of the virtual site. Figure 35 illustrates the positioning of 10 cameras together with the path constraint for each camera. The paths through the Great Enclosure from each of the viewpoints were assigned a walking pace of 0.7m/s therefore demonstrating a casual walk through.



Figure 33: Aerial snapshot showing 10 of the 16 viewpoints loaded into the Great Enclosure

Finally, to allow for better lighting in the tour, a daylight object was added to simulate late afternoon time of 16:00. The final achieved setting was for summer period with all vegetation green and lively.



Figure 34: Daylight object in scene highlighted by the red circle

4.6. Storyboarding virtual paths through the Great Enclosure

16 viewpoints were initially placed in the 3D scene of the Great Enclosure, each with its own animation towards another viewpoint. However, as the number of elements in the scene increased, it was noted that the scene became more and more unstable resulting in frequent

crashes of the development environment, 3D Studio Max 2010. The scene grew beyond the processing power of the hardware. Figure 39 below gives an indication of the resources that were now being consumed by the development environment.

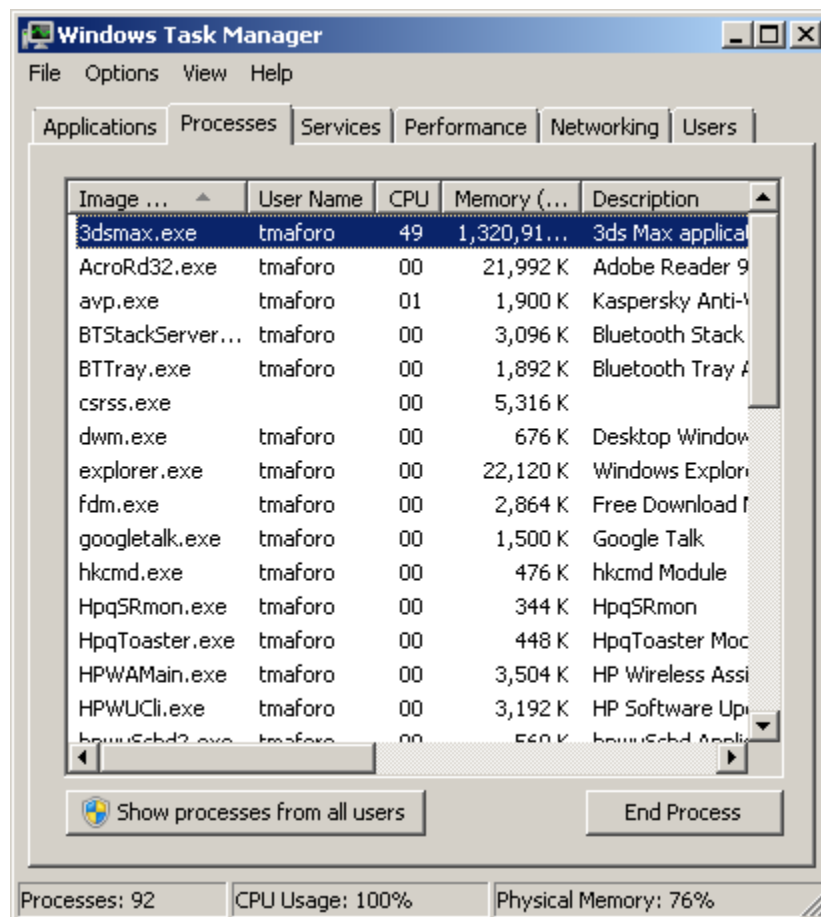


Figure 35: Task Manager showing the general CPU an memory usage of the development environment as the size of the scene increased.

Even though the available memory was upgraded to 3 Gigabytes, 3D Max continually experienced problems of sudden closure when an error occurred. The graphics card, Graphics Media Accelerator (GMA) X3100, with a maximum memory of 384Megabytes could not substantively cope with the size and requirements of the site. As a workaround for the stated challenges, the number of viewpoints was reduced to only two. Even then, performance still continued to be a challenge. It was however noted that sudden closures of 3D Max were therefore resolved as a temporary measure. There is therefore need for a computer with higher specifications to carry out additional work on the site.

4.7. Embedding audio and visual cues for highlights in the scene

Initially, audio and visual cues were expected to be included in the tour. However, with constant crashes experienced with 3D Max as the size of the site grew, it was practically impossible to include these components. Initially, the scene was had nearly 56, 000 polygons. This number increased to a value of 417, 168 polygons. Overall, the work related with this specific objective was not achieved. Nonetheless, there are continued efforts to optimize the scene of the Great Enclosure with the hope of extending the available components in the scene.

4.8. Publishing the completed work to the web using VRML

The virtual world of the Great Enclosure was exported to VRML97 for navigation with two viewpoints when the model was completed.



Figure 36: Top view with one of the paths highlighted.

