# Three-dimensional scanning as a means of archiving sculptures.

Dissertation submitted in fulfilment of the requirements for the awarding of the degree

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# DECLARATION

I, the undersigned, hereby declare that this dissertation is my own independent work and that the dissertation, or parts thereof, has not previously been submitted by myself to any other institution in order to obtain a qualification.

30/09/2011

Date

Signature

# SUMMARY

This dissertation outlines a procedural scanning process using the portable ZCorporation ZScanner® 700 and provides an overview of the developments surrounding 3D scanning technologies; specifically their application for archiving Cultural Heritage sites and projects. The procedural scanning process is structured around the identification of 3D data recording variables applicable to the digital archiving of an art museum's collection of sculptures. The outlining of a procedural 3D scanning environment supports the developing technology of 3D digital archiving in view of artefact preservation and interactive digital accessibility. Presented in this paper are several case studies that record 3D scanning variables such as texture, scale, surface detail, light and data conversion applicable to varied sculptural surfaces and form. Emphasis is placed on the procedural documentation and the anomalies associated with the physical object, equipment used, and the scanning environment.

In support of the above, the Cultural Heritage projects that are analyzed prove that 3D portable scanning could provide digital longevity and access to previously inaccessible arenas for a diverse range of digital data archiving infrastructures. The development of 3D data acquisition via scanning, CAD modelling and 2D to 3D data file conversion technologies as well as the aesthetic effect and standards of digital archiving in terms of the artwork – viewer relationship and international practices or criterions of 3D digitizing are analysed. These projects indicate the significant use of optical 3D scanning techniques and their employ on renowned historical artefacts thus emphasizing their importance, safety and effectiveness. The aim with this research is to establish that the innovation and future implications of 3D scanning could be instrumental to future technological advancement in an interdisciplinary capacity to further data capture and processing in various Cultural Heritage diagnostic applications.

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# DEFINITION OF TERMS

*Definitions not referenced have been formulated by the author in order to clarify concepts.*

Data Processing

The production of a polygonal model from unstructured data acquired via a point cloud data in 3D file format in order to represent the best digital construction of the surveyed object or site which is applicable to data fusion, multispectral analysis and other diagnostic applications.

Digitizing reality

A commercial term used for 3D scanning emphasizing the current advances in 3D scanning technology (Grinstead et al. 2006: 284).

External Scanning Environment

The external scanning environment consists of the following levels;

i. Macroscopic level - the socio-technical environment, which refers to the object's social context and the technical culture it encompasses.
ii. Mezzo level - the external environment integrated with the objects purpose.
iii. Microscopic level - refers to the internal characteristics of the object interacting with the external environment (Bernard et al. 2007: 146).

Image-Based

When a technique is defined as 'image-based' it is seen as photo-realistic and having no difference between a view rendered from the model and a photograph taken from the same viewpoint (Rizzi et al. 2010: 94).

3D Information Visualization

The use of computer supported, interactive, visual representations of abstract data to amplify cognition by analyzing and transforming non-spatial data into an effective visual form. The mind directly perceives data in a highly efficient way and discovers knowledge and insight from it (Eden, 2007: 247).

Laser Triangulation – 3D Scanning

3D Laser equipment uses laser triangulation which is a stereoscopic method where the distance of an object is calculated by a directional light source and a video camera. As the object's surface scatters the light, the device uses certain algorithms to establish the target object's 3D coordinates (X, Y, and Z). This data is stored as a group of references points known as a 'point cloud'. The point cloud mapping of an object's surface is the laser's production of several thousand reference points which are then converted to form a surface through a complex digitization process of 'connecting the dots' (Gagne, 2006: 66).

Metadata

"Metadata refers to information about the data. Metadata is valuable, since they can be used for tracing down original sources, acquisition times, qualities, metrics, and even ownership" (Patias, 2007: 2).

3D Modelling

The complete process of object reconstruction by converting a measured point cloud into a triangulated network (''mesh'') or textured surface (Remondino and S. El-Hakim, 2006: 269).

Reality-Based

Reality-based refers to the use of hardware and software to survey reality or the physical world as it really is. The as-built site or actual artefact is documented and reconstructed from real physical data and dimensions (Rizzi et al. 2010: 87).

Photogrammetry

Digital photogrammetry determines the intersected lines of sight generated from the points on the object to produce three-dimensional coordinates. With two photographs, one from the facade of the object and one from an angle, researchers are able to determine the similar points of the object in both photographs by using an automatic algorithm. These images are orientated and a 3D result emerges (N. Paparoditis and O. Dissard, 2002: 170).

# ACRONYMS

| | |
|---|---|
| **AIM** | Advanced and Innovative Models and Tools |
| **ARCO** | Augmented Representation of Cultural Objects |
| **CA** | Coordination Action |
| **CAR** | Computer-Aided Restoration |
| **CH** | Cultural Heritage |
| **CMM** | Coordinate Measuring Machines |
| **CMOS** | Complementary Metal Oxide Semiconductor |
| **CRPM** | Centre for Rapid Prototyping and Manufacturing |
| **CUT** | Central University of Technology, Free State |
| **dpi** | dots per square inch |
| **EDL** | European Digital Library |
| **EPOCH** | Excellence in Processing Open Heritage |
| **ERATO** | Evaluation and Revival of the Acoustical heritage of Theatres and Odes |
| **FBK** | Bruno Kessler Foundation |
| **FIBR** | Funds for the Investment of Basic Research |
| **FLAAR** | Foundation for Latin American Anthropological Research |
| **HCI** | Human Computer Interaction |
| **INOA** | Italian National Institute of Optical Applications |
| **KFF** | Kacyra Family Foundation |
| **LOD** | Levels of Detail |
| **MUD** | Multiuser Domain |
| **NRC** | National Research Council of Canada |
| **NURBS** | Non-Uniform Rational B-Splines |
| **PTM** | Polynomial Texture Mapping |
| **RP** | Rapid Prototyping |
| **RPM** | Rapid Prototyping and Manufacturing |
| **SFIT** | Swiss Federal Institute of Technology |
| **STL** | Stereolithography |
| **STAR** | Semantic Technologies for Archaeological Resources |
| **TLS** | Terrestrial Laser Scanning |
| **VAST** | Virtual Reality, Archaeology and Cultural Heritage Technology |
| **VLE** | Virtual Learning Environment |
| **VR** | Virtual Reality |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organization |

# LIST OF FIGURES

**CHAPTER 4**

# STRUCTURE OF THE DISSERTATION

This dissertation is submitted via publication output route in the form of two journal articles and ten case studies (chapter 4). The results from the ten case studies were also presented at the 2009 Rapid Product Development Association of South Africa's (RAPDASA) annual international conference.

The first article (chapter 2) provides a general overview of the developments surrounding 3D scanning technologies; specifically their application to the digital archiving of Cultural Heritage (CH) sites and projects. In the second (chapter 3) the diagnostics of 3D scanning projects, particularly sculptural projects are discussed. Three international Cultural Heritage projects are discussed with emphasis on the procedural documentation and the anomalies associated with the physical object, equipment used, and the scanning environment. Chapter 4 outlines a procedural scanning process using the portable ZCorporation Z Scanner® 700. The procedural scanning process is structured around the identification of 3D data recording variables applicable to the digital archiving of 10 sculptures in The Oliewenhuis Art Museum's permanent collection. In conclusion, the overall components are discussed focussing on the potentialities of 3D scanning technologies for documentation, preservation, and virtualization.

# CHAPTER 1

## Introduction and background to the study

### 1.1 Introduction

In the last 20 years the industrial and commercial market has seen the introduction of non-contact three-dimensional (3D) scanners. David Gagne (2006: 66) a program manager for Creaform © describes this evolution of technology as allowing 3D data acquisition of parts for reverse engineering where accurate surfaces are reproduced through the generation of point cloud data files. Initially 3D scanners were only available to large industrial companies who could afford the technically advanced coordinate measuring machines (CMM). In addition to the high cost of these machines, companies were obliged to employ experienced meteorologists to operate these devices. CMMs are known for their complex setup procedures and calibrating processes.

Gagne (2006: 66) refers to the advancement of CMMs as the second generation 3D scanners. The advancement of technology in the CMM includes the introduction of smaller equipment and laser scanners adapted to portable CMM arms. Although the increase in 3D scanning mobility made the technology more popular with industry, the equipment still required specialists for its operation. According to Gagne (2006: 66) the advancement of scanning technology over the years has led us to the development of third generation 3D scanners. Gagne lists the latest features as including;

- Self positioning (eliminating the need for external positioning devices such as an arm, CMM, or tracker)
- Part scanning of any size without limitation
- The target object or part can be moved while being scanned
- Plug-and-play capabilities
- User flexibility - it can be used by anyone (eliminating the need for highly trained staff)
- Fully portable – equipment is easily set up or moved from location to location
- Superior data acquisition speed – faster scanning sessions
- It creates STL instead of point clouds
- Real-time rendering – scanned data is featured as the scan commences

The equipment used in the Oliewenhuis Art Museum project affiliated with this research is fully portable, has plug-and-play capabilities, creates STL files from the point cloud data, and allows for real-time rendering.

At the onset of 3D scanning approximately 20 years ago, the technology held very little significance for industries dealing with Cultural Heritage and its preservation. The implementation of the third generation of Laser Imaging-Based scanners presented a new era for many industries using data and image surveying technologies. Gagne's (2006: 66) research also gives an indication of this third generation of 3D scanning technology as optimal for recording 3D data for documentation and study. One of the earliest manifestations of the use of 3D scanning technology in the Cultural Heritage (CH) field can be attributed to well known archaeologist, civil engineer and CEO of Cygna Corporation, Ben Kacyra. His creation of a system laser mapping tool was originally intended for civil engineering and construction, but his interest in ancient architecture and civilizations sparked a technological collaboration which peaked the interest of many other researchers and their associated institutions. A number of Cultural Heritage 3D data acquisition projects followed, for example, the 3D scanning of a collection of Renaissance artist Michelangelo's statuary by Stanford University in 1999, the 3D data acquisition of Leonardo da Vinci's Mona Lisa by the National Research Council of Canada (NRC) in 2004, the 3D reconstruction of the Great Buddha of Bamiyan by the Swiss Federal Institute of Technology in 2004, and a 3D recording and study of Lorenzo Ghiberti's bronze reliefs by a collaborative research group from the University of Rome, Italy and University of Munchen, Germany in 2009. Additional noteworthy projects are discussed further in the forthcoming chapters.

According to Lica Pezzati and Raffealla Fontana (2009: 5) researchers from the Italian National Institute of Optical Applications (INOA) the third generation of three-dimensional scanners is constantly evolving, and the latest commercial accessibility, accuracy, precision, and reliability has made it appealing to the data collecting and archiving aspects of Cultural Heritage industries. Pezzati et al. (2009: 7) further suggests that these optical laser 3D scanners are especially vital to Cultural Heritage diagnostics because of their safety and effectiveness. These devices are seen as highly-accurate instruments that allow for dense data sampling at high acquisition rates, propelling 3D data acquisition of historical artefacts into a new era of 3D surveying. Moreover, Pezzati et al. (2009: 4) proposes that the acquired 3D data and subsequent 3D models collected can be used for a range of historical and artistic studies whilst remaining long-lasting and easily accessible. The physical counterpart of the digitized 3D model remains untouched and preserved whilst the 3D data is analyzed for the conditions of conservancy (object alterations over time), health monitoring (effects of microclimatic variations), and restoration treatments. These 3D models also form an elevated means of communication as they are used for virtual reality applications. An interactive virtual environment does not necessarily replace the physical location or experience, but enhances its physical counterpart and augments its original context. An artwork can be enjoyed outside of its habitual surroundings and be accessed by multiple viewers via interactive web exhibitions.

Despite all these applications and advantages of 3D data and its acquisition, global initiative FOCUS K3D, whose aim is “to foster the comprehension and use of knowledge intensive 3D media” (Veltkamp 2010: 1), reports that the involvement with and recognition of 3D data is still limited amongst Cultural Heritage and Research institutions. According to FOCUS K3D researchers, Marios Pitikakis, Patrick Salamin, Daniel Thalmann, Chiara Catalona (2009: 13), the use of 3D digital resources may be limited, but a larger problem occurs in the organization and management of the 3D data. In concurrence with this statement, F. Remondino and A. Rizzi (2010: 90) researchers from the Bruno Kessler Foundation’s 3D Optical Metrology Group, proposes that despite its applications, and the involvement of international organizations, 3D content in the cultural heritage field is still not a default approach for documentation and research.

Remondino et al. (2010: 91) lists the following reasons; namely, the cost, efficient 3D model production, the mindset that 2D documentation is ‘enough’, and a difficulty to integrate 3D worlds with the more standard 2D material. With continued presented research, the advantages of 3D data acquisition, processing and 3D knowledge management may be exposed. A wide spectrum of further applications including analysis, studies, interpretations, conservation policies as well as digital preservation and restoration warrants the frequent use of this technology .The current commercial availability of this technology also promotes its use and the generation of methodologies and techniques with a global 3D surveying standard.

E.Paquet, C. Lahanier, D. Pitzalis, S. Peters, G. Aitken, and H.L. Viktor (2006: 3) researchers from the National Research Council (NRC) of Canada proposed at the 7$^{th}$ International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006) that the use of 3D scanner technologies has provided the world with the critical component for amassing an unambiguous body of information characterized by the shapes of the artefacts which might be passed down to future generations. Therefore, it is our responsibility; according to Remondino et al. (2010: 100) to digitally record and model our heritages with more international collaborations in mind, in order to further global information sharing and ultimately create a culture which is accessible in all possible forms to all possible user and clients.

### 1.2 The Problem

Institutions like The Oliewenhuis Art Museum located in Bloemfontein, Free State, South Africa present a need to archive their sculptural artefacts in order to make their collection more accessible to a wider audience. This research proposes to explore the application of 3D scanning technology to the archiving and 3D data acquisition of sculptures within the Oliewenhuis Art Museum's permanent collection. By presenting a comprehensive overview of all the factors relating to 3D data acquisition, processing, and preservation, the research seeks to address Eden's (2005: 67) declaration that library users are more adept at using 3D content than librarians are. Supporting this, Pitikakis et al. (2009: 14) describes the awareness of 3D data acquisition in Cultural Heritage applications by the relevant institutions as only a vague understanding, and therefore subsequent use of this technology is minimal. According to Pitikakis et al. (2009: 14) no standard methodology or metadata exists for 3D data acquisition endeavours. With this collected data and the presented diagnostics of other international projects, this research intends to promote the use of recorded metadata in the 3D surveying of Cultural Heritage sites and artefacts.

### 1.3 Hypothesis

It is hypothesised that the 3D scanning technology of ZCorp's ZScanner® 700 can be applied to the archiving and 3D data acquisition of sculptures housed within a museum environment.

### 1.4 Aim and Objectives

To provide a basic overview of the developments and technical challenges surrounding 3D scanning. The researcher will limit the case studies to ten sculptures from the Bloemfontein Oliewenhuis Art Museum's permanent collection. The selection will represent a sample of textures, surface qualities, scale and complexity of shape. This study only proposes to focus on metadata diagnostics and 3D data acquisition, rather than the development of a 3D interactive web-page. An informative overview is essential for the exposure of various industries to the use of scanning technology and its relevancy in future trade collaborations. (i.e. concurrent engineering, design and manufacture). The innovation and future implications of 3D scanning could be instrumental to future technological advancement in a variety of disciplines and industries.

### 1.5 Methodology

As a primary approach, relevant research is presented to discuss the use and advantages of 3D scanning technology; outlining its versatility. This research will follow the two-article route. The first article (Chapter 2), a literature review, will report on the chronological development of 3D scanning, the technical challenges, and will conclude with a series of recommendations aimed at art galleries and museums regarding the development of a 3D virtual gallery space, 3D content management, and the standard international practices. The second article (Chapter 3), will report on the above mentioned case studies, namely the use of 3D scanning in the data logging of results and archiving of specific sculptures. Chapter four supports proceedings by outlining international projects and their methodologies as well as examining the presented case studies more closely in relation to said methodologies. For the case studies, the Central University of Technology's CRPM (Centre for Rapid Prototyping and Manufacturing) 3D scanning equipment was used to digitally record the sculptures from the Bloemfontein's Oliewenhuis Art Museum. The Oliewenhuis Art Museum has made sculptures suitable to the parameters of the ZScanner® 700 scanning environment available for scanning from their permanent collection.

According to A.M. Manferdini and F. Remondino (2010: 110), members of research initiatives from the University of Bologna and 3D Optical Metrology Unit, Italy, 3D models generated from these scans are being used as a highly intuitive interface between different kinds of information. These 3D models not only serve as a virtual object, but also as a diagnostic model of survey and preservation. These models and their scanning systems serve as an informative example to future projects in reference to Pitikakis et al.'s (2009: 13) suggestion that no particular method or system is reportedly being used to standardize the content management and diagnostics of 3D surveying projects. The growth of 3D data acquisition, processing and presentation therefore depends on an increased involvement from cultural institutions to match the significant technological progress. By providing this relevant research, this project aspires to contribute to the development of 3D surveying and the awareness of it uses in Cultural Heritage applications.

# CHAPTER 2

## 3D Scanning: Data acquisition, processing, and preservation of Cultural Heritage sites and projects

### 2.1 Overview

This chapter provides an overview of the developments surrounding 3D scanning technologies; specifically their application to the digital archiving of Cultural Heritage (CH) sites and projects. The research presented here establishes that the innovation and future implications of 3D scanning could be instrumental to future technological advancement in an interdisciplinary capacity to further data capture and processing in Cultural Heritage diagnostic applications. A comprehensive technological overview is presented to facilitate CH industries in understanding the relevancies of 3D scanning technologies in their future.

The first part of this chapter presents a general overview and characterisation of developments surrounding 3D scanning technologies. Part two explores the development of 3D data acquisition via scanning, modelling and 2D to 3D conversion technologies. The implications for various CH applications and the archival cultural heritage projects are discussed in section three.  Part four discusses the aesthetic effect and standards of digital archiving in terms of the artwork – viewer relationship and international practices or criterions of 3D digitizing is analysed. The chapter concludes with future developments and concluding remarks.

### 2.2 Introduction

Research into fields that are interdisciplinary such as using Computer Vision and Reality Based 3D Data Capturing for Cultural Heritage requires an outlook that can only be described as multi-perspective. The Graz University of Technology's Institute of Computer Graphics and Knowledge Visualization in Austria reports that many cultural heritage artefacts are excavated for scientific reasons, but because of the effects of erosion and poor weather conditions these artefacts are not considered reliable enough for museum exhibition. They are typically archived in the museum, never to be seen by the public and more importantly, not accessible to professional historians, archaeologists, and art historians. This leads us to assume that the artefacts that are visible to the public (i.e. museum exhibitions) constitute only a small percentage of the world's cultural heritage collective. Berndt, et al. (2010) researchers from Graz University of Technology's Institute of

Computer Graphics and Knowledge Visualization also suggest that artefacts that are not 'buried for a second time' in museum archives gain less attention than they fairly should because they are still bound to a specific physical location. Therefore many cultural heritage objects and artefacts are not being properly appreciated or researched and carve out a miserable existence. Research presented in this chapter not only shows how digital media can free these constraints, but how research can be promoted in Cultural Heritage applications, how important the 3D scanning of CH has become due to erosive and destructive elements and how the organizations heading these developments are all turning to 3D data collection methods.

Four global initiatives; namely UNESCO (United Nations Educational, Scientific and Cultural Organization), FLAAR (Foundation for Latin American Anthropological Research), CyArk (part of Ben Kacyra's Family Foundation), and Canada's NRC (National Research Council) each provide a different perspective on the 3D data capture and research of CH. A prolific organization such as UNESCO provides CH researchers and institutes with global standards, practices, and laws for the preservation of historical sites and artefacts. FLAAR for example, has a role which is more technology specific. Although they have projects in place, FLAAR has made it their charge to assess and report on the technology available to the CH preservation community. Entering exclusively into the commercial market, CyArk has made it their undertaking to reach the general public and make CH available to educational and cultural tourism media. Lastly, Canada's NRC represents a governmental endeavour in the preservation of CH. All of the above organizations correspond to a specific perspective of CH data capture and its decisive purpose in our current and future civilization.