On the basis of the walkthrough created, two short videos were developed and uploaded onto YouTube for access from the following links:

<http://www.youtube.com/watch?v=S7939PDMIKI>

<http://www.youtube.com/watch?v=w3E0yGKDWBo>

4.6. Summary

The study was based on existing initiatives to develop a library of cultural heritage sites in 3D. A model developed from range scan data of the Great Enclosure was obtained with permission of the owner, Heinz Ruther of the Zamani project. Preliminary work on the model involved cleaning and repairing resulting in better approximation of the Great Enclosure. The activities undertaken to develop an interactive 3D environment included:

- Cleaning and repairing of the initial 3D model to remove
 - unreferenced vertices
 - non manifold vertices and faces
 - duplicated vertices and faces
- Mesh reconstruction to fill in the various holes that were a predominant feature of the original 3D model.
- Development and application of textures to the mesh components then followed, approximating an actual look and feel of the Great Enclosure.
- Camera view-points assisted in the development of navigable paths through the 3D model. However, the number of viewpoints was limited due to the increased demand on processing power and memory that the hardware failed to provide.
- Exporting the finished model to VRML.

Embedding of audio-visual cues proved to be a challenge as the instability of the 3D model continued to increase. Despite these challenges, a working model was created illustrating a casual walk through the Great Enclosure.

CHAPTER 5. CONCLUSIONS

5.1. Introduction

The study focused on how the use of virtual environments can be applied to cultural heritage sites in the country as a way of increasing awareness and portraying the cultural diversity and significance of these sites. The overall aim was therefore to develop a tool that would allow an interactive virtual tour through the Great Zimbabwe National Monument, more specifically the Great Enclosure. The following objectives were thus met:

1. To translate of 3D spatial data into a working 3D environment.
2. To develop and apply photorealistic textures to the 3D environment
3. Storyboarding virtual paths through the Great Enclosure
4. Publishing the completed work to the web using VRML

However, not all objectives were met. Some of them still remained outstanding at the time of completion of the study, these are:

1. Embedding audio and visual cues for highlights in the scene
2. Publishing of a research paper on the work done

This chapter reviews the research objectives that were outlined above, additionally summarizing the notable aspects discovered during the development of the interactive virtual tour of the Great Enclosure. Moreover, other findings encountered during the course of the study are discussed. Recommendations, in light of the findings of the study, will be outlined and described with a view to set out the future direction of this study. The research process adopted will also be scrutinized as part of the reflection section.

5.2. Research Objectives: Summary of Findings and Conclusions

The application of 3D to cultural heritage site is not a new phenomenon as identified in the literature review. However, in the context of Zimbabwe, interactive virtual tours of these sites still have to be introduced as an alternative approach to visualize cultural heritage sites. The study illustrated the feasibility of achieving interactive virtual environments which approximate the look and feel of local cultural heritage sites through provision of a tool that will be used as a basis for the dissemination of information pertaining to these sites.

However, to confirm the overall conclusions that can be drawn from this study, highlights for each of the stated objectives are given in the next sections.

5.2.1. To translate 3D spatial data into a working 3D environment

The 3D model was initially refined in MeshLab, and then ported to 3Ds Max where the rest of the activities continued. The result was a low resolution model of the Great Enclosure. The number of vertices and faces increased significantly through the cleaning and repair process as new vertices and faces were created to patch up holes and as some parts of the model were smoothed to have a more realistic feel.

5.2.2. To develop and apply photorealistic textures to the 3D environment

Photorealistic textures were developed and applied to the 3D model. However, in some cases the transition between different texture maps was not seamless. In the real world, there is usually always continuity on the terrain. Painting and sculpting enhancements were added to the most recent version, 3D Max 2012 which would enable improvements on the application of textures to much finer details.

5.2.3. Storyboarding virtual paths through the Great Enclosure

Two paths through the Great enclosure were set up in the Great Enclosure allowing navigation at a walking pace. Initially a total of 16 viewpoints had been created, but resulted in the model being unstable. Hardware support for the model became limited as it grew in complexity. Therefore, only two effective walkthroughs were finally made part of the 3D scene.

5.2.4. Embedding audio and visual cues for highlights in the scene

As the size and complexity of the 3D model had already resulted in reduced performance of the computer, additional increases in the size of the site only made it unstable. Thus, attempts were made to develop the interactive model without the cues as a demonstration of the feasibility of such an approach to visualizing cultural heritage sites in the country as a way to disseminate cultural information in an interactive way.

5.2.5. Publishing completed work to the web using VRML

A VRML model of the site was created with access into the Great Enclosure via the two viewpoints created. In addition, videos were created from the web tour and made available through YouTube.

5.2.6. Publishing of a research paper on the work done

Publication of the work done, being one of the post-study objectives is still to be carried out. Challenges within the scene of the Great Enclosure highlighted in earlier sections related to the specific objectives, need to be addressed whilst the preparation for publication is being made.

5.3. Recommendations

Given the challenges highlighted in the research findings, the generally direction for the study lies in continuous improvement of the 3D scene with main reference to user-centric navigation and a heightened level of interactivity facilitated by audio and visual cues. The key points to be addressed include hardware challenges, optimization, and porting to a flash game environment. These points are detailed out in the following sections.