Key Humanitarian Organizations across the globe like UNESCO have maintained a steady course in discovering new methods and processes in which to support the importance of Cultural Heritage Documentation. UNESCO has long since claimed that a heritage can be seen as an arch between what we inherit and what we leave behind. The organization has instigated the launch of several projects supporting and progressively developing the importance of cultural heritage documentation. "One of UNESCO's mandates is to pay special attention to new global threats that may affect the natural and cultural heritage and ensure that the conservation of sites and monuments contributes to social cohesion," © UNESCO 1995-2007. Cultural and Historic landmarks and locations across the planet have been marked as 'world heritage sites' by UNESCO. These sites were chosen to reflect the natural and cultural wealth that belongs to all of humanity and according to UNESCO these sites are crucial to the constitution of our world. "They (the sites and monuments) symbolize the consciousness of States and peoples of the significance of these places and reflect their attachment to collective ownership and the transmission of this heritage to future generations", © UNESCO 1995-2007. Several of these sites marked by UNESCO as "World Heritage" sites have been experimental subjects of 3D scanning. F. Remondino and A. Rizzi (2010) from the 3D Optical Metrology Group with the Bruno Kessler Foundation (FBK) in Trento, Italy give examples of 3D documentation used at UNESCO world heritage sites; namely in the Etruscan necropolis of Tarquinia (Italy), and Laces's prehistorical Stela (Italy).

UNESCO may have spear-headed the movement for preservation of CH, but the importance of CH documentation is also supported by several other global initiatives. Rizzi et al. (2010: 84) suggests that there is an increasing pressure to not only document Cultural Heritage sites, but also to digitally record these artefacts and sites. Rizzi et al. (2010: 85) proposes that methodologies, new sensors, multi-resolution 3D representations and the improvement of existing ones are continuously developing and contributing to 3D documentation, conservation and the presentation of Cultural Heritage sites. This development of technology and technique has brought about a significant growth in the Cultural Heritage documentation field.

The Foundation for Latin American Anthropological Research or FLAAR was founded by the Hellmuth brothers Nicholas and Daniel roughly 30 years ago. FLAAR's mission includes research, education and outreach of how digital imaging technologies can record visual links to the past, present and future, especially related to pre-Columbian cultures of Mesoamerica. So far FLAAR is largely recognized as a beta tester for imaging technology (hardware and software). The Hellmuth family has a prolific background in architecture. George Hellmuth, the father of the FLAAR founders, started HOK Architects, the largest architectural company in the world and the firm Hellmuth & Hellmuth was founded approximately a hundred years ago by their great uncle and grandfather. At present the Hellmuth brothers are focusing most of their attention on the

**Figure 2.1)** Nicholas Hellmuth at Museo Cultura Cotzumalhuapa; 3D scanning a precolumbian head sculpture. FLAAR © 2009.

evaluation of 3D modeling for architectural history (especially pre-Columbian architecture of the Mayan civilization).

In 2009, claiming to be a leader in digital printing technologies, FLAAR added 3D imaging technologies to its FLAAR Reports. To date their FLAAR reports are read and acknowledged by over a million people each year, including 20% of all Fortune 500 companies. FLAAR is a technological consultant for all the Bureaus of the Federal US government including the US Military, Intelligence Agencies and all Federal departments. The FLAAR team exhibits and participates in the RAPID conferences every year, as well as organizing trade shows and exhibitions of their own in conjunction with major software and hardware corporations (i.e. IB-ProCADD© and ZCorp©). Their state of the art reports evaluate digital cameras, digital photography software, wide-format inkjet printers, inkjet inks, substrates and media, and the entire workflow including color management and ICC color profiles. With their added 3D division, FLAAR not only wants to add coverage of 3D imaging technology, but also intends to become a forerunner in evaluating, reviewing, publishing, and promoting 3D scanning, 3D rapid prototyping, 3D imaging software and additive manufacturing. FLAAR coordinates projects and evaluations around the world, especially in Latin America, Europe, USA, and Asia.

Another organization that is changing the face of Cultural Heritage data collection is the 501c3 non profit organization CyArk. Like other institutions and foundations, CyArk has recognized the danger faced by cultural heritage sites which are constantly at risk due to daily exposure to the effects of natural environments. Not all artefacts are housed in

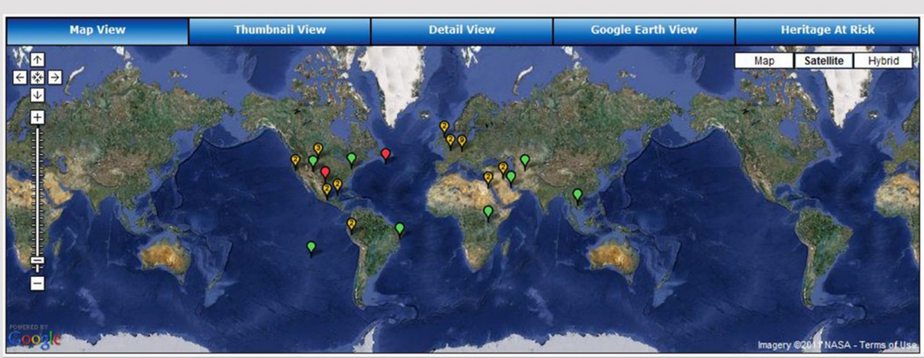



**Figure 2.2)** Active sites of CH CyArk projects. Public access to 3D models and point clouds. CyArk © 2011.

museums and they are therefore not safe from the elements, natural disasters and human aggressions. CyArk has set a goal of archiving and digitally preserving cultural heritage sites through 3D data collection and providing open access to data created by laser scanning, digital modelling, and other state-of-the-art technologies (Fig 2.2).

The CyArk website (www.cyark.org) and 501(c) 3 non-profit organizations were established officially in 2008 and was started as a branch project of the Kacyra Family Foundation (KFF) founded by Ben and Barbara Kacyra. Co founder and CEO of Cygna Corporation, civil engineer Ben Kacyra is accredited with one of the most important contributions to the field of archaeology with the creation of a system laser-mapping tool which was originally developed and used in construction to keep accurate records of the real-time physical dimensions of buildings in order to keep builders from deviating from the architect's plans. Kacyra eventually sold this technology to Leica and seeing a void in the accurate capture of archaeological data, Kacyra started the CyArk project in 2003.

CyArk as a project is unique in that it provides public access to 3D content on its website. Via the internet and their website, a member of the public is able to access the point clouds and 3D models of approximately 21 Heritage Sites (for free) with smaller cluster projects running at each geographic site.

The CyArk Foundation uses the data captured at these sites for the eventual creation of ancient virtual landscapes to promote educational and cultural tourism media. CyArk uses a unique system which they refer to as the Total Process for Digital Preservation. This process is a standard modus operandi for CyArk sites and initiatives globally. CyArk's © (2008) Total Process for Digital Preservation includes the following steps:

**1.** A site is chosen based off many factors, specifically individual site need, and its significance to human culture.

**2.** Upon arrival at a project site, the CyArk team uses a variety of methods to thoroughly collect and document the site. These include traditional survey techniques, new photographic processes, and 3D laser scanning.

**3.** Collecting data in such a manner allows CyArk to create a multitude of "deliverables" including CAD drawings, High Dynamic Range photographs, accurate 3D Point Clouds, and multimedia for educational and cultural tourism.

**4.** Once these files have been created they are securely stored in the CyArk archives and made available to site managers and the public in the Heritage Sites section of their website.

"Preserving cultural heritage sites through collecting, archiving and providing open access to data created by 3D laser scanning, digital modelling, and other state-of-the-art technologies," (CyArk © 2008).

The National Research Council (NRC) of the Canadian Government is another example of a premier organization using 3D scanning technology to record and utilize CH data. Established in 1916, the NRC is comprised of more than 20 institutes and programs across a wide variety of disciplines. One of its key research areas, Technology and Industry Support, has been creating and commercializing software and systems technology under the leadership of its Institute for Information Technology. Research programs coupled to this department include; 3D Imaging, Modelling and Visualization, Human-Computer Interaction, Intelligent Internet Applications, Knowledge Discovery, and Learning and Collaborative Technologies.

The 3D Imaging, Modelling, and Visualization research program is a long term proposal to lead new standards in traceable 3D measurements. They propose to expand the use of Digital 3D Imaging and modelling technologies and developing improved non-contact visual inspection methods. The NRC's researchers have collaborated on a number of projects to test and demonstrate the documentation and digitization of international museums and cultural agencies. Some of the more prestigious partners include; the Canadian Museum of Civilization, the National Gallery of Canada, the Canadian Museum of Nature, the British Museum and the Centre de recherché et de  restauration des musees de France.

Notable projects headed by the NRC's Institute of Information Technology include; the Erechteion: Surface reconstruction of a large and complex structure from heterogeneous 3D data in Athens, Greece (2007), the 3D examination of the Mona Lisa in Paris, France (2004), the High Resolution 3D Scanning of Paintings using a XYZ – RGB Portable Colour Scanner at the C2RMF in Paris, France (2004), participation in the Digital Michelangelo Project in Florence, Italy (1999), the Hieroglyphic Stairway at the Peabody Museum of Archaeology and Ethnology in Boston, USA (1998), and the NRC Scans of Cuneiform Tablets from Stanford University in Stanford, USA (1998).

The key to determining viability in any research endeavour is to examine the results; namely the actual CH 3D data capturing projects and their results. The above organizations have clear involvement in the 3D digitizing and recording of many important CH artefacts and sites across the world; whether it be financial, technological, or only by demonstrating the opportunities for increased productivity and quality using the latest imaging technologies and 3D scanners.

The critical component that 3D data provides to permanently record objects and create digital objects has launched the projects of several research teams. Some of the more notable CH projects in the last 15 years using recent developments in 3D scanning and related optical techniques include; the 3D mapping of Michelangelo's David with researchers M. Dellepiane, M. Callieri, F.Ponchio, and R. Scopigno (2004), Leonardo Da Vinci's Mona Lisa recorded by the National Research Council of Canada (2004), Ancient Mesopotamian cuneiform texts tablets by the Johns Hopkins University's Applied Physics Laboratory (2009), The Digital Michelangelo Project: 3D Scanning of large statues by the Computer Science Depart of Stanford University(2000), the digitizing Michelangelo's Pieta by the IBM T.J Watson Research Centre (1998), and the acquisition of a section of Rome's Coliseum (2000).

The understanding of how efficient 3D data capturing can be has led many research institutions to develop their own 3D data scanning systems that record their research specific results. These systems were often painstakingly developed due to a lack of relevant software particular to data compilation in Cultural Heritage preservation and research.

With the 3D archiving of Michelangelo's David, one of the focuses of the project was to become methodological in planning and adopting innovative ways for the documentation of the restoration processes. Thus challenging researchers to evaluate possibilities in which current approaches to 3D archiving and documentation can be improved further. Over the last decade laser-based devices have grown into a relevant tool and have become affordable to industries independent of production costs and revenues. In the case of digitizing Michelangelo's David, the research team still relied on the use of various data collecting methods, for example; 2D photometric mapping, contact measuring and 3D scanning. The 3D capture of Michelangelo's David and subsequent research is discussed further in Chapter 4.

### 2.3 3D Data Acquisition

With the development of new 3D data capture technology and the discovery that objects can be stored virtually, researchers are discovering new methods or techniques for data acquisition. Each technique selected for a project is chosen to represent the most comprehensive information about an object, site, or structure. Researchers, according to Rizzi et al (2010: 87), are recognizing the need for digital documentation of archaeological sites at different scales and resolutions. Mehrnoosh Vahdat (2010: 10), a researcher for the International Digital Library Program in association with Oslo University College, Parma University and Tallinn University, argues that there is still a large portion of information professionals in the CH field who are unaware of the significance that 3D data acquisition holds in their discipline. The idea of trading in classical surveying and tradition physical data acquisition methods for computer-based 3D acquisitions still eludes the average researcher. By listing the current techniques and their relevance, researchers may be able to adapt these techniques into viable methods. The techniques discussed in the following section include; 3D scanning and terrestrial range laser scanning (TLS), reality-based 3D modelling, and imaged-based 2D to 3D conversions.

#### 2.3.1 Techniques

Lica Pezzati and Raffaella Fontana (2009: 2) researchers at the National Institute of Optical Applications in Firenze, suggest that the most commonly used technique for 3D measuring and data acquisition is often based on different principles and each methodology captures different complementary information. Optical triangulation, time-of-flight, and other interferometric methods (such as holography) were and are used the most. Pezzati et al. (2009: 3) adopts a schematic division of these techniques into two methods; namely active and passive. In figure 3 active methods suggest that the object must be actively illuminated, whereas passive methods employ ambient light.

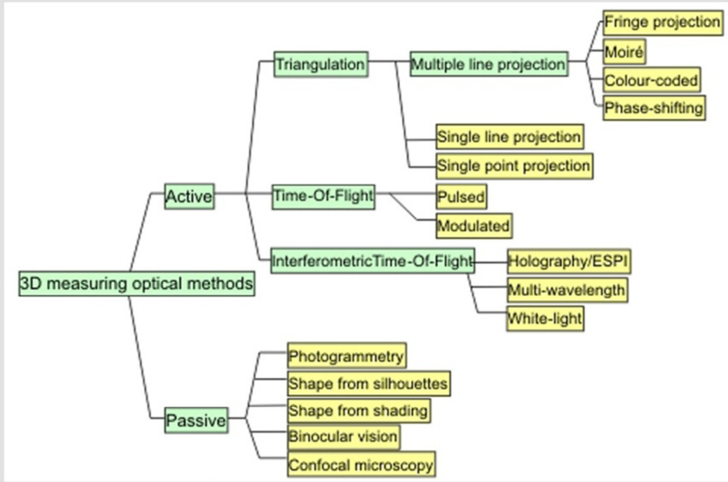



**Figure 2.3)** Classification of main optical 3D measuring techniques. Pezzati et al. (2008)

Rizzi et al. (2010: 88) suggests that a large heritage site chosen for virtual documentation often requires the 3D archivist to choose a technique which contains the following properties:

- Accuracy: Precision and reliability are two important factors of the surveying work, unless the work is done for simple and quick visualization.
- Portability: The technique for terrestrial acquisitions should be portable due to accessibility problem of many sites, absence of electricity, location constraints, etc.
- Low cost: Most archaeological and documentation missions have limited budgets, and they cannot effort expensive surveying instruments.
- Fast acquisition: Most sites or excavation areas have limited time for documentation not to disturb works or visitors.

#### 2.3.1.1 Portable 3D and Terrestrial Range Scanning

Manufacturers were perhaps the pioneer users of 3D sensor and scanning technology, but archivists are now taking advantage of its latest accessibility. The introduction of portable handheld 3D scanners accompanied by supporting user friendly software is described by Gagne (2006: 66), a program manager at Creaform Inc, as the third generation of 3D scanners.  Developments in 3D scanning technology have aided various fields of research and design with its appealing characteristics of speedily saving, coping, sharing, and manipulating complex data sets. Leading global research communities have enthusiastically applied 3D scanning for the preservation, restoration and documentation of Cultural Heritage sites and artefacts. Several projects, including the scanning of *Minerva of Arezzo* by Rocchini et al. (2001) and the University College London's Ancient Merv Project (2007) scanning the UNESCO world heritage site in Merv,Turkmenistan, have used 3D scanning to accurately digitally capture surface data for reverse engineering purposes by way of 3D data point cloud mapping technology. Gagne (2006: 66) lists the latest features as including; self positioning (eliminating the need for external positioning devices such as an arm or tracker), part scanning of any size without limitation, the object part can be moved while being scanned, plug-and-play, it can be used by anyone (eliminating the need for highly trained staff), fully portable, superior data acquisition speed, it creates STL instead of point clouds, and lastly real-time rendering.

3D Laser equipment uses laser triangulation which is a stereoscopic method where the distance of an object is calculated by a directional light source and a video camera. The recording of an object's surface data is often referred to as 'digitizing' the object. As the object's surface scatters the light, the device uses certain algorithms to establish the target object's 3D coordinates (X, Y, and Z).  This data is stored as a group of references points known as a 'point cloud'. Gagne (2006: 66) describes the point cloud mapping of an object's surface as the laser's production of several thousand reference points which are then converted to form a surface through a complex digitization process of 'connecting the dots'.

Due to its scanning range, portable 3D scanning devices are specifically used for smaller CH artefacts and larger sites and structures are often digitally recorded using laser range sensors.  Rizzi et al. (2010: 88) explains that terrestrial laser range sensors work from very short ranges (a few centimetres) up to a few kilometres and the instrument is placed in different locations so that the instrument can detect different viewpoints. Terrestrial range sensors are able to, in accordance with surface properties and environment characteristics; deliver an accuracy of approximately a few hundred microns up to a number of millimetres. In 2008, TLS or Terrestrial Laser Scanning was used by the University of Salamanca in Spain to monitor the health of a monument in the World Heritage List; a medieval wall located in Avila Spain. Diego Gonza'lez-Aguilera, Javier Go'mez-Lahoz, Angel Munoz-Nieta and Jesu's Herrero-Pascual, the project's research team proposes that TLS has become a new alternative for the health monitoring of structures as it incorporates novelty approaches and computer methods.

Jim Clark (1997: 206) an industrial applications engineer working for 3D Scanners Ltd, reported that depth ranging using optical laser triangulation could be seen as a mature and reliable non-contact scanning technique used in a variety of metrology applications such as gauging, profiling and 3D surface mapping. The progress of laser based devices provided 3D surveying with a new era for system process development. Pezzati et al. (2008: 2) suggest that this growing technological progress enables the design of highly accurate instruments for quota measurements and allows dense data sampling at high acquisition rates.

Rizzi et al. (2010: 90) states that 3D scanners are now becoming a standard source for acquiring surface data and its versatility lends itself to many applications. The growing technological progress of laser-based includes devices that are able to record high resolution colour data (i.e. Konica Minolta's© VIVID™range, Cynovad's Pro50 Scanner©, Creaform's EXAscan™ and Nikon Metrology's K-Scan MMDx™)), as well as High Definition or HD scanners (i.e. NextEngine™ Desktop 3D HD Scanner) with CMOS (Complementary Metal Oxide Semiconductor) sensors capturing more than four times the detail and synchronous colour data of previously released scanners. HD 3D scanners include twin laser arrays which make it possible to capture data from 1,600 dpi (dots per square inch); setups require no calibration, and scanning speeds lasting only seconds. The standard accompanying software packages for 3D scanners released since 2008 are also promising to be more user-friendly and may include the ability to retopologise scanned data. According to FLAAR's 2010 report from the RAPID 2010 3D Expo in Anaheim, California, there is still not one perfect product or scanner for all applications. Accordingly they have divided the following 3D scanners into levels; namely beginner, entry-level, mid-range, and high-end. Beginner level scanners presented at the RAPID 2010 Expo include; threeRivers 3D™, 3D3 Solutions™, and NextEngine™ scanners. 3D scanners included in the entry level are; ZCorp's© Zscanner® 700 (used for the case studies in Chapter 3) and the Zscanner® 800 (colour scanner), Creaform's© Handyscan 3D™ range, and Nikon ModelMaker MMDx and MMC. For the mid-range level of 3D scanners, RAPID 2010's exhibitions included; Dimensional Imaging's© DI3D™, FARO's© Photon, Konica Minolta's© Range 7 and other models, and ATOS'© Capture 3D™. Lastly, Steinbichler© Vision Systems is recognized as the high-end level of 3D scanners. FLAAR's 2010 report also recommends the use of entry-level scanners such as the Zscanner® 700 for tertiary institutions and universities as teaching equipment because of their lower cost and ease of use. A graduation to mid-range scanners after the technology is familiar is only logical.

FLAAR's RAPID 2010 report also states that the main market for 3D scanners is in industry, with the technology mainly being purposed for scanning machine parts. Larger, more advanced, non portable 3D scanners such as Metrotom™ from Zeiss© are reportedly half-million dollar machines and not intended for field use. The future of 3D scanning for Cultural Heritage applications therefore lies in the smaller portable machines found in the beginner to partial mid-range machines.

#### 2.3.1.2 Reality – based 3D Modelling

3D modelling is often seen as a last step in converting gathered 3D surface data into workable archival data and is considered a data processing technique. However, F. Remondino and S. El-Hakim (2006: 269) researchers from the Swiss Federal Institute of Technology and the National Research Council of Canada suggest that 3D modelling is often perceived as the process of converting a measured point cloud into a triangulated network (''mesh'') or textured surface, while it should describe a more complete and general process of object reconstruction. When a technique is referred to as 'reality-based', Rizzi et al. (2010: 87) refers to the use of hardware and software to survey reality or the physical world as it really is. The as-built site or actual artefact is documented and reconstructed from real physical data and dimensions.

With the use of traditional 'contact' methods of object and site measuring (namely; callipers, rulers and/or bearings), reality-based 3D modelling may be a more cost effective approach to 3D digitalization. Remondino et al. (2006: 270) refer to requirements for many applications that should be investigated when approaching a data acquisition technique; high geometric accuracy, photo-realism, modelling of complete details, the automation, its cost, portability and flexibility. 3D modelling is classified as a 'passive' data acquisition technique. Using 2D image measurements or correspondences, 3D object information is recovered through a mathematical model. Other methods within this technique include acquiring shape from shading, shape from texture, shape from specularity, shape from contour (medical applications) and shape from 2D edge measurements from multiple views according to Remondino et al. (2006: 271). Reality based 3D modelling relies on projective geometry or procedural modelling. These methods are all portable and low cost. Although reality-based modelling may be cost effective, it still requires many hours of processing which leads to a constant dependence on the software chosen according to Rizzi et al. (2010: 88). Many researchers are viewing this technique as an additive tool to creating the virtual 'props' and backdrops surrounding the 3D scanned artefacts in virtual exhibitions (discussed in section 3 of this chapter).

#### 2.3.1.3 Imaged-based 2D to 3D Conversions; Photogrammetry

When referring to a technique as ‘image-based’, Rizzi et al. (2010: 94) suggests defining this technique as photo-realistic and having no difference between a view rendered from the model and a photograph taken from the same viewpoint. Images are required and achieved using a texture mapping phase; for example projecting images or orthophotos onto 3D geometry (i.e. Photogrammetry). Photogrammetry is a non-contact information acquisition method of remote sensing which records, measures and interprets images as the fundamental medium for measurement. With image-based techniques the acquisition method is primarily photographic (image orientated), whereas reality-based techniques rely on the traditional data acquisition methods mentioned in the previous section.

According to Rizzi et al. (2010: 88) image-based 2D to 3D conversions (mainly photogrammetry and computer vision) require mathematical formulation. In most cases a minimum of 2 images is needed and a 3D data can be calculated using perspective or projective geometry. Using the principle of triangulation, a technician takes photographs from at least two different locations on the artefact to formulate an automatic individual point which is alike or homologous in the two images. Photogrammetry researchers, N. Paparoditis and O. Dissard (2002: 170) explain that digital photogrammetry determines the intersected lines of sight generated from the points on the object to produce three-dimensional coordinates. With two photographs, one from the facade of the object and one from an angle, researchers are able to determine the similar points of the object in both photographs by using an automatic algorithm. These images are orientated and a 3D result emerges.

Remondino et al. (2006: 272) suggest that these conversions of 2D images into 3D models used in photogrammetry are often preferred in cases of lost objects, monuments, or architectures with regular geometric shapes. Data handling for this technique does however require an experienced working team but does not require a high budget and is particularly used when a project has time and location constraints for data acquisition and processing.

A photogrammetric reconstruction of the Great Buddha of Bamiyan in Afghanistan was completed in 2004 by the Swiss Federal Institute of Technology (SFIT) in affiliation with UNESCO. Standing 53 meters high, the Great Buddha was demolished by the Taleban government militia in 2001 (despite international protests from UNESCO). Using images found on the internet posted by tourists, A. Grun, F. Remondino, and L. Zhang (2004: 177) were able to digitize the statues for future use (i.e. its physical reconstruction or a miniature replica; this project is still in negotiations by both the SFIT and UNESCO).

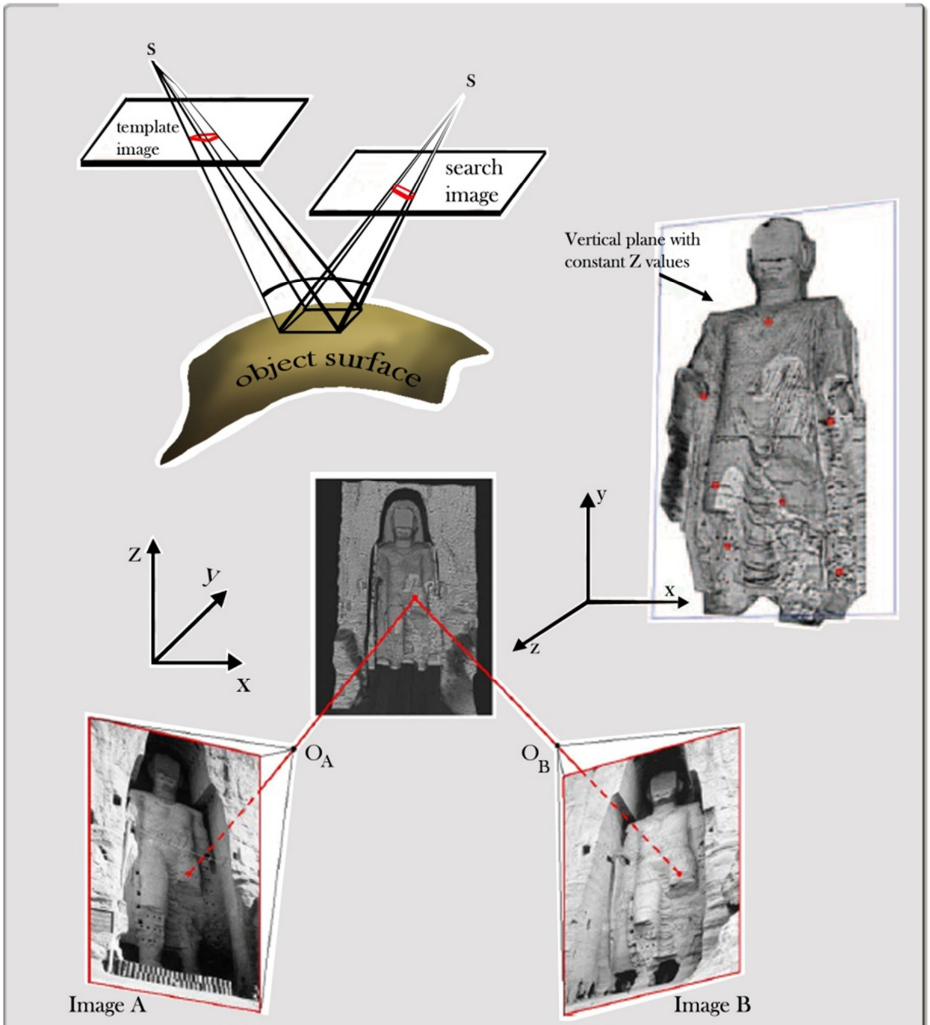



**Figure 2.4)** The image triangulation principle applied to derive 3D information from 2D image coordinates (Buddha of Bamiyan) using mathematical formulation. Rizzi et al. (2010: 89) and Grun et al. (2004: 187)

In future research projects, the photogrammetry technique can be converted into a process in which image metadata preserves the original data used in the calibration process and this process can form part of building the 3D model according to M.Vehdat (2010: 14) a researcher for the Erasmus Mundus Programme in association with Parma and Tallinn Universities. Photogrammetry and image-based techniques could lead to professionals analyzing features of their 3D models which will lead to accurate, high-quality and well-defined 3D data.

#### 2.3.1.4 Data Integration – Multi sensor and Acquisition Sources

In the past Cultural Heritage projects used singular techniques to acquire their research specific data. According to Remondino et al. (2010: 91), the state-of the-the-art approach is to use and integrate multiple sensors and technologies. One technique is not enough to quantify relevant scientific data. The 3D documentation and modelling of large complex sites needs a combination of the above mentioned techniques. Remondino et al. (2010: 91) suggest that an approach is multi-sensorial if it exploits the intrinsic potentials and advantages of each technique. Weaknesses in one technique should compensate for weaknesses in another and each technique should achieve different geometric Levels Of Detail or LOD. All the techniques chosen should combine to attain a more accurate and complete geometric survey for modelling, interpretation, representation, and digital conservation. The introduction of precision colour laser scanners, for example 4DCulture's X-Scan, which caters specifically for artists, curators, and students and promises 1 – 2 million possible colours per pixel might change the face of data acquisition techniques in the future, but 3D scanning in colour still does not address all the concerns of digital conservation and artefact processing and for institutions who have already acquired 3D scanning equipment, the advent of colour acquisition to the technology may not be enough. Remondino et al.'s (2010: 91 ) research proposes that 3D modelling based on multi-scale data and multi-sensors integration has to date yielded the best 3D results in terms of appearance and geometric detail.

Remondino (2010: 92) further emphasizes the importance of distinguishing between geometric modelling, 3D shape acquisition, registration, and processing.
A multi-sensor and resolution concept also requires a seamless integration of model features. Data sets acquired need to depict different geometric LOD of the scene or structure, taking in to account the appearance modelling namely; the texturing, blending and simplification, and rendering - if the ultimate objective is public viewing. Variations in lighting, surface specularity, seamless blending of textures, user's viewpoint, simplification and LOD are just a number of the facets outlined.

One of the case studies that illustrate a multi-sensorial approach best is the capture of high resolution 3D data sets of Sutra inscriptions in China by N.Schmidt, F. Boochs, and R. Schutze, a research team from the Institute for Spatial Information and Surveying Technology University of Applied Sciences Mainz, Germany. With the use of five techniques, namely; Polynomial Texture Mapping (PTM), Stereo Photogrammetry, Laser Scanning, Structured-Light 3D Scanning, and Panoramic Photography, Schmidt et al. (2010: 129) were able to successfully digitize and document 8th to 12th century Buddhist stone inscriptions, marked as important assets in Chinese culture.  The researchers suggest the use of multiple techniques when dealing with objects that may not be accessible with high-tech equipment. Each technique represents an alternative form of content and usage and provides a researcher with a multi-perspective view, but all the techniques should provide good informational contrast for optimal results. With the data collected from the Sutra's, Schmidt et al. (2010: pg 129) concluded the following from the two lesser known techniques:

- Stereo Photogrammetry – Provided good visual information and a precise basis for measuring, but needs good contrast for optimal results. Manual or automatic post processing needs to be applied given that spatial information is not included.
- Polynomial Texture Mapping (PTM) provided a plastic visualization used for manual interpretation. PTM is mostly used to display an object under various lighting direction (an object is photographed from various lighting directions). This technique provides a deeper look onto each character of the inscription, but the data is still only two dimensional.

R. Sitnik and M. Karaszewski(2010: 28) from the Warsaw University of Technology, Mechatronics Faculty predict data acquisition systems taking a multi-perspective approach may in the near future become completely autonomous. They argue that with the rapid development of scanning devices today, automation of measurement is fast becoming the next standardized documentation technique. By removing the human element, a recording objective can be obtained without user interaction in a shorter amount of time and the costs of digitization can be reduced. According to Sitnik et al. (2010: 29) the 3D digitalization of CH is becoming more popular and therefore gradually transferring from experimental operations to normal practice. These automated systems for data capture and processing still require the relevant software; which will validate its existence. To qualify as an automatic measurement system, these systems will need to be able to perform all calculations and measuring functions without user intervention and involve all the components of Remondino et al.'s (2010) multi-sensor and multi-resolution 3D modelling pipeline in the figure below.

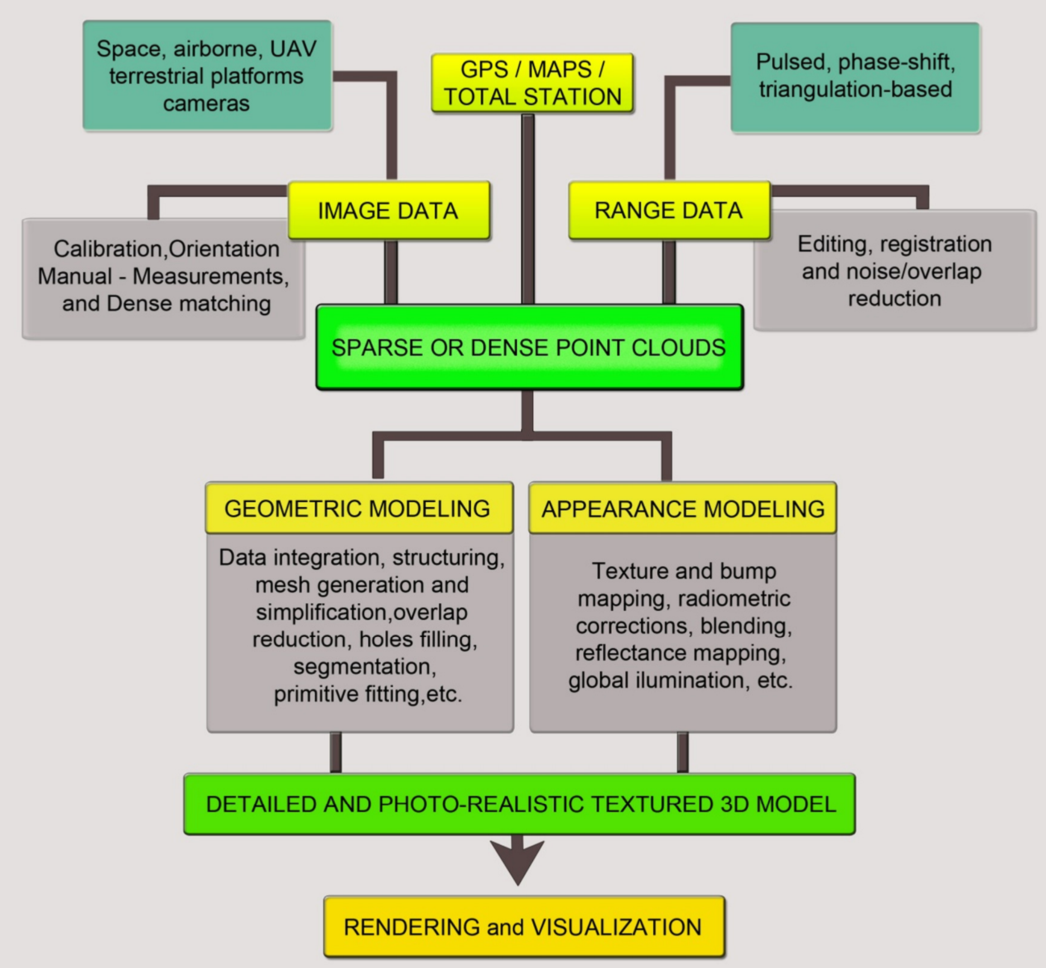



**Figure 2.5)** Remondino et al.'s (2010) multi-sensor and multi-resolution 3D modelling pipeline based on the integration of diferent techniques for the generation of point clouds and textured 3D models.

### 2.3.2 Problems and Anomalies

There are two applications within conservation and restoration of CH, according to S. Georgiou, D. Anglos, and C. Fotakis (2008: 2) members of the Institute of Electronic Structure and Laser Foundation for Research and Technology in Greece, namely; diagnostic and analytical. Before a data acquisition technique is chosen for a project, certain factors have to be identified to choose the complementary analytical or diagnostic technique. These factors are often the overall cause to problems and deficiencies within the collected data. Some of these anomalies are solved with processing, but it is critical that the initial data collecting means are chosen with insight into past projects, the technologies and techniques currently available, the variables within the physical data collection site, and the material and complexity of the target objects.

Remondino et al. (2010: 93) relays more practical examples, for instance the dependence on favourable weather conditions and possible flight restrictions when satellite and aerial images are used. Terrestrial Laser Scanning, for example, which is often used in larger sites, depends entirely on the geometry and material (i.e. size, location, surface) of the target object or site. With TLS, problems associated with the dimension, accessibility, and climate variables often arise. These irregularities cause delays, occlusions, missing data, wide-baseline images and poor geometric configurations. Remondino et al. (2010: 93) also suggests that self-occlusions or holes in coverage can be attributed to the complexity of some parts. Additionally, a scanning environment can be hindered by plants, trees, restoration scaffolds, or tourists. Researchers might not consider the inclusion of a higher viewpoint for data acquisition which could result in missing parts (e.g. rooftops, top views). Laser scanning and active sensors often have difficulty recording an object material which has a significant influence on the acquired data, causing penetrations and bad reflections. Larger scanning systems also have transportability and usability problems when campaigns are located in remote areas.

The main goal of conservation and research should be to arrest the decay of artefacts by stabilising them from further decay through digital recording and subsequent non-invasive limited sampling according to Georgiou et al. (2008: 2). Therefore the diagnostic and analytical digital acquisition technique chosen for a project needs to encompass all the requirements and pro-actively solve possible variables that may occur before processing.

**2.4 Data Processing**

Once the point cloud of a 3D data is acquired through scanning or mathematically engineered from images and photogrammetry, a polygonal model of the unstructured data needs to be produced to represent the best digital construction of the surveyed object or site. In order for geometric data to be useful in fusion, multispectral analysis and other diagnostic applications, Remondino et al. (2009: 6) stresses the importance of alignment or modelling. This next step in archiving is also known as data modelling. According to Remondino et al (2006: 272) it is still a difficult task, in particular for large and complex sites, to recover a complete, detailed, accurate, and realistic 3D model from only the data acquisition phase of a project. The data processing of an object or site consists of several well-known steps outlined by Remondino et al. (2006: 272) and include; design (sensor and network geometry); 3D measurements (point clouds, lines, etc.), structuring and modelling (segmentation, network/mesh generation, etc.), texturing and visualisation. Remondino et al. (2006: 279) suggests that the conversion of a point cloud into a polygonal surface requires the following steps:

(1) Pre-processing: In this phase erroneous data is eliminated and noise is smoothed out and points are added to fill gaps. The data may also be re-sampled to generate a model of efficient size (in case of dense depth maps from correspondence or range data).
(2) Determination of the global topology of the object's surface, deriving the neighbourhood relations between adjacent parts of the surface. The operation typically needs some global sorting step and the consideration of possible constraints (such as break lines), mainly to preserve special features such as edges.
(3) Generation of the polygonal surface: triangular (or tetrahedral) networks are created satisfying certain quality requirements, for example, a limit on the network element size or no intersection of break lines.
(4) Post-processing; after surface generation, editing operations (edge corrections, triangle insertion, polygon editing, hole filling) are commonly applied to refine and correct the generated polygonal surface.

These steps are completed on results which according to J.A. Beraldin, M. Rioux, L. Cournoyer, F. Blais, M. Picard, and J.Pekelsky (2007: 2) , researchers for the NRC's Institute of Information Technology are a function of intrinsic characteristics which include; the instrument (calibration, measurement principle, etc.), the scanned material (in terms of reflection, light diffusion, and light absorption – the amplitude response), the working environment, and coherence of the backscattered light (phase randomization). Researchers usually use their own formulated software for processing, but commercial reverse engineering software packages are available such as Cyclone™, Geomagic©, Polyworks©, and Rapidform© which perform the above steps suggested by Remondino et al. (2006: 279).