5.3.1. Address Hardware Challenges

A major constraint identified towards the end of the study was hardware limitations. A 32-bit environment, coupled by the insufficiency of the memory on the graphics card for the computer created a bottleneck in the development of the interactive environment when the site grew to an excess of 400, 000 polygons. For additional activities on the site, the following hardware specifications would be ideal.

- 64-bit system architecture
- 64-bit application environment
- Graphics memory of 1Gigabyte
- Minimum memory of 2Gigabytes

With these specifications, the instability of the Great Enclosure scene is expected to be resolved.

5.3.2. Scene optimization

The significant increase in the number of polygons was a major cause of concern as the scene was being developed. Approaches for optimizations are still under investigation albeit with the eventual possibility that there might be reduction of the precision of the site. However, as the purpose for this study was the provision of an interactive tool for raising awareness of cultural heritage sites, the trade-off for performance over precision is acceptable for as long as the resulting interactive environment is a good approximation of the cultural heritage site from the perspective of a non technical tourist exploring the site.

Moreover, it is therefore expected that with optimizations applied to the scene, audio and visual cues will be generally be added easily to the scene. These serve to simplify navigation through the site, allowing the users to immerse themselves in the virtual environment with ease. As the scene will be made accessible through a browser, some work has to be carried out to make it lightweight, thereby reducing the loading time for the application, and improving its performance.

Subsequently, more viewpoints can therefore be added giving the user an opportunity to gain entry to the site from any viewpoint.

5.3.3. Port 3D world to an interactive flash environment

Having created the preliminary tool, another alternative deployment mechanism is the porting of the 3D world consisting of the Great Enclosure to a flash environment thereby facilitating a game-like environment that allows user-controlled navigation with informative points elaborated within the site.

Flash provides a lightweight medium for deployment of multimedia applications over the internet.

5.4. Self-Reflection

Originally starting the dissertation was marked with excitement as the initial ideal was rooted in e-learning which at the start appeared as a very promising topic. However, as investigation into the topic progressed, the scope continued to widen up to a level where it became unmanageable. The topic was therefore abandoned, only to start another from scratch.

To avoid unnecessary waste of time and the risk of becoming disoriented in the middle of the dissertation, due consideration was given before settling for another topic. It had to be an area where the researcher held especially strong interests. For this researcher, 3D has always been a very fascinating area, providing potentially unlimited applications in various social and economic sectors. Interest in 3D provided intense motivation to investigate more, thereby facilitating the implementation of the work related to the study. In some cases, entire nights were spent building up the interactive 3D environment for cultural heritage site.

One of the sticking points was the chapter on research methods in which it was initially difficult to ascertain the nature of the study. However, after detailed analysis and some strong comments from the supervisor, the study could really be considered as a form of action research. Continued exploration of the area, guided by regular comments from the supervisor assisted a great deal up to the end of the study.

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APPENDIX A: GLOSSARY

Manifold: in geometry and topology, a manifold is defined as a topological space that on a small enough scale resembles the Euclidean space of a specific dimension, called the dimension of the manifold. (Wikipedia 2011)

Virtual Environment: Related to Virtual Reality, this term applies to computer-simulated environments in which places in the real world, or imaginary are simulated giving a feeling of physical presence in these places. Usually the visualizations are displayed either on a computer screen or through special stereoscopic displays.

Web Application: This is a software application that is accessed over a network such as the internet or an intranet. It may refer to an application in which access is achieved via a web browser.

APPENDIX B: CRITERIA FOR SELECTION OF WORLD HERITAGE SITES (UNESCO, 2010)

To be included on the World Heritage List, sites must be of outstanding universal value and meet at least one out of ten selection criteria. These criteria are explained in the Operational Guidelines for the Implementation of the World Heritage Convention which, besides the text of the Convention, is the main working tool on World Heritage. The criteria are regularly revised by the Committee to reflect the evolution of the World Heritage concept itself.

Until the end of 2004, World Heritage sites were selected on the basis of six cultural and four natural criteria. With the adoption of the revised Operational Guidelines for the Implementation of the World Heritage Convention, only one set of ten criteria exists.

	Cultural criteria	Natural criteria
Operational Guidelines 2002	(i) (ii) (iii) (iv) (v) (vi)	(i) (ii) (iii) (iv)
Operational Guidelines 2005	(i) (ii) (iii) (iv) (v) (vi)	(viii) (ix) (vii) (x)

Selection criteria:

- i. to represent a masterpiece of human creative genius;
- ii. to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;
- iii. to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;
- iv. to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;
- v. to be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;
- vi. to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal

significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria);

- vii. to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
- viii. to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;
- ix. to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;
- x. to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

The protection, management, authenticity and integrity of properties are also important considerations.

Since 1992 significant interactions between people and the natural environment have been recognized as cultural landscapes.