### 2.4.1 Digital Libraries and 3D Content Storage

It is the eventual goal of most CH 3D archiving initiatives that the data gathered can be used for the manipulation, storage and digital reconstruction for education and media purposes. René Berndt, Gerald Buchgraber, Sven Havemann, Volker Settgast, and Dieter W. Fellner from the Graz University of Technology's Institute of Computer Graphics and Knowledge

Visualization suggest these undeniable benefits for 3D digital artefacts over their physical counterparts or ‘real’ artefacts:

- Democratization of the past by public access to CH.
- Immediate engaging experience: interactive detailed 3D exploration, keeps the precious object “in your hands”.
- Virtual Restoration: digital artefact can be restored in different ways; physical artefacts are in only one way.
- Protection of the real: access to digital artefacts is in many cases sufficient, so less usage of the real artefact.
- Ease of manipulation: no weight, no collisions, and an easier creation of assemblies (scenes).
- Scale matters less: very large or very small digital artefacts are much easier to handle than real ones.
- Re-contextualization: a digital artefact can be shown in a scanned excavation site or in a 3D reconstruction.
- Geometric measurements: easier to perform
- Documentation: Digital conservation and damage can report links to surface areas of a digital artefact.
- Information integration: The digital 3D object could serve as a master model to which all other data sources refer (text documents, images and annotations).

The FOCUS K3D (ICT – 2007 – 214993), a Coordination Action (CA) of the European Union’s 7$^{th}$ Framework Programme has recently described in their state-of-the-art report or STAR that Archaeology and Cultural Heritage is one of the four areas of industry that has both consolidated and emerged in the use of 3D digital resources. Marios Pitikakis, Patrick Salamin, Daniel Thalmann, Chiara Catalona (2009: 4) authors of the FOCUS K3D’s STAR state that archaeology and the CH domain has recently been characterised by an increasing volume of 3D digital content and digitization efforts. A main effort according to the authors is the organization and presentation of these recorded sites and artefacts to ‘virtual visitors’ in virtual web/computer based exhibitions and also the development of education training applications for connecting these real and virtual artefacts. Pitikakis, et al. (2009: 17) list the following digital libraries and 3D content projects:

- Europeana or EDL – the European Digital Library (launched in 2008) is a museum and archive giving users direct access to over 2 million digital objects; mainly 2D resources such as books, manuscripts, and photographs covering most of Europe's textual heritage. At this point, a metadata interoperability model is being proposed to handle the critical mass 3D content will add to their current database load.

- EPOCH – Excellence in Processing Open Heritage is a network of approximately one hundred European cultural institutions joining efforts to improve the quality and effectiveness of the use of Information and Communication Technology for CH. Its aim is to provide a clear organizational and disciplinary framework for increasing the effectiveness of work at the interface between technology and the CH of human experience represented in monuments, sites and museums.
- AIM@SHAPE – Network of Excellence: Advanced and Innovative Models and Tools for the development of Semantic-based systems for Handling, Acquiring, and Processing knowledge embedded in multidimensional digital objects. This network introduced Knowledge Management techniques in Shape Modelling, with the aim of making explicit and sharable the knowledge embedded in digital shapes and building a common framework for reasoning, searching and interacting with the semantic content related to the knowledge domain. These techniques were developed into a framework called the Digital Shape Workbench (DSW) with three domain specific ontologies; the Product Design Ontology, the Virtual Human Ontology and the Shape Acquisition and Processing Ontology.
- 3D-COFORM – Tools and Expertise for 3D Collection Formation. This initiative aims to establish 3D documentation as an affordable, practical and effective mechanism for long term the long-term documentation of tangible cultural heritage.
- STAR – Semantic Technologies for Archaeological Resources. This project aims to apply semantic and knowledge-based technologies to the digital archaeology domain. It proposes the development of new methods for linking digital archive databases, vocabularies and the associated grey literature.
- ViHAP3D – Virtual Heritage: High-Quality 3D Acquisition and Presentation. It aims at preserving, presenting, accessing, and promoting cultural heritage by means of interactive, high quality 3D graphics. The project aims to develop new tools to address three problem areas: a) 3D scanning for the acquisition of accurate and visually rich 3D models, b) post-processing, data representation, and efficient rendering for the detailed interactive display and inspection of such models and c) virtual heritage tools for the presentation and navigation in high-quality digital model collections.
- ARCO – Augmented Representation of Cultural Objects. ARCO is a research project that aims to develop technology for museums to create 3D Virtual Exhibitions on the

Web. Virtual exhibitions are created by digitizing museum artefacts, which are then transformed into Virtual Representations, which can be X3D or VRML models or scenes.

- DELOS – Network of Excellence on Digital Libraries. This initiative's main objects include; research, whose results are in the public domain, and technology transfer, through cooperation agreements with interested parties. DELOS is working on the development of a Digital Library Reference Model that is designed to meet the needs of the next-generation systems, and on a globally integrated prototype implementation of a Digital Library Management System, called DelosDLMS, which will serve as a concrete partial implementation of the reference model and will encompass many software components developed by DELOS partners.
- MultimediaN N9C E-culture project. The objective of this project is the development of a set of e-culture demonstrators providing multimedia access to distributed collections of cultural heritage objects. The demonstrators are intended to show various levels of syntactic and semantic interoperability between collections and various types of personalized and context-dependent presentation generation.
- SCULPTEUR –Semantic and content-based multimedia exploitation for European benefit. The vision of SCULPTEUR was to develop both the technology and the expertise to help create, manipulate, manage and present the hundreds of European cultural archives of 3D models and associated multimedia objects, exploiting the Semantic Web technology, and make available cultural heritage to European people and the world.
- CROSSMOD – Cross Modal Perceptual Interaction and Rendering: a New Generation of Audiovisual Virtual Environments. The goal of the CROSSMOD project is to study, advance, and develop cross-modal perceptual techniques and to improve the efficiency and realism of audiovisual 3D virtual environments.
- Virtual Rome – a web-based Virtual Reality project on the archaeology landscape of Rome. It is an Open Source web VR project, based on geospecific data, 3D models and multimedia contents, with front-end (VR webGIS) and back-end (VR webLAB) on-line solutions, for the interpretation, reconstruction and 3D exploration of the archaeological and potential landscape of ancient Rome. The purpose is the creation of a three-dimensional on-line 3D environment, embedded into a web-browser.
- ERATO – Identification Evaluation and Revival of the Acoustical heritage of ancient Theatres and Odes. The main objectives of this research are identification, virtual restoration and revival of the acoustical heritage in a few, selected examples of the

theatre and the roofed odium in a 3D virtual environment. The virtual restitution will integrate the visual and acoustical simulations, and will be based on the most recent results of researching archaeology, theatre history, clothing, performance and early music.

- LIFEPLUS – Innovative Revival in Ancient Frescos. Its aim is the innovative revival of ancient frescos-paintings and creation of immersive narrative spaces, featuring real scenes with behaviour virtual fauna and flora. Presented is a case study application on virtual heritage. Ancient Pompeian fresco paintings are 'brought to life', through 3D animation of their content, superimposed on their real environment. The whole experience will be presented to the user on-site during his/her visit, by means of an immersive, mobile Augmented Reality-based Guide featuring wearable computing and multi-modal interaction. The LifePlus mobile system is required to operate in two main modes: The "sight-seeing" operational mode is designed to support the visitor with location based multimedia information facilitating sight-seeing of the area by provision of both practical and historical information in form of text, images, short movies overlaid on the head mounted display. In "AR" simulation mode, the visitor is exposed to the VR simulation scenario blended into the real imagery of the site.
- CAHRISMA – Excellence in Processing Open Cultural Heritage. The main objectives of this initiative are the identification, revival and conservation of architectural heritage in a new way. Object and subjective evaluation and audio visual reconstruction of Sinan's mosques and Byzantine churches in real-time 3D virtual environments are the basic approaches to reach the goals of the research. Virtual restoration, virtual conservation, determination of different significant acoustical effects and improvement of the acoustical criteria for architectural design will be main results. By means of this wide frame research, in the fields of acoustics, architecture and simulation technologies conceptual and practical innovation will be created.

Virtual museums or digital libraries present an opportunity for researchers to present variability in the content, structure, navigation, design, and complexity of the 3D content and digital artefacts according to P. Moscati (2007: 40) a researcher for the Italian National Research Council. Moscati et al. (2007: 40) also suggests that the pertinent trait needed for future developments of virtual exhibitions and digital libraries include a stronger dependency between context, form and content and between the whole and its parts. With this in mind 3D content displayed becomes a medium of multimodal communication which constitutes the use of multimedia 'texts'; each exhibiting content specific information, structural and rhetorical properties, arranged hyper textual traversal structures, pre-scripted narrative, immersion, and personalization; ultimately defining user experience. Prospectively, virtual exhibitions are meant to produce a 'whole constructed experience' according to Moscati et al. (2007: 41) and resemble their physical gallery counterparts by establishing a programmatic order open to collaborative emergence of meaning through visualization.

#### 2.4.2 3D Information Visualization

Bradford L. Eden (2007: 247) an associate university librarian for technical services and scholarly communication at the University of California refers to information visualization as the use of computer supported, interactive, visual representations of abstract data to amplify cognition. 3D Information Visualization can also be defined as a process of analyzing and transforming non-spatial data into an effective visual form. The mind directly perceives data in a highly efficient way and discovers knowledge and insight from it. The information is rapidly understood by the user and the visual appearance of data objects and their relationships are graphically represented. When the objects of visualization are virtual, they become graphical entities whose attributes can be manipulated by programs, algorithms and parallel processes (Eden 2007: 248). Spatial metaphors also form a fundamental part of virtual environments. A viewer or user is able to experience a fuller extent of position, size, shape and colour.

The possibility of using 3D modelling in CH has caused a consequential effective and intuitive vehicle for communication according to A.M. Manferdini and F. Remondino (2010: 110), members of research initiatives from the University of Bologna and 3D Optical Metrology Unit, Italy. Manferdini et al. (2010: 112) suggests that 3D information collected in databases becomes an interface to share and visualize CH objects. Manferdini et al. (2010: 112) refers to this availability of 3D reproductions as causing a shift in researchers' cognitive model and working approach. 3D models are being used as a highly intuitive interface between different kinds of information. Their geometric complexity and wide range data linking capabilities makes 3D data models versatile enough to be organized following semantic rules. Currently most semantic models are visualized through geo-referencing, querying and data sharing via web based open-source systems.

The FIBR project (Funds for the Investment of Basic Research) in association with the CNR – ITABC of Rome, the Department of Archaeology of the University of Pisa and the University of California have been occupied in experimental research in collaborating multidisciplinary fields such as virtual heritage, robotics, computer science and archaeology. Part of the aim of the project is to show the new possibilities in approaching 3D information visualization using innovative modalities. M. Forte and E. Pietroni (2009: 57) members of this team suggest that a multi-user domain on the web aimed at a multidisciplinary scientific community could not only create a capacity in which loading, sharing and interacting with data will be realized, but also create a spatial virtual environment which increases the level of learning and scientific communication. They designed a schematic model for the design of a web-based interactive virtual museum. With their design, they propose to redefine virtual-cyberarchaeology into a reconstructive and collaborative simulation process. Using embodied communities of user/scientists, the learning process becomes one of awareness and imitation, which is according to Pietroni, et al. (2009: 60) forms the foundation of any information unit and cultural transmission.

With the distributed mind in cyber space, Pietroni et al. (2009: 60) suggests a new frontier for our capacity of learning, understanding, communicating and transmitting culture. However, despite the speed at which technology evolves, it is not necessarily matching the pace at which the methodological processes of many disciplines evolve, especially, according to Pietroni et al. (2009: 62) the humanities and CH. The CH academic community has to date left Virtual Reality (VR) technology unacknowledged, despite its uses as a successful operative tool for simulation, research, interpretation and learning in scientific fields like medicine, industrial design and engineering. VR technology in CH for 3D e-learning and for e-communication to share interpretations, hypothesis and data in the same virtual domain are part of the proposal for the FIBR project.  Pietroni et al. (2009: 62) lists these pro-active solutions; a proposal from the University of California, Merced, to create a virtual learning environment or VLE and the use of VLE to pioneer new technology in a multiuser domain or MUD. The VLE will provide scholars with innovative means to search, mine, display, teach, and analyze humanities-related data. The MUD will be a collaborative environment employed by the VLE to allow group access to a team of researchers or a class of students and give them the opportunity to interact. This interaction and simultaneous access for the exploration of virtual worlds provide an evolved view; unlike VR systems with a limited user capability.

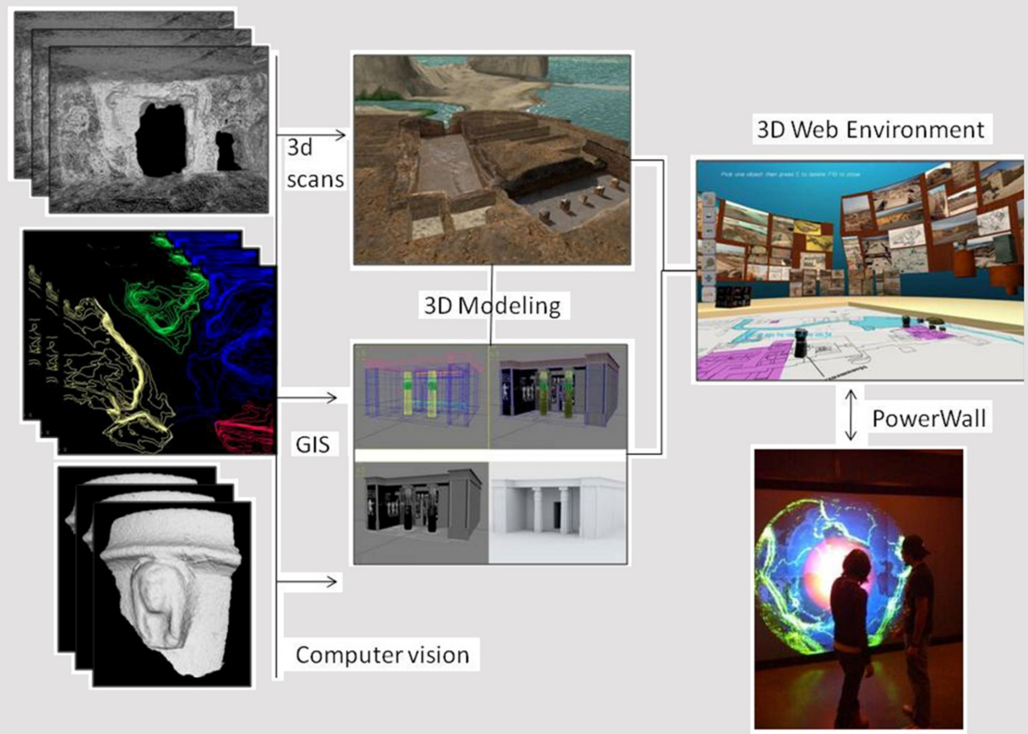



**Figure 2.6)** Pietroni et al.'s (2009) 3D digital pipeline of participatory learning and virtual collaborative environments. On the left data capturing by GIS, Computer Vision, Photogrammetry and Laser Scanning; at the center reconstruction by 3D modeling. Finally, on the right, the process of collaborative interaction on line (3D Collaborative Web) and in the PowerWall (off line).

### 2.5 Principles and Standards for Digitization

Part of the focus of the FOCUS K3D is to promote the adoption of best practices in the use of semantics in 3D content modelling and processing. In their STAR report (2009: 4) they have recognized Archaeology and Cultural Heritage as emerging in the massive use of 3D digital resources. According to their research, the main goal for the digitizing of Cultural Heritage artefacts and sites is to present this content to virtual visitors through virtual exhibitions. Although the technological process is complete, Pitikakis et al. (2009: 4) report that the involvement of cultural institutions at this time however is still limited.

STAR reporters Pitikakis et al. (2009: 4) concur with Pietroni et al. (2009: 62) in the finding that the main interest of the CH community should be to focus not only on the presentation of acquired or scanned 3D data to 'virtual visitors' through web-based exhibitions, but also the organization and management of the data. According to their research, 3D digital content, when compared to text – or image-orientated technology, still requires a standard practice for capturing, storage, and management. 3D digital representations are often neglected in efforts to create large-scale libraries and there is also a lack of effort by CH institutions to acquire and use the technology. A survey performed by Pitikakis et al. (2009: 5) revealed that the deficiencies and problems occur in the management phase of 3D collections. As this form of data becomes popular, there are numerous debates about suitable approaches which should be adopted for the management, preservation, delivery mechanisms, and copyright of this data.

Part of the problem, according to Pitikakis et al. (2009: 5) is the fairly mature nature of digitization technologies superseding the tools and software necessary for 3D knowledge management; which are not yet readily available or within easy reach for cultural institutions. A collaborative group of researchers, Vibrandt et al. (2004) from various institutions in Japan namely; the University of Aizu, the IT Institute of Kanazawa, and the Hosea University in collaboration with the University of California, USA, and The Aizu History Project based in Los Angelos, have analyzed reports from The Research Libraries Group and the National Science Foundation/Library of Congress (USA). With their research, Vibrandt et al. (2004: 29) suggest that the growth in digital technologies allows for the development of applications and processes, but not automatically the critical hardware and software needed to bridge the gap between older and newer systems. The vitality of the data is essentially lost to research libraries and institutions. Data from older systems also run the risk of becoming obsolete with the yearly advances of new software, hardware, and equipment. Vibrandt et al.(2004: 30) state that despite the awareness of digital archiving and the obsolescence problem, market forces alone have so far proven to be inadequate in providing or developing solutions. In a more current scenario, Berndt et al. (2010: 167) corroborates with Vibrandt et al's (2004: 30) findings by describing datasets as storage intensive, difficult to integrate with other media types and unable standardize with formats available to the public. Furthermore, Berndt et al. (2010: 169) report that the situation today can only be described as 'hen-and-egg'; 3D data is not widely used due to lack of tools, and tools are not being developed because of lack of interest. Berndt et al. (2010: 169) also refers to 3D technology that is specifically location-based as limited when referring to its sustainability. Sustainability, according to their research, can only be achieved using specific standards. The lack of standards in the global community utilizing 3D technology to record and communicate is possibly the biggest problem facing 3D technology today according to Berndt et al. (2010: 170).

Which format to choose, how to link the data to a web resource (and vice versa), how to create and archive the information and how to deploy it via web delivery are all questions which might solve some of the above dependency issues. Vibrandt et al. (2004: 30) suggest that a large part of the solution lies in the development of an abstracted form of proven mathematical representation which becomes an open standard and will be less likely to become obsolete. The source code should be open for public inspection and be freely modified, recompiled and tested. All procedures are then made public and consequently transparent. Vibrandt et al. (2004: 31) suggests that the public inspection will lead to accuracy in data and in acquisition procedures.

### 2.5.1 International Practice

With the cooperation of various institutions and companies from 11 countries, FOCUS K3D's Pitikakis et al. (2009: 13) performed a survey on a broad category of users; including scientists, professional developers, creators of 3D content, as well as dealers of 3D repositories and end users on their usages for 3D digital content. Most users admitted that they had just started using 3D data and are still experimenting; therefore their number of models are still limited. Most of the data storage of 3D models is saved on local disks, CD's and DVDs and they are proprietary. Models for public usage and research surveyed as being partial to limited.  Software used to manage and manipulate the data include mostly open source systems; for example Studio MAX, Maya, Blender, OpenScenegraph, Coin3D, Octave, and Meshlab.

According to Pitikakis et al. (2009: 13) the most popular 3D data acquisition techniques being used by researchers are laser based optical techniques. No particular method or system was or is reportedly used for the content management. Only two of the research-orientated institutes were developing their own system for 3D content management and only for their specific applications. Many institutes have done no actual scanning and opted for purchasing models from other institutions or acquiring them from public repositories for free. For visualization, existing software is used. Minimal effort is being made to develop research specific tools to use within existing software. Smaller institutions asserted that they are not in a position to experiment with novel ICT-based approaches. The survey performed by Pitikakis et al. (2009: 14) also exposed that most institutions are not organizing or cataloguing their 3D content according to any standard. The classification is mainly according to the nature and resolution of the 3D models, which is usually automatic.

Metadata created for 3D digital content is in general created manually according to Pitikakis et al. (2009: 14). Other creation methods include; semi-automatically, a rule-based system, OWL language, ontologies, and taxonomies for traditional collection. Survey participants also revealed that most 3D content users deem the geometric, structural, temporal, and semantic features of the data content most important; whereas only a few researchers recorded the geometrical, textural, and descriptive properties for textual documentation. Future research activities may include an X3D extension to attach semantic data, realistic shaders and many other data types to the originally recorded content.

Only 50 percent of users are satisfied with the search and retrieval methods available and users are suggesting a more specialized 3D search engines based on semantics and geometry (Pitikakis et al. 2009: 14). Pietroni et al. (2009: 62) report that this gap between data capturing and accessibility is a key problem in archaeology. This means that there is a small percentage of open communication to the public. The few researchers who have developed expertise in working with 3D content are also not satisfied with the current methods and technologies for handling the recorded 3D models and are developing their own methods. Pitikakis et al. (2009: 14) reports that in general, CH researchers agree that 3D knowledge technologies provide the following solutions:

- Documentation and identification of scanned partial and complete artefacts.
- Automatic extraction of geometric and semantic information from models.
- Better visualization
- Improved search using semantic and geometric criteria.

Many of the participants of the survey have also agreed that acquired 3D data should be open source and support open standards. As previously suggested by Pietroni et al. (2009: 62), the environment for these open source 3D content databases should be collaborative in nature with semantic integration, interoperability, scalability, and flexibility in regards to new approaches. The standards for data and resource management should however be more rule-based, and according to Pitikakis et al. (2009: 14) consist of less manual reconstruction and more automation where possible with use of metadata for easy information retrieval. General consensus proved that the current limitations in 3D data acquisition, processing, and preservation are due to methodologies instead of equipment.

### 2.5.2 Digital Surrogacy

3D scanned models are often referred to as 'digital replicas' because of their versatility according to Berndt et al. (2010: 167). Emphasis however should be made to assure CH operatives that a digital replica should in no way be seen as a replacement of the original. Pietroni et al. (2009: 63) advises that when information is separated or segmented into separate factors of description, i.e. linear texts, models, spaces, maps, taxonomies, etc., it often leads to a decrease in the level of knowledge and the interpretation process is left invalidated. Therefore, Berndt et al. (2010: 167) promotes concept of using the digital artefact as an enhancement to the original; in essence a complementary element to the object as a whole. By adhering to the one form of representation, Pietroni et al. (2009: 63) reports that 3D CH researchers run the risk of constructing a huge quantity of information free from any standards of reliability or communication processes.

Berndt et al. (2010: 168) suggests a complementary digital exhibition as a solution. In this scenario, a 3D kiosk is placed next to the precious real artefact showing the digital artefact. An example of is Callieri et al.'s (2008) Virtual Inspector which used the Arrigo showcase. Visitors of the exhibition were able to discover complex details for themselves; for instance the hollow back of the heavy stone statues which are hidden in the physical counterpart exhibited in the same room. Berndt et al. (2010: 168) also suggest the use of embedded 3D interactive media, through the use of for example iPad and eBook devices. Digital museum catalogues loaded on these devices could provide the user with; intuitive user interfaces, excellent large display, and personalized information and guided tours. Individual interests and requirements could be fine-tuned into the device or application settings.

According to Pietroni et al. (2009: 63) the identity, learning, perception, and communication of virtual communities is embodied in the principle of enaction. Enaction refers to the perception-action interaction in the environment which subsequently creates or has the capacity to create knowledge and information. With this knowledge, users are able to share new differences and feedback, use a simulation process to validate or criticize models and cybernetic territories, and create unique opportunities for analysis and discussion for advanced forms of knowledge.

#### 2.5.2.1 Authenticity and Copyright

The acquisition and use of 3D digital replicas for the sub sequential development of web-based user interface cybernetic territories may be more complex than first realized. Researchers M. Mudge, M. Ashley, and C. Schroer (2005: 2) from the University of California Berkeley propose that the widespread use of digital surrogates in CH scholarship needs to adhere to an empirical provenance, a perpetual digital conservation, and the democratization of technology. Essentially empirical provenance dictates that 3D content needs a transparent qualitative evaluation of its authenticity and reliability. Mudge et al. (2005: 2) also suggests that empirical provenance could guide decisions for the conservation of digital representations through their aesthetic quality, usefulness to convey ideas and the completeness of information. In conjunction with empirical provenance, perpetual digital conservation requires users of digital surrogates to use specified archival conservation methods to acquire empirical data. These methods will ensure availability of data for future generations. This conservation plan or method should include capacity for contribution and lead to responsible stewardship from individuals, organisations and institutions worldwide.

There are several international charters, conventions, and copyright laws which were originally established not only for the preservation of CH artefacts and artworks, but also to solidify the concepts of nature conservation and the preservation of cultural properties globally. “It is essential that the principles guiding the preservation and restoration of ancient buildings should be agreed and be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions” (The Venice Charter, i.e., The International Charter for the Conservation and Restoration of Monuments and Sites, 1964). The conventions more frequently referred to include; the Berne Convention’s Paris Act (1971), UNESCO’s World Heritage Convention (1972), the International Charter for the Conservation and Restoration of Monuments and Sites (1964) and the Universal Copyright Convention (1952). Mudge et al. (2005: 2) suggest that the more users who study and work with digital replicas increase their use and compatibility. This increase of use leads to a new generation of digital surrogates requiring adapted regulations and conventions. Conventions should also be understood to mean not only the protection of international cultural artefacts, but also the establishment of a globally recognized and standardized system for identification, recording, and conserving.

In terms of sculptural artefacts, UNESCO’s World Heritage Convention’s Paris Act (1976: 3) states that works of monumental sculpture and painting which are of outstanding universal value from the point of view of history, art or science (definition of Cultural Heritage-Article 10) warrants the (Article 5) assurance of effective and active measures for protection, conservation and preservation. Each country according to what is appropriate, should adopt a general policy which aims to give the cultural and natural heritage a function in the life of the community (Article 5a). Countries who are affiliated with this convention are also required to develop scientific and technical studies and research to work out operating methods capable of counteracting the dangers that threaten its cultural heritage (Article 5c). In terms of the copyright of these artefacts, it is important (Article 5d) that the appropriate legal measures are taken in terms of identification, protection, conservation, presentation and rehabilitation.

As many new users approach 3D data acquisition, processing and preservation, a familiarity needs to be established as to which practices and methodologies are acceptable globally according to Rizzi et al. (2010: 92). Best practices need to be established to develop authenticity in surveying, preserving and reconstructing copyrighted objects.

The Technical Committee 19 – Computer Vision for Cultural Heritage Applications was created by the International Association for Pattern Recognition or IAPR to promote Computer Applications in CH. Part of the objective of the TCH19 is the stimulation of the developments of components; i.e. the hardware or software that should be used by the researchers in Cultural Heritage to acquire and manipulate 3D data. Rizzi et al. (2010: 92) also supports the London Charter which is currently seeking to define basic objectives and principles for the use of 3D visualization methods by institutions and individual users across the world.

Collaborative researchers J.Doyle, H.Viktor, and E.Paquet (2009: 33 – 35) from the NRC and University of Ottawa's School of Information Technology and Engineering propose these requirements for the possible future end user;

1. The end user should be able to access the preserved digital document.
2. The content should be executable, i.e. the host machine should be able to render the document in its original environment.
3. The end user should be able to interpret and understand the content of the digital document.
4. All the above should be possible without the end user experiencing any errors or complexity.
5. The preserved digital object should be authentic in the sense that it is the same object that was preserved and both its content and functionality remain the same through time (i.e. the data object does not become corrupted, or lose data through a process such as migration, for example). The content of the data refers to the data it represents (e.g. a set of geometric points and topologies representing a 3-D anthropometric body scan).Preserving functionality also requires that the rendering application be preserved so that future users can interact with the preserved data object. Preserving the rendering application is necessary as many software applications do not ensure backward compatibility, and hence there is no guarantee that future, more sophisticated versions of the software will be able to render the preserved digital document.

6. Metadata should accompany the digital document instructing the future end user on how to execute the document, as well as explaining the document content, its intended behaviour and a description of the software required to run it.
7. The digital preservation framework should be durable. It should run on any computing platform any number of years in the future.

In terms of future presentation and visualization, the international Cultural Heritage community agrees that 3D models and digital replicas should be synonymous with intellectual integrity, reliability, transparency, documentation, standards, sustainability, and protected global user access.

### 2.6 Concluding remarks and future implications

A general awareness of the current 3D technologies is present in the Cultural Heritage community according to Pitikakis et al. (2009: 14), but in general the benefits of this technology is not familiar to them and subsequently the use of 3D content is still minimal. "Library users are probably more familiar and comfortable with interacting in 2D and 3D than librarians are." (Eden, 2005: 67). Although significant technological progress has been achieved, cultural institutions are keeping their involvement limited which has led to some constraints in the growth of 3D data acquisition, processing and presentation in this field.

It is important that institutions and Cultural Heritage organizations comprehend that the availability of 3D digital replicas, compared to traditional photographs, drawings or video sequences, communicate more effectively the intrinsic 3D characteristics of the physical objects or scenes they portray (Manferdini et al. 2010: 112). Added to the superior portrayal are the metric, accuracy and photo-realism of the 3D models which should also be taken into consideration according to Manferdini et al. (2010: 112). Combined with the transcendent experience of accessing and exchanging knowledge, 3D content has become a very powerful tool in forming analytical and interpretive bonds between the past and the future.

Current uses of 3D content in Cultural Heritage fields are generally motivated by documentation, virtual tourism and exhibition, education resources, and viewer interaction and according to Remondino et al. (2007: 270) warrants certain specific requirements. These requirements include; geometric accuracy, photo – realism, automation, low cost, portability, and flexibility of the modelling technique. The selection of the right acquisition technique could prove to satisfy all the above requirements. It is therefore imperative and one of the larger challenges for the future of 'virtual heritage' those possible guidelines and communications are in place to discuss and exchange methods, technologies and epistemologies (Koutsoudis et al. 2007:8).

For institutions that have recognized the significance of 3D content in Cultural Heritage, Rizzi et al. (2009: 3) suggests that the actual problem or challenge not only lies with selecting the appropriate methodology, modelling procedures, standards and production workflow, but also with ensuring the authenticity of the object or artefact whilst displaying it on a interactive platform. Pietroni et al. (2009: 63) reports that 3D CH researchers run the risk of constructing a huge quantity of information free from any standards of reliability or communication processes. According to Pitikakis et al. (2009: 4) the potential for enhancing awareness of 3D content management lies in better communication between CH research facilities and the committees and institutions that protect the physical counterparts of the digital replicas. New approaches have to be development which encompasses the unique quality of 3D data, and according to Pitikakis et al. (2009: 4) significant debate is ensuing as to whether the approaches currently adopted for digital libraries are suitable as 3D objects and collections are becoming more acknowledged.

Rizzi et al. (2010: 98) proposes that the reported examples of CH 3D projects show the potentialities of 3D surveying technologies to document, share, and manage our heritages. The dynamic growth of active optical sensors, spatial information systems, 3D modelling procedures and visualization ensures a prospective future in which researchers will be able to simulate reality in a more objective and reliable way for diverse purposes throughout time.

# CHAPTER 3

## International Benchmarking: 3D Scanning Project Review

### 3.1 Overview

In chapter 2 examples of the virtual documentation of Cultural Heritage (CH) sites was discussed in conjunction with the various scanning techniques and processing methods. In this section, however, the diagnostics of 3D scanning projects, particularly sculptural projects are discussed. The three international projects, namely; Michelangelo's "David" and "Pieta", and "The Minerva of Arezzo", represent the significant use of optical 3D scanning techniques and their employ on renowned historical artefacts thus emphasizing their importance, safety and effectiveness – i.e. curatorial safety.

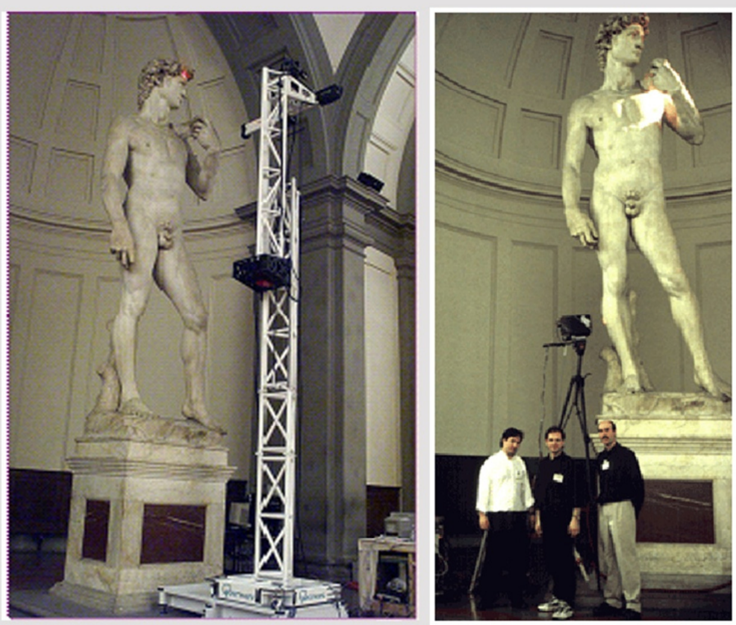


**Figure 3.1)** Scanning structure for The Digital Michelangelo Project - "David". Dellepiane et al. (2008: 2179)

### 3.2 Digital Archiving of International Cultural Heritage Sculpture Projects

#### 3.2.1 The Digital Michelangelo Project: *David*

Officially launched in January 1997 (with a planning period of 2 years), The Digital Michelangelo Project: *David* was one of the first applications using 3D scanning technology to record the structure of a Cultural Heritage artefact. The project includes 9 other statues by Renaissance artist Michelangelo with the smallest scanned object (a map fragment) being 1 inch and the largest structure the statue of *David.* The statue which measures over 5 meters tall and weighs approximately 800 kilograms was part of a one-year 3D scanning project for the capture of various digital models digitizing a large and coherent collection of statuary of Renaissance artist Michelangelo. The Digital Michelangelo Project was first initiated by Prof. Marc Levoy of Stanford University with a research team of 22 people (2 professors, 1 research associate, 1 technical staff member, 6 PhD students, and 12 undergraduates). Up until 1999, no project had attempted to digitize a large statue with enough precision to serve as a primary resource for scientific work. The Stanford University Team also invited a team of researchers from the Visual Information Technology group of the NRC (Canada's National Research Council - G. Godin, J.A. Beraldin, and L. Cournoyer). The NRC was involved to provide detailed high-resolution views of selected smaller patches on the sculpture using their own high-resolution auto-synchronized laser range scanner. Usually mounted on a three-axis translation system, the team developed a compact portable configuration which mounts the sensor head to a computer controlled turntable which in turn is mounted on a sturdy tripod.

**Figure 3.2)** The auto-synchronized Laser Scanner mounted on a tripod at the Galleria dell' Accademia, Florence,Italy. NRC© (1999).

The primary focus of the project was to document and measure the high-resolution surface shape and therefore only a single laser wavelength (red) was used instead of the polychromatic laser which is for simultaneous colour and range measurement. The surface patches were selected to represent a variety of types of tool marks, marble types and surface polishing.

Lica Pezatti and Raffaella Fontana (2008: 7), researchers from the National Institute of Optical Applications in Italy who participated in the project, report that the project totalled to 30 nights of scanning and an additional 1000+ hours of post scanning processing to assemble and align the model together after the data has been acquired. This does not include the 1,500 hours used to configure the software to handle the increasingly large datasets. The project consisted of 480 individually aimed scans and for each scan the gantry was moved to a new position (the gantry weighing 1800 pounds). Each part of the statue was covered by at least two scans, with difficult sections covered 5 or more times – these 480 scans total up to 2 billion polygons. For each position of the scanner, one image was taken with a calibrated spotlight and one without; subtracting the two eliminates ambient lighting. 7,000 colour images were taken. The data captured totalled up to 32 gigabytes, which in 1999 was a significant amount.

Part of the project was assigned to documenting the status of the *David* before and after the restoration to report on the 'health' of the sculpture, that had not been touched since 1873, when it was moved to the Accademia from Piazza della Signoria.

**Figure 3.3)** Scaffolding surrounding Michelangelo's David. Pezatti et al. (2008: 8).

According to Pezatti et al. (2008: 8) the analysis of the surface roughness allows for the understanding of previous restorations or how ageing has compromised the marble surface. A conoscopic micro-profilometer was used for the larger scanning measurements. In the two year planning period a scanning system which could reach the top of the statue and capture data from a safe distance named the Stanford Large Statue Scanner was jointly developed and fabricated by the researchers and Cyberware of Monterey, California. The instrument, which is very sensitive to vibrations, had to be mounted on the base of the statue using special felt pads. This special mounting had to be devised after it became apparent that the motion of the instrument and the physical environment disturbs the sensor's recording. Measuring was set to start after a few seconds delay allowing operators to leave the 10m high scaffolding. Other modifications for harder to reach areas required the development of a second scanner; a jointed digitizing arm and small triangulation laser rangefinder made by Faro Technologies and 3D Scanners Ltd were also realized for this purpose.

The eventual results of the project – a skeletal archive of 3D models, are made accessible to individuals via an online catalogue. These models are available for scientific purposes only and users must first obtain a license from Stanford University. For commercial use of these models, a user must apply directly to the Italian government. Levoy and his research team also offer information about the Scanalyze™ software package used to align and merge their 3D models, including binaries and source code, Volfill™ – the diffusion-based hole filler for larger polygon meshes, the OSplat™ multi – resolution viewer for large polygon models, and ScanView™ – a secure viewer that permits unlicensed users to examine the models.

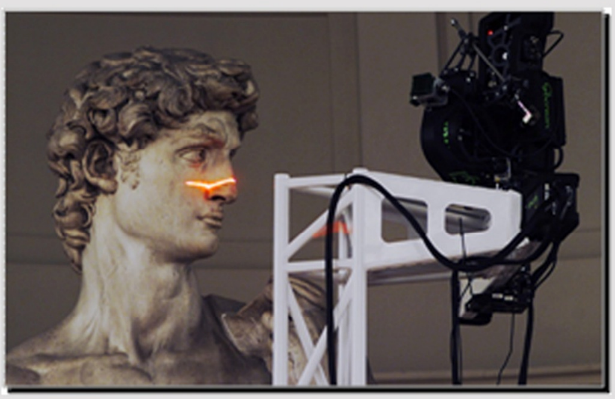


**Figure 3.4)** The scanning system at work during large surface measurements. Pezatti et al. (2008: 8).

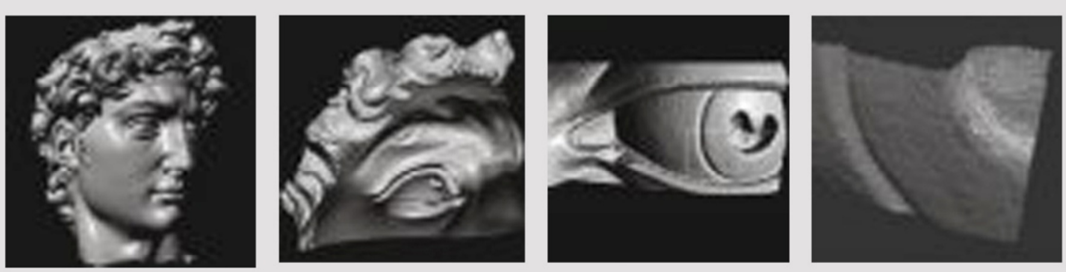


**Figure 3.5a)** 2mm resolution 3D model of David's head. **b)** 1mm 3D model of the right eye. **c)** 0.25mm 3D model of the eye. **d)** triangle mesh obtained by scanning a portion of the eye several times from different directions. Christensen (1999: 184)

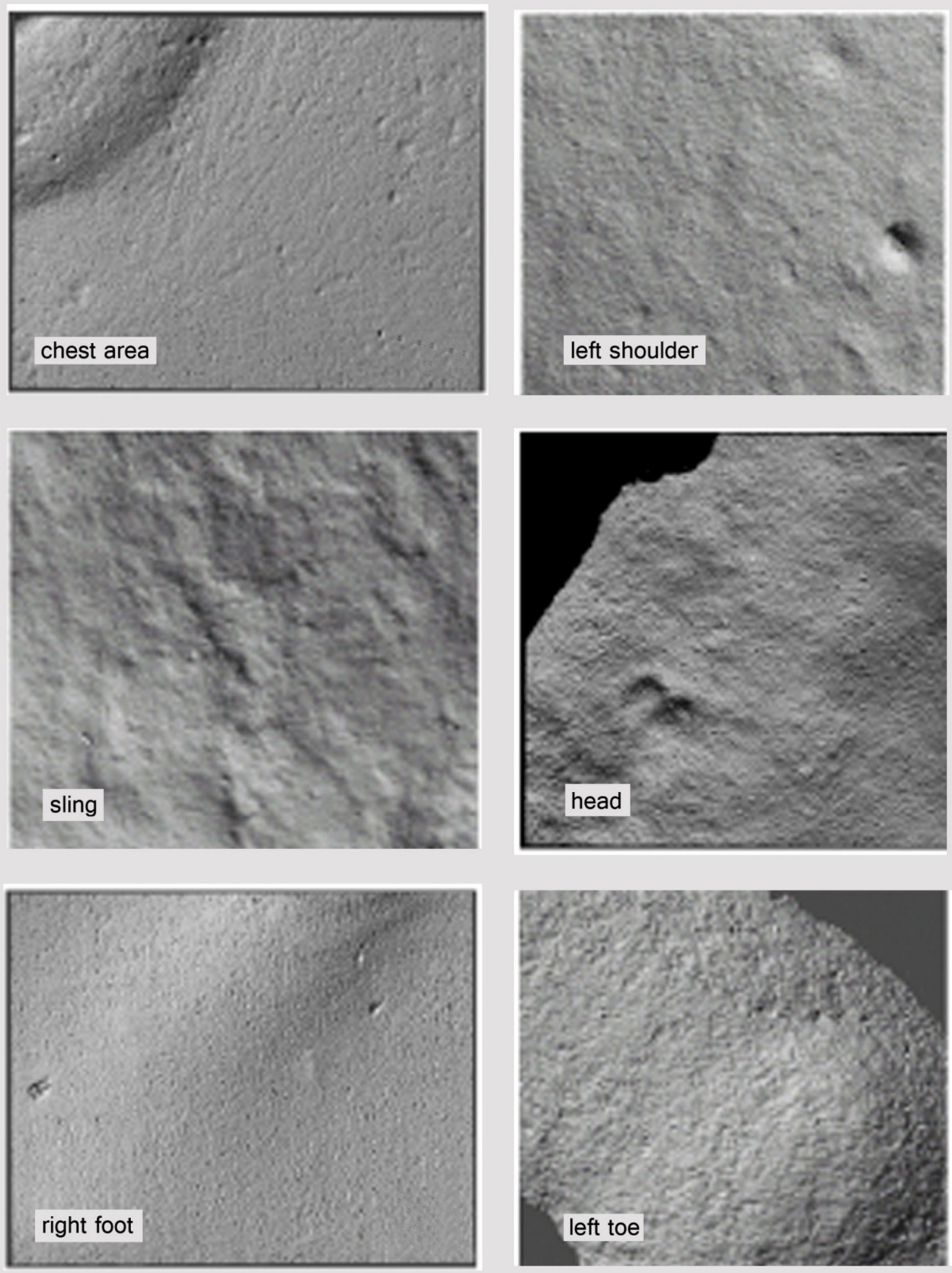



**Figure 3.6)** Surface roughness measurements patches from Michelangelo's David. Dellepiane et al. (2008: 9).

Since June, 2004, no further work had been done on the 3D models of the Michelangelo's statues mainly for the lack of funding. As a result, only Michelangelo's David has a high-quality 3D model at 1.0mm resolution (56 million triangles). Since then, Marc Levoy and his research team have welcomed any research group or institution to further the work and as a result, in 2008, researchers M. Dellepiane, M. Callieri, F. Ponchio, and R.Scopigno from the

ISTI- CNR in Italy focussed on creating definitions and solutions to qualify modern restoration by integrating different scientific approaches under the same global focus as the project in 1999. According to Dellepiane et al. (2008: 2180) this project was an opportunity to experiment with modern visual data management approaches, but after surveying the conservation status of the surface of the statue, researchers realized that a plan or visual data management scheme to integrate 2D and 3D data was needed.

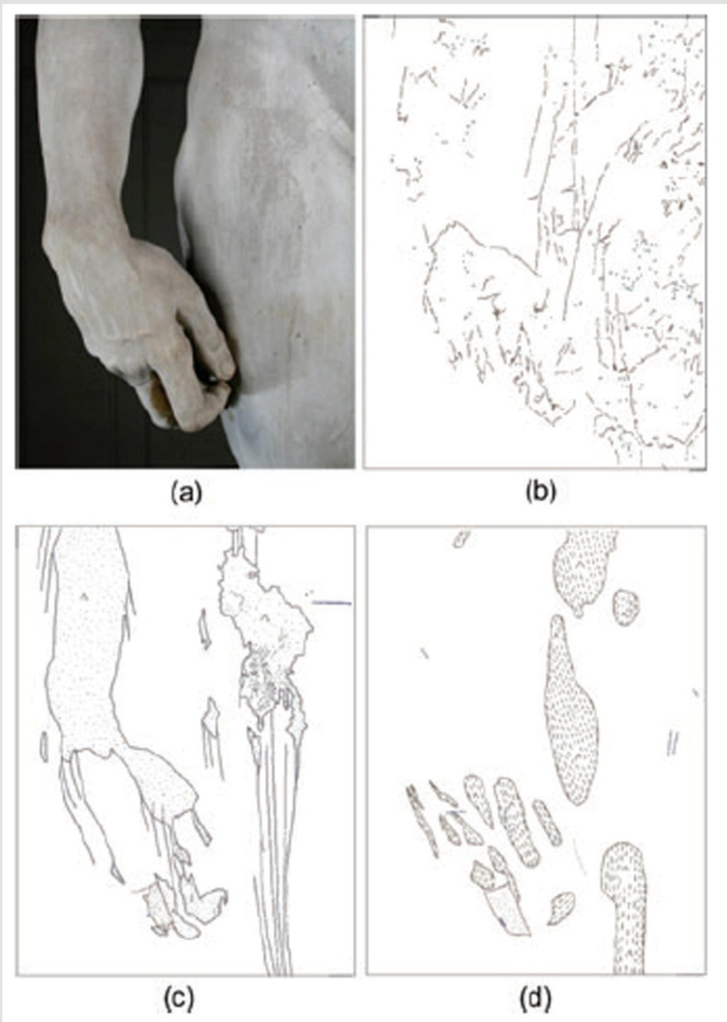



**Figure 3.7a)** An example of the photographic set with corresponding **(b)** imperfections **(c)** deposits and **(d)** consumption reliefs. Dellepiane et al. (2008: 2181).

The limited technological experience of the restorers responsible for the statue was a hard constraint on the project and a technological solution was at that time abandoned. A recent analysis of the results yielded led Dellepiane et al. (2008: 2181) to suggest designing a tool which in the data processing phase of restoration can be used by the restorer to draw the survey directly on the 3D model, i.e. using a painting/drafting system to make the relief. At the time (1999), however, the researchers relied on manual relief drafting followed by a digitization phase and final mapping. The restorers performed a precise graphic survey of the surface with accurate annotations on the high resolution photos. Dellepiane et al. (2008: 2182) report that these annotations describe in detail the imperfections in the marble (small holes and veins), deposits or strains (e.g. brown spots or the traces of straining rain), and traces of

Michelangelo’s workmanship. Using different colours to indicate the same phenomena on different sheets, the restorers drew on transparent acetate layers positioned onto each of the 61 high-resolution photos taken (in addition to the scanned surface patches).

Dellepiane et al. (2008: 2179) report that the algorithms or hardware resources, interactive resources, and interactive visualization of highly dense 3D and 2D has only become possible recently and therefore proposed a new project using the information from the original

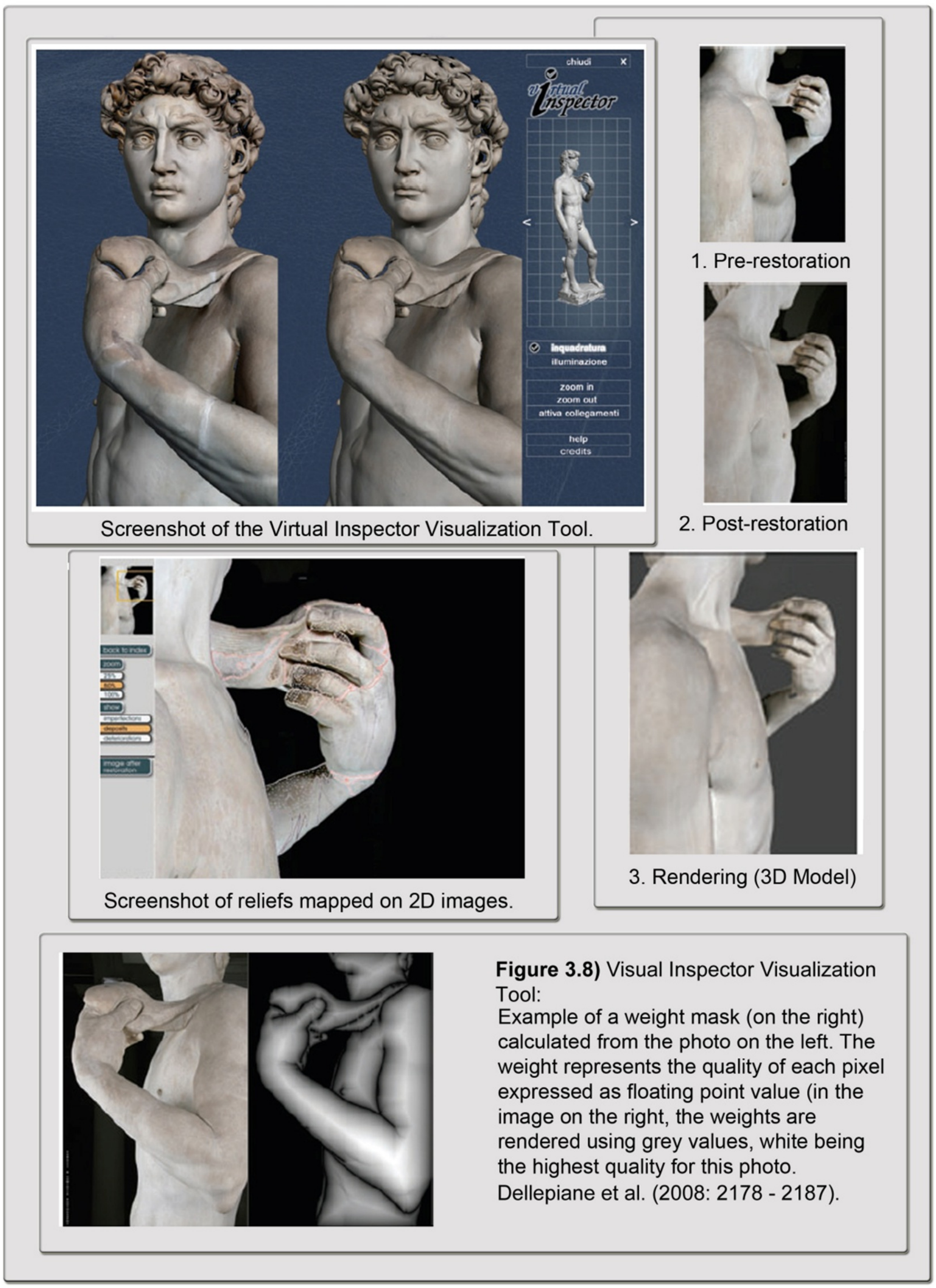
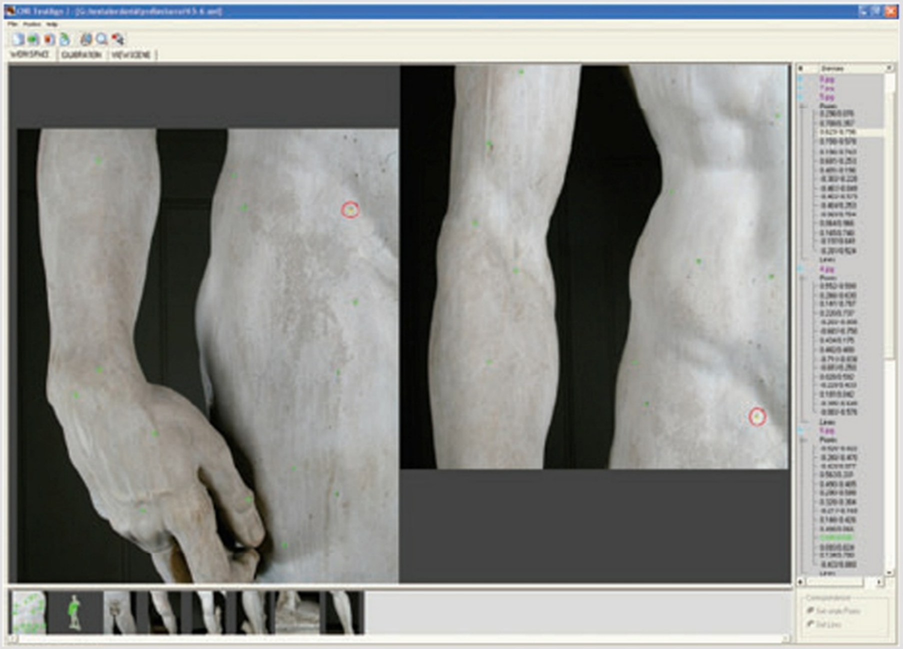
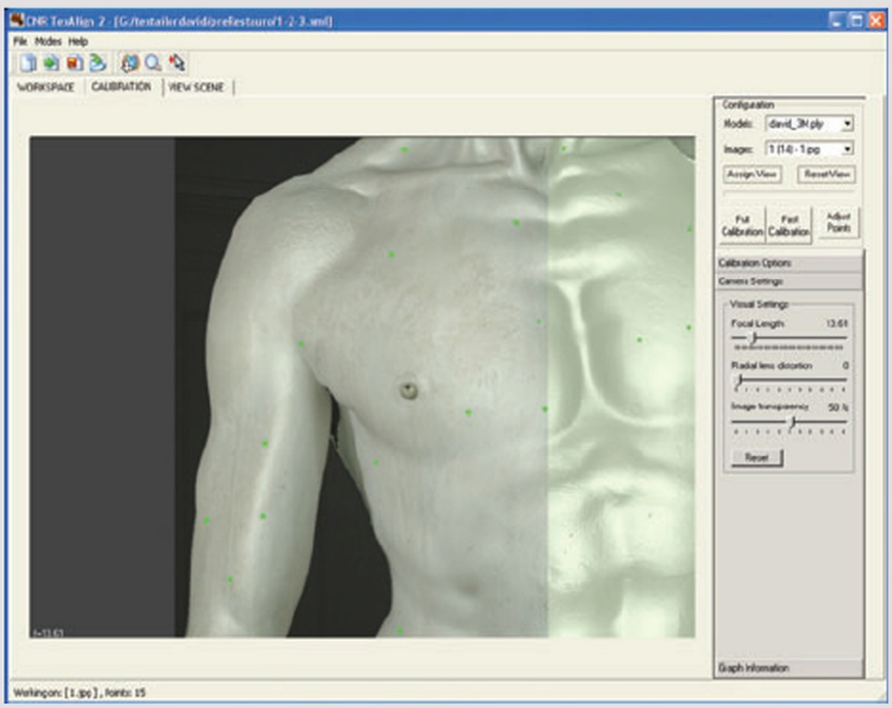



**Figure 3.8)** Visual Inspector Visualization Tool:
Example of a weight mask (on the right) calculated from the photo on the left. The weight represents the quality of each pixel expressed as floating point value (in the image on the right, the weights are rendered using grey values, white being the highest quality for this photo. Dellepiane et al. (2008: 2178 - 2187).

**Figure 3.9)** Dellepiane et al.'s (2008:2183) Image Alignment Tool.



Screenshot of Virtual Inspector's Image Alignment Tool with an example of overlapping RGB images (red circles indicate an image-to-image correspondence).




Screenshot of the Image Alignment Tool with an example of an image-to-3D model correspondence.

documentation. Dellepiane et al. (2008: 2182) developed their own web based visualization tool system called "Virtual Inspector". The program is currently still only available on DVD due to copyright issues. Features of the program are illustrated in the figures below.

Dellepiane et al. (2008: 2185) used Michelangelo's *David* as a representative case to illustrate the possibilities of advancement or support to the restoration process using Computer Vision technologies. Using their 'Virtual Inspector', a restorer could map large sets of RGB images on a very detailed model, sketch reliefs, spot particular points, and extrapolate indications about the material. Dellepiane et al. (2008: 2185) suggest that the introduction of colour and light blending technologies in the future may provide the controlled illumination and adoption of sophisticated techniques to estimate the illumination and material features – rendering a 3D digitized model even more effective in historical and scientific analysis than the original physical object.

### 3.2.2 Michelangelo's *Pieta*


**Figure 3.10)** Photograph of Michelangelo's Pieta in the Museum of the Opera del Duomo. Rushmeier et al. (2002: 59).

Inspired by the results of The Digital Michelangelo Project, Michelangelo's "Pieta" was initially chosen to examine questions about the composition of the figures, to determine the shape left when Michelangelo removed several pieces that have subsequently been re-attached, and to speculate on the shape of a piece that is still missing. As with Michelangelo's *David* researchers H.Rushmeier, F. Bernardini, J. Mittleman, and G.Taubin (2002) from the IBM JT Watson Research Centre New York, USA also focussed on the surface texture and tool marks found on the artwork. Rushmeier et al. (2002: 59) recorded the following goals for this project; creating a digital model of Michelangelo's *Pieta*, describing the design of a structured light scanning system, and acquiring input for accurate detailed rendering.

According to Rushmeier et al. (2002: 59) accounts from Michelangelo's contemporaries reveal that he planned to install the Florentine Pieta as his own tomb monument. He first executed the large statue in the 1550's. Carved from a single block of marble, the sculpture measures 2.25 meters tall and consists of the central Christ figure that rests across the lap of the Virgin Mary supported by Mary Magdalene on the left. Rushmeier et al. (2002: 59) reports that the figure behind and above supporting the Christ figure is believed to represent

Nicodemus and have the face of Michelangelo himself. In 1555, using a hammer, Michelangelo attempted to destroy his unfinished sculpture consisting of Mary Magdalene, the Virgin Mary, Nicodemus, and the body of Christ. The sculpture was separated into 15 mangled pieces (excluding the left leg of Christ, which went missing) and later reconstructed by one of Michelangelo's students, Tiberio Calcagni, into the artwork we know today. The reason for this spontaneous destruction is unknown and largely attributed to the volatile temperament famously attributed to Michelangelo who also abandoned the sculpture after its demolition. Working with art historian Jack Wasserman of Temple University in Philadelphia, USA, who was researching his book (Michelangelo's *Florence Piet*a), Rushmeier et al. (2002) endeavoured to investigate what prompted Michelangelo to mutilate his work using digital representations to reconstruct the original work and the artist's process. With the ultimate rendering in mind, Rushmeier et al. (2002: 60) proposed to render the sculpture with altered geometry to see it as Michelangelo saw it with parts removed.

**Figure 3.11)** Structure of the scanning system developed for the Pieta. Rushmeier et al. (2002).

According to Wasserman (2002: 272) "the ability to stand each figure of the Pieta up straight without distorting the dimensions and proportions will provide valuable insight into the question of what Michelangelo's proportions were like, his general concept of proportions, and how he meant the work to be viewed at his tomb site". Wasserman and Rushmeier et al. (2002: 60) collaborated to produce a sufficiently-detailed 3D model that would transcend all these nuisances, allowing a researcher to examine the statue at his leisure from any viewpoint, to add or remove parts, and to analyze it using computational techniques impossible in reality.

**Figure 3.12)** Images rendered from Michelangelo's Pieta under two diferent lighting conditions. Rushmeier et al. (2002).

Like most Cultural Heritage projects, the *Pieta,* measuring 2.25 meters and carved out of a single block of marble had to be recorded within the museum environment and with minimal contact to the artefact. The base scanner was purchased from Visual Interface Inc. and consisted of 6 small black and white cameras capturing the striped pattern images projected on an object by the scanner. Using principles of stereo computer vision, the software used to process the models computes a triangle mesh from the captured images. Mounted on the top of the structure is a colour camera that captures images that later registers with the triangle mesh. Using the same principle as the Stanford Group's *David*, Rushmeier et al. (2002: 63) used a photometric system consisting of five lights and their varying conditions to eliminate ambient light and compute surface normal's at a higher resolution than the meshes. By comparing the surface appearance under varying lighting conditions the researchers also extracted the flat colour reflectance's that do not include the effects of any single light source.  For the alignment of these patches, Rushmeier et al. (2002: 64) used a tool similar to that of Dellepiane et al.'s (2008: 2185) 'Virtual Inspector'; namely, an array of laser dots that were projected on the statue to provide fixed landmarks or reference points.

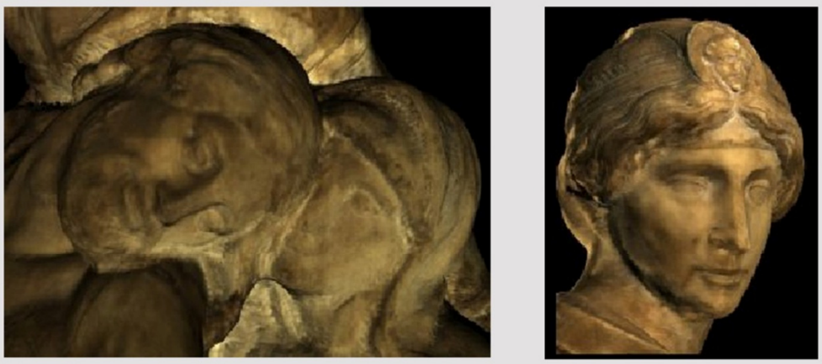


**Figure 3.13)** A synthetic image of the face of Mary, Jesus and Nicodemus obtained from the scanned 3D model using geometric and photometric data. Rushmeier et al. (2002: 62).

Rushmeier et al. (2002: 60) created their own scanning structure using a Faro Arm and an existing multi-view camera. According to their results a reduced number of vertices are needed for efficient data storage and rendering. Retaining detail from the point cloud whilst simplifying the base geometric model has been seen as a possible solution by some researchers. This approach still requires a high precision initial scan, fitting a triangle mesh to a dense point cloud and significant processing. Rushmeier et al. (2002: 59) specifically chose to use colour and texture data from photographs that are mapped and aligned to the geometry, since this method is cost effective and requires a minimal amount of technological equipment. Originally, Rushmeier et al. (2002: 59) lists certain constraints on the project which led to the ultimate choice of data acquisition technique, namely; restricted access to the artwork, the complex geometry of the artwork, physical space surrounding the artwork is limited (for equipment and technicians), and the artwork may not be touched or moved.

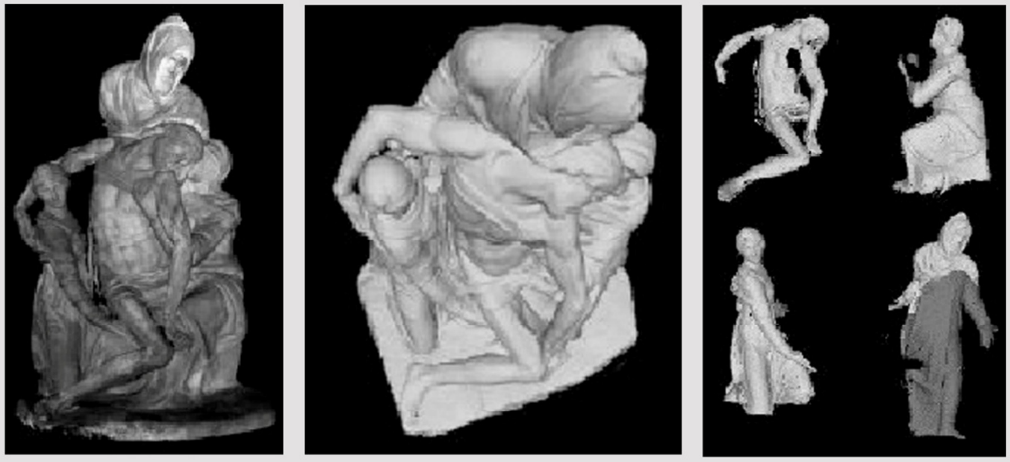
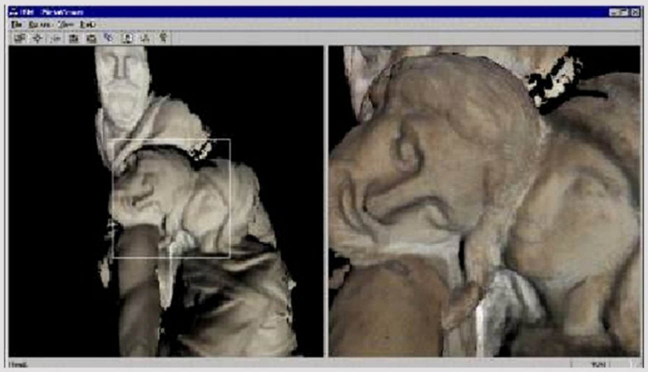


**Figure 3.14)** 3D model of Michelangelo's Pieta from different points of view; front, top, and with parts removed. Rushmeier et al. (2002).

Admittedly, Rushmeier et al. (2002: 66) suggest that although it may seem more cost effective to use a photogrammetric system, it may not be the most effective way to issue the desired results. Rushmeier et al. (2002: 61) encountered a host of difficulties trying to initiate this cost effective and data efficient scanning system. Amongst the most pertinent problems was estimating the specular component of reflectance, since the camera used had a limited dynamic range. They offer a solution in scanning at a courser resolution, but this approach leads to significant overlapping maps of normal's and reflectance's. Careful calibration of these surface maps could form them into a consistent, but numerous overlapping is insufficient for storage and rendering. Rushmeier et al. (2002: 66) further suggest that a method is needed for merging and reducing the number of surface maps without loss of resolution.  The combination of various modes of point and image is optimal for recording complex objects efficiently and economically.  To solve the above anomalies, Rushmeier et al. (2002: 61) used a considerable amount of processing time to perform a series of operations of alignment on the individual small meshes. Using their points of reference (the laser projections), they developed an automatic conformance step that accounts for measurement errors within each mesh by comparing the overlapping normals and reflectance's. Points from the smaller meshes are then merged into a single triangle mesh using Rushmeier et al.'s (2002: 63) Ball Pivoting Algorithm.  A large amount of scanned data alignment and model processing is needed due to the scanner's capturing range; in this case an area of approximately 20cm by 20cm.

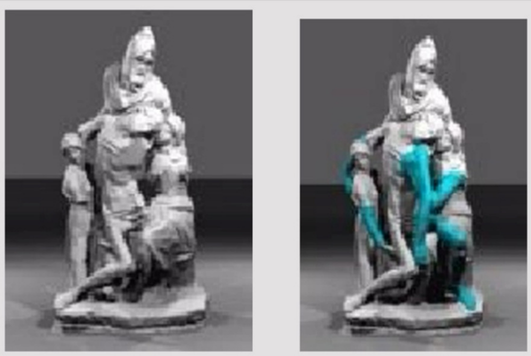
Ultimately, the model produced by Rushmeier et al. (2002: 66) was sufficiently complete consisting of 14 million triangles and more than 1 gigabyte of additional surface details. The research team was also able to deliver a model with precisely defined and impossible views, a model imbedding the statue in virtual environments, a model of precise measurements, and model that can be modified and viewed interactively. Their ultimate goal, however was

**Figure 3.15)** 3D models and environments processed by Rushmeier et al.(2002).

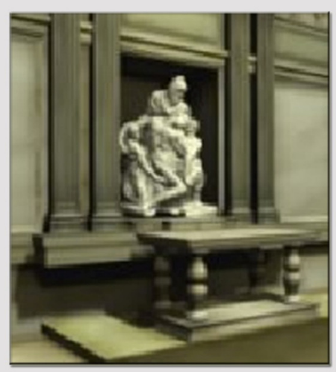


Screenshot of the hybrid viewer developed for easy interactive viewing developed by Rushmeier et al.(2002).

Framed section of the scene invoked by an offscreen renderer (on a remote server) that creates the desired image from a database that represents the full-detail model.



Reconstruction of Christ's missing leg on the 3D model.



Virtual environments created to illustrate the statue in the as it would have appeared (above) under the huge vault of the Florence Duomo and (left) in a garden at the Bandini palazzo.

to provide art historian Jack Wasserman with a virtual model that he can interact with directly. Unfortunately, hardware and software limitations on an average computer at that time {and to some extent currently according to Remondino et al. (2010: 94)} excluded some of the surface details and navigation speed of the originally scanned data. Rushmeier et al. (2002: 65) had developed a viewer that avoided these limitations to a degree, but it geometrically simplified the model and supplied in essence an altered version of the statue although it could be interactively navigated.

### 3.2.3 The *Minerva of Arezzo*


**Figure 3.16 a)** The Minerva of Arezzo. **b)** The digital model of the Minerva of Arezzo. Pezzati et al. (2009: 3).

The 3D scanning of the *Minerva of Arezzo* was initiated by a team of fourteen researchers, namely; C. Rocchini, P. Cignoni, C. Montani, P. Pingi, R. Scopigno, R. Fontana, M. Greco, E. Pampaloni, L. Pezzati, M. Cygielman, R. Giachetti, G. Gori, M. Miccio, and R. Pecchioli. Using two different hardware scanning technologies, the projects intention was to demonstrate how 3D scanning techniques can be integrated with standard diagnostic archival methods. The objective of the project was to build a complete 3D digital model of the Minerva statue in each of the restoration phases. The progress of laser based devices provided 3D surveying with a new era for system process development. Lica Pezzati and Raffaella Fontana (2009: 3) researchers at the National Institute of Optical Applications in Firenze, Italy, suggest that this growing technological progress enables the design of highly accurate instruments for quota measurements and allows dense data sampling at high acquisition rates.

**Figure 3.17)** The Minverva of Arezzo (detail).
Rocchini et al. (2001: 1).

The Minerva is a bronze statue discovered in Arezzo in the 1500's. The origin of the statue is still unknown and its features are attributed to be either Hellenistic (third century B.C.) or Roman Imperial (first century A.D.). Standing at a height of about 155cm, and weighing 150kg, the Minerva is cylindrically shaped with a protruding arm which extends out 40cm making it a large structure with complicated surface variants. Apart from these measurements, the lower part of the Minerva had to be restored using wood and plaster with the right arm (from the shoulder) integrated in 1785 which was made from bronze.

The unstable conditions of the structural wooden elements within the statue and extensive corrosion of the bronze compelled Rocchini et al. (2001: 4) to ensue the scanning process in order to determine which measures could be taken for complete restoration. With 3D scanning, archival data such as this can be safely acquired and be organised for an easy and interactive visualization, manipulation, and analysis. A structured restoration plan can be created from steps already prompted by the manipulation of 3D data. A total of 119 separate measurements or range maps were acquired according to Pezzati et al. (2009: 3) each with a spatial density of 16 points (vertex) per $mm^2$, and a different part of the statue's surface is framed with these points. In figure 3.16b above, the range maps were registered and joined merging them into a single 3D mesh which is then converted into the rendered model illustrated in the three figures below.

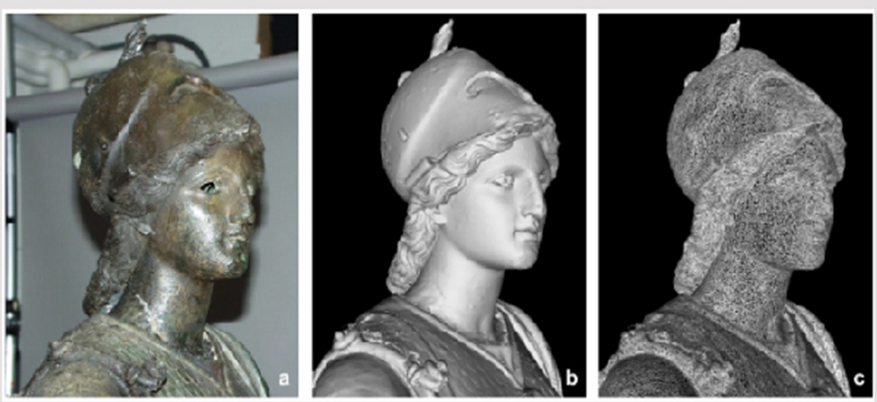


**Figure 3.18a)** Detail of the Minerva's head. **b)** A raking light image of the digital model of Minerva's head. **c)** A triangulated mesh image of the Minerva's head. Pezzati et al. (2009: 3).

According to Remondino et al. (2006: 279) a 3D triangulated mesh is the result of the original point cloud data acquired and then mathematically rearranged by algorithms to generate a polygonal surface consisting of triangular or tetrahedral networks which as a result presents the objects surface in structured ‘patchwork’ of polygons (see figure 3.18b).

**Figure 3.19)** Low cost scanner based on structured light and consumer electronic technology designed by Rocchini et al. (2001: 2).

The two scanning systems; namely structured light and laser scanning achieved moderate success on this project (Rocchini et. al. 2001: 2). The structured light scanner was developed as an optical scanner which consisted of an emitter; which projects the structured light on the target object, and a sensor; which acquires the images of the distorted pattern reflected by the object surface. The overall geometry is reconstructed using triangulation and calculating the known location of the emitter-sensor pair. The structured light system was chosen for its affordability, accuracy and resolution. The researchers Rocchini et al. (2001: 3) chose this system as its instruments reportedly supported the acquisition of the surface complexities in the statue’s geometry. The system itself was developed by the researches thus providing ease of operability, flexibility and technological improvements.

**Figure 3.20)** The experimental setup of the laser scanner designed by the Istituto Nazionale di Ottica Applicata (INOA) in Florence. Rocchini et al. (2001: 3).

The second scanning system; namely the laser scanner developed by the INOA in Florence, Italy provided Rocchini et al. (2001: 4) with a 3D data acquisition instrument specifically designed for Cultural Heritage Applications. Rocchini et al. (2001: 4) agree that laser scanners are possibly the most versatile among the active non-contact devices for 3D measurement that are available. Advantages listed by the research team include; setup simplicity, small size and high resolution. As with the previous system, the laser scanner is principally based on optical triangulation. The object is illuminated by a light source, forming an image of this light spot by means of a lens on the surface of a linear light sensitive sensor. The distance of the object from the instrument is then determined by measuring the location of the light spot image, providing a baseline for the angles to be calculated.

In terms of the results yielded by the scanning of the Minerva, Rocchini et al. (2001: 5) report that defects occurred early on concerning the acquisition of colour data as metal (bronze) materials are highly reflective and therefore scanned data returns void. The researcher's solution was to combine the laser scanning system's data with photo mapping in order to acquire the colour data. A multidisciplinary research team was appointed to operate the chosen technologies and at the end interpret the experimental results. Certain scanning systems and software used by Rochinni et al. (2001: 2) required the speciality of trained technicians and therefore the process was complicated and the goal of the project more limited. They listed one of their future ambitions to be the development of restoration specific 3D scanning technologies. These applications will foster research specific technology to promote Cultural heritage preservation and restoration. With the structured light scanning system, Rocchini et al. (2001: 4) acquired 146 range maps with the help of a rotating platform. Each range map sampled a section of approximately 70cm X 50cm. The scanner completed a piece-wise pseudo-cylindrical scan with each scan raised to the next height for the next section. In accordance with their objective and despite the high reflectivity of the bronze surface, a complete model of the Minerva was produced (shown in figure 4.16b). At the time, Rocchini et al. (2001: 5) claimed that the technologies chosen for this project were only experimental, and their long term goal includes designing a different approach to foster these technologies and provide specific applications orientated to meet restoration needs. The results presented were mainly to provide a technological push to the Cultural Heritage data acquisition methods available.

**Figure 3.21)** 3D digital model of The Minerva of Arezzo. Rocchini et al. (2001: 5).

### 3.3 Concluding Remarks

Each scanning session discussed demonstrates the different characteristics and variables not only present in works by various artists in different time periods, but also the characteristics of the virtual environment and the variables of technology used. These factors prove that each scanning session presents a new challenge and must therefore be handled individually and approached with meticulous inquiry. All the acquired information and models produced has potential to provide structure in establishing archiving sculptures through 3D scanning as a viable medium.

Using the information provided by these studies, the case studies presented in Chapter 4 uses the procedural documentation and the anomalies documented from these well-known cases as base knowledge for further exploration. The only difference is the physical object, equipment used, and the scanning environment.

# CHAPTER 4

## 3D SCANNING: DIGITAL ARCHIVING OF SCULPTURES

### 4.1 Overview

This chapter outlines a procedural scanning process using the portable ZCorporation Z Scanner® 700. The procedural scanning process is structured around the identification of 3D data recording variables applicable to the digital archiving of sculptures. Presented in this chapter are several case studies that record 3D scanning variables such as texture, scale, surface detail, light and data conversion applicable to varied sculptural surfaces and form. Even though results reveal that valuable procedural 3D scanning information was gained, portable scanning using the Z Scanner® 700 still presents technological limitations for the digital archiving of sculptures. However, 3D portable scanning could provide digital longevity and access to previously inaccessible arenas for a diverse range of digital data archiving infrastructures. In conclusion the outlining of a procedural 3D scanning environment supports the developing technology of 3D digital archiving in view of artefact preservation and interactive digital accessibility.

### 4.2 Introduction

The accurate digital data capture of various 3D structures via three-dimensional (3D) scanning has proven beneficial to a number of industries and their associated applications. According to researchers from the University of Tennessee, USA B. Grinstead, S.Sukumar, D. Page, A. Koschan, D. Gorsich and M.A Abidi, (2006: 283) with most 3D scanning applications the captured data is used directly as digitally recorded form or as an established basis for further 3D product development. Recent South African research surrounding the data capture of archaeological artefacts from "African Cultural Heritage Sites" displays the application of 3D scanning technology to digital archiving. Researchers involved in the project, namely; H. Ruther, M. Chazan, R. Schroeder, R. Neeser, C. Held, S.J. Walker, A. Matmon, and L.K. Horwitz (2002: 4) have in addition applied the use of digital archiving technology to the development of a "Landscape Database". The development of such a database forms an integration between the metrically accurate measurement of spatial data and non-spatial contextual data; namely books, reports, expert descriptions of sites and published scientific papers. Through digital archiving Ruther et al. (2009: 20) propose to create an awareness and initiate 3D scanning as a reliable data preservation methodology for "African Cultural Heritage Sites" through which future research, conservation and educational activities are facilitated. The data recording of archaeological sites, architectural structures, artefacts and natural sites by using 3D scanning technology has improved considerably over the last few years and rapidly continues to evolve. In the past, graphic artists would reconstruct an artefact from a library of pre-constructed primitives or from several meticulous measurements. Grinstead et al. (2006: 284) defines the current advances in 3D scanning technology as “digitizing reality”.

“Digitizing reality” or the general term 3D scanning has largely infiltrated the American market on a commercial level and claims to become an established technological component within industry. The market is dominated by USA based companies such as Genex Technologies, Eyetronics, and Cyber F/X who provide 3D scanning services to almost any area of commerce according to the 2009 *Wohler’s Report* (2009: 58). These companies offer high quality equipment, skilled teams of technicians and cutting-edge technology for 3D data recording and 3D reverse engineering services. In South Africa, the development of 3D scanning is largely dependent on research projects such as the abovementioned “African Cultural Heritage Sites” and “Landscape Database” development, which in turn is affiliated with a collaborative agenda called *Aluka* – an international programme that creates digital libraries from resources about and from Africa. According to Ruther et al. (2009: pg 19), developing a database of this nature may assist some African countries to access valuable heritage data in order to prevent the erosion of cultural legacies, while in others it may fulfil an educational role of preserving Indigenous Knowledge Systems (IKS).

This research project focuses solely on the parameters surrounding 3D scanning applicable to the individual user and the portability of the applied technology. The ZCorporation ZScanner® 700 was used due to its availability, portability, plug-and-play capabilities and its image based/non-contact XY scanning accuracy up to 40 microns (figure1). The ZScan™ software automatically produces a stereolithography (.STL) file for output to a 3D printer or a .STL compatible software package. In conjunction with the scanning device an Intel desktop computer supported by Windows XP Professional SP2, 32-bit running software (less than the updated 64-bit) powered by a dual core processor and onboard 2.66 GHz system architecture with the minimum 4 GB of memory was used. A range of scanned sculptures are presented as individual case studies for which the Z Scanner® 700 was used as a data recording tool for the outlining of a procedural scanning process which can be performed on site by a single user. The outlined scanning process reflects on the advantages and limitations experienced while using this 3D scanning technology. Each case study’s scanning procedure is structured around the identification of 3D data recording variables. Sculptures were specifically chosen to introduce challenging data recording capabilities within the 3D scanning environment; thus experimenting with light, texture, surface detail, size, form, data conversion and the overall stability of the technology. By examining each of the recording variables, new procedural environment features to the complex task of "digitizing reality" are introduced.

**Figure 4.1)** ZCorporation ZScanner® 700.

The recording of artefacts via 3D scanning not only provides digital longevity and easy visual access; but also serves as an introduction to previously inaccessible arenas for a diverse range of digital data archiving infrastructures. The outlining of a 3D scanning environment supports the developing industry of 3D digital archiving in view of artefact preservation and interactive digital accessibility.

**4.3 Digital Archiving**

**4.3.1 Technological Implications**

Research findings reveal that the continued handling of historical objects frequently leads to damage. Therefore, governments and large organisations generally support a shift towards digitally preserving technical and industrial heritages since maintaining physical objects within museums has become expensive or deemed a delicate and often redundant task. However, according to A. Bernard, F. Laroche, S. Ammar-Khodja and N. Perry (2007: 143) from the University of Nantes, France with the implementation of digital preservation, questions arise on how to manage and valorise digitalization within the framework of a museum or site. This matter further relates to the frequently debated ethical issues surrounding authorship and authenticity when digitally archiving objects and documents. The elucidation of this subject was discussed in Chapter 2.

#### 4.3.1.1 On-site Scanning

An object is defined by the impact of its two environments, namely; its characteristics and the contextualised outside world. Internally the object is categorised according to time as functionality, its structure, material and colour. The external perception or outside world is categorised into different environments into which the object is placed; for example a macroscopic, mezzo or microscopic level (Bernard et al., 2007: pg 145). Within the manufacturing industry, reverse engineering or 3D scanning as means of data capture mostly revolves around the internal characteristics of an object. The 3D scanning of a single object functions as an entity and therefore the surrounding site is not considered. Contrastingly, when digitally recording an archaeological site using 3D scanning, accuracy of data is determined by the contextualised site in conjunction with the object's internal characteristics.

According to Bernard et al. (2007: pg 146), the object or site targeted for archiving should not be removed or disassociated from its context, as those elements are needed for its virtual re-contextualisation. As mentioned above, the site where the scanning process takes place becomes important in its capacity as a contextualised environment. In this research, the scanning of artworks within a museum context falls somewhere between recording the external environment and the internal object's data characteristics. Several sculptures from the Oliewenhuis Art Museum's permanent collection, located in Bloemfontein were selected for the scanning case studies. Sculptures within the permanent collection circulate according to a rotational schedule every 2-4 weeks. Logistically this implied that sculptures assigned for scanning had to be scanned on-site bearing in mind exhibition schedules and more importantly security and insurance implications surrounding possible handling or the removal thereof.

#### 4.3.1.2 Non-contact Laser 3D Scanning

The following criteria for non-contact laser scanning established by Bernard et al. (2007: 146) prescribes that the operational factors surrounding 3D scanning technologies be questioned; the relevance of measurements, the necessity of digitizing repeating features in an object, relocation and palpation of the object and exposure to radiation. The non-contact system ZScanner® 700 imaging-based scanner used for this research project addresses these issues as follows. The ZScanner® 700 operating software exports the digitally recorded facets in a universal stereolithography (.STL) data format. Repeating features are easily copied and placed at the exact XYZ coordinates. The ZScanner® 800 is a portable device with plug-and-play functionality. As a laser-based scanner, it generates shorter waves as means of measurement so there is no actual contact or radiation exposure to the physical object.

#### 4.3.1.3 Artefact Preservation

When scanning to preserve an artefact, an object's physical and environmental characteristics as well as overall condition determine a successful data recording. Technical features such as material properties, accessibility, size, volume and surface detail need consideration in order to achieve accurate results. In industries, where reverse engineered data is further modified using 3D CAD the initial scanned data is mostly used as an accurate measuring tool, reference piece or to establish existing irregularities. The digital preservation of artefacts through 3D scanning requires that the recorded data should mimic the physical world and therefore extended 3D CAD manipulation disrupts the reliability of the archived artefact. This too further relates to the previously mentioned issues surrounding debated ethics with regard to authorship and authenticity when digitally archiving objects and documents.

## 4.4 CASE STUDIES

### 4.4.1 Sculpture Selection

Several sculptures varying in material properties, volume, size and surface detail are used as case studies for this research. As mentioned, the sculptures form part of the Oliewenhuis Art Museum's established permanent collection and the digital recording of these artefacts supports the museums long-term 3D artefact archiving strategy. The selection consists of works by South African artists with some sculptures dating as early as 1920 therefore the suitability of using a 3D non-contact scanner.

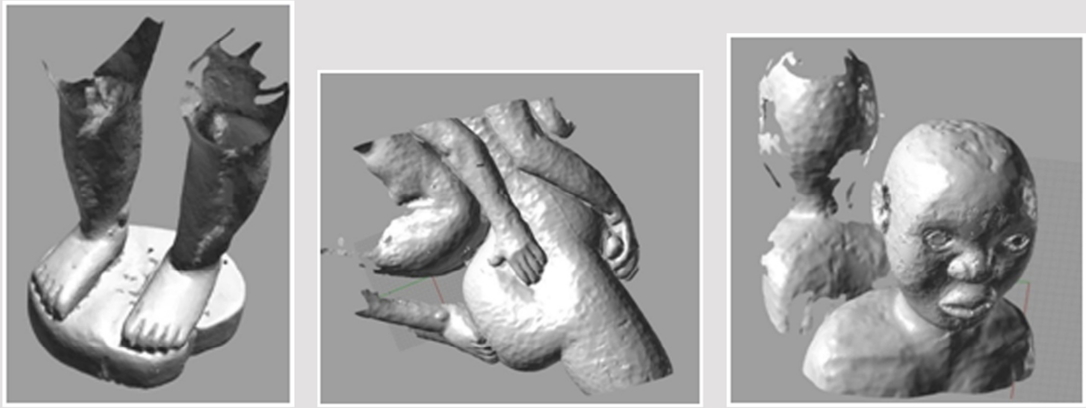
The first two scanning sessions took place within the active gallery space as the works formed part of the permanent exhibition on display. Technical scanning factors such as light and space within the active gallery space revealed adequate results. Patrons were able to view the surrounding works as well as the scanning session in progress as part of an educational initiative. Logistics surrounding the installation and placing of the sophisticated scanning equipment in a public space required frequent removal to secure storage.

Hereafter the scanning sessions were conducted in the museums secure sculpture storage facility where the 3D scanning equipment was safe and technical aspects of the scanning environment stabilised for the duration of the case studies.

#### 4.4.1.1 Scale and Form

**Figure 4.2)** Joel Noosi "Old and Young" (n.d.)

Early on, it became evident that the scale of the object or individual sections should not exceed a parameter of 50cm X 50cm X 50cm. This is due to the scanners built in software specifications. Sculptures exceeding this size required systematic scanning in sections such as Joel Noosi's "Old and Young" (figure 4.2) which measured roughly 1.3 meters in height and about 60 cm in width. This sculpture was scanned in three sections (figures 3.3a, 3.3b, 3.3c) paying specific attention to detail and complex surfaces. These parts were later repaired and placed to fit using GeoMagics© supporting CAD software. An overall finding revealed that the form of the object plays a role in the scanners ability to read and record data. A closed-form object with a lower degree of surface variation records faster and more accurately. Scanning open-form detailed objects requires technological improvements to the scanner, as often the recording session became unstable through inadequate scanner data capture capacity causing the entire session to fail and therefore loss of data occurring. This also could have occurred because of the installed 32-bit operating system capacity as opposed to the recent suggested 64-bit by the manufacturers and suppliers or due to the 4 Gig RAM installed on the computer. However, attaching a simple object to a complex surface and repairing the difference using supporting software proved a solution to capture complex open-forms.



(3a) (3b) (3c)

**Figure 4.3a,4.3b,4.3c)** Joel Noosi "Old and Young" scanned data.

**4.4.1.2 Surface Texture**

Recording surface texture relies on surface indicators such as detail, reflectivity and adjoining areas. Within the scanning environment, each surface receives detection according to its variances. For example, the reflectivity of an object relies on the qualities associated with the surface plane of that object. Simply explained, a smooth surface area absorbs less light than an uneven surface. Rhona Stern's bronze sculpture "William" (figure 3.4a) demonstrates a highly fluctuating surface, which absorbs and reflects light continually. Not only does this work vary in reflectivity, but when viewed topographically, its uneven surface rearranges into a series of multifaceted joints. The free-form nature of these joints allows for easy surface detection and therefore scanned successfully (figure 3.4b).

(a) (b)

**Figure 4.4)** Rhona Stern "William" (n.d.)

### 4.4.2 Scanning Environment

The procedural scanning environment consists of three components; the objects internal environment, external site environment and virtual environment. A successful scanning environment encompasses capturing the relationship between the first two components and communicating the calibrated data within the virtual environment.

#### 4.4.2.1 The Object

As previously mentioned various internal object characteristics within a contextualised environment determine the object as a whole which is further categorised by functionality, structure and medium (Bernard et al., 2007: 148). The scanning environment of an isolated object undervalues this relationship as its role directs towards data capture of the object alone. In view of the fact that the objects in this study are works of art, it is vital to consider their contextualisation and internal characteristics as part of the scanning environment, which eventually transfer to a virtual environment where these categories expand as the works themselves become visually and aesthetically communicative to a viewer.

#### 4.4.2.2 The Physical Environment

Research done by P. Dias, M. Matos, and V. Santos (2006: 486) from the Department of Electronic Telecommunications and Mechanical Engineering of the University of Aveiro, Portugal suggests that many commercial solutions exist for scanning smaller dimension objects, but none for scanning the larger external environments in which these objects exist. The scanning of large-scale environments presents technical problems such as the acquisition of data, variation in lighting sources and complexity of geometry. Bernard's et al. (2007: 146) classifications of the external scanning environment consist of the macroscopic level, seen as the socio-technical environment, which refers to the object's social context and the technical culture it encompasses. The second level known as the mezzo level refers to the external environment integrated with the objects purpose. The third microscopic level refers to the internal characteristics of the object interacting with the external environment. In essence, these levels form a timeline of past, present and future in which the object engages. When recording archival artefacts, it is important to capture these components within the objects basic reconstruction e.g. Oliewenhuis Art Museum. See figure 3.5 below.

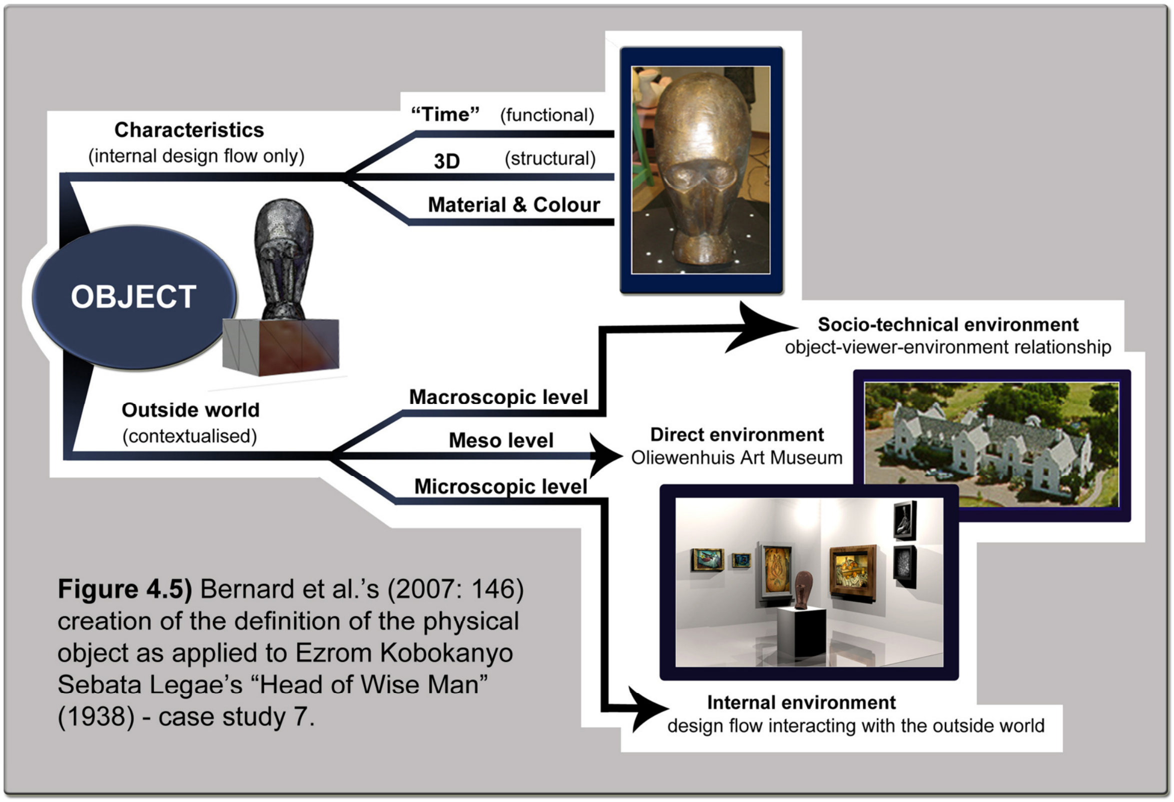



**Figure 4.5)** Bernard et al.'s (2007: 146) creation of the definition of the physical object as applied to Ezrom Kobokanyo Sebata Legae's "Head of Wise Man" (1938) - case study 7.

#### 4.4.2.3 Virtual Environment Calibration

The 3D digital archiving of an object embedded within an external environment as opposed to an isolated object requires that the characteristics of both internal object and external site environments be recorded accurately. The motivation behind archiving sculptures within the permanent collection of the Oliewenhuis Art Museum is twofold: 1) to explore the digital preservation of artefacts through 3D scanning technology and 2) initiating future interactive web access to 3D digital artworks. As mentioned the sculptures are housed within a museum context where specific placement of artworks often varies. Because of this, case study data reflecting the external site environment deemed less significant than for e.g. an external archaeological site environment and therefore the sculptures will not be integrated into a virtual environment until such time that the full spectrum of the collection can successfully be scanned. In most of the case studies, the ZScanner® 700 was able to capture all of the surface area and necessary detail. The sculptures are defined as part of the permanent collection therefore Oliewenhuis being the external site environment. At a later stage the virtual 3D CAD engineering of each sculpture's scanned data in relation to the external site is inevitable to fulfil the archiving and virtual database objectives. The current recorded data should be regarded as part of a digital archival process and therefore can be stored for record keeping until such time that the museum plans to develop its own infrastructure to digitally archive on a regular basis.

### 4.4.3 Data Recording Session

Below outlines the procedural steps of a typical data recording session. The scanning sessions averaged at 2 hours per session with some sculptures requiring several additional scanning due to size, detail or technical failure. The manufacturers of the scanner, Creaform™, claim that the lengthy time taken to scan can also possibly be attributed to the inadequate installed 32-bit operating system as previously mentioned; however, according to members of the 3D Optical Metrology Unit in Trento, Italy, Manferdini et al. (2010: 120) it may not be the operating systems bit rate, but general computer architecture which limits the maximum size of useable operational memory. At this time, Manferdini et al. (2010: 120) reports that the size of the data obtained from 3D measurement is greater than the memory capacity available in typical PC-class computers. Theoretically the limit for 32bit systems is set at 4GB, but Manferdini et al. (2010: 120) reports that this size shrinks to 2 or 3GB for single application. With this memory limit, a user can only load approximately four directional measurements of about 500MB each into RAM, which according to Manferdini et al. (2010: 120) is not an adequate amount. The 64bit computer architecture may address more memory space, but in reality in AMD64 there is only 48 addressing bits which gives a user results in a 256TB limit and the limit is therefore sharper (in desktop systems 24GB and in servers 192GB). The cost of this amount of RAM modules is also significant. A solution presented for this problem by Manferdini et al. (2010: 120) includes a designed calculation allowing the use of cooperating external memory sources which requires additional programming skills and tools, thread management mechanisms, synchronization objects, and running applications in multithread mode. All of the above tasks may be what limits an individual user approach, i.e. with the ease of portability and plug-and-play capabilities. In conclusion, Manferdini et al. (2010: 121) reports that despite great research, no powerful, reliable and flexible package currently exists which truly addresses the problems faced by 3D data acquisition researchers. It is therefore up to the individual user to adapt and adopt a resourceful approach which will yield the maximum results.

#### 4.4.3.1 Positioning and Capturing Targets

The sculpture should be accessible from all angles to allow minimal handling. The scanning session is launched after the ZScanner® 700 has been connected and the scanners laser beam detected by the ZScan™ software. The first task within a new session is to capture the positioning features. Positioning features placed at 2cm-3cm intervals on the object are adhesive, magnetic or attached to a net used to record larger surface areas. Once the feature tab is activated, the user maintains an estimated 30cm scanning distance rotating around the object. Software gauges the optimum distance throughout the process. Distance is indicated by a colour coded bar reflecting the various distances; red being too close, yellow out of the laser's range and green indicating a suitable distance. At this point, the user is able to identify the basic form of the object as outlined by the positioning features. The actual data recording of the object commences once all of the positioning features have been captured.

#### 4.4.3.2 Recording Surface Data

The surface scan tab activates the data recording session. It is important to manipulate the scanner in slow steady sweeps up and down the length of the artefact whilst moving around the sculpture, similar to a spray-painting technique. The scanner requires adjusting to a higher resolution when scanning areas that are more detailed. Capturing the surface data takes longer than recording the positioning points and requires a methodical hand co-ordinated technique. Excess surface reflection and texture irregularities disrupt the recording session requiring most surfaces to be scanned more than once, upon which data is successfully captured.

#### 4.4.3.3 Lighting Features and Variables

As mentioned earlier, the ZScanner® 700 is an active, non-contact, laser-based scanner relying on light for detection and therefore varied natural and artificial light sources affect the duration of scanning session. A specific case study by Rocchini et al. (2001: 3) confirms that the effective recording of surface texture depends on adequate lighting conditions. The illumination-invariant surface reflecting properties (also called *albedo*) evident on the surface of the object were computed by removing highlights and diffusing shading on the physical object with different lighting effects. Multiple scanned sessions were taken from the same viewpoint under varying lighting conditions to allow for easy removal of lighting effects (Rocchini, Cignoni, Montani, Pingi and Scopigno 2001: 4).

#### 4.4.3.4 Post Scanning Procedure and Data Conversion

The scanning process can be categorised into three phases; scanning, aligning and fusing. Most supporting scanner software is able to translate the scanned data into its final format, which is most often destined for 3D printing. The final phase termed fusing refers to the combining and aligning of the scanned surfaces to create the solid form. Uyar and Erdogdu (2009: 340) successfully used software programs such as SolidWorks© and Ansys

Workbench V11© for surface repair work and exported mesh file translation when exploring the re-engineering of form via 3D scanned data. The archiving of data in this research requires that all surface features are exactly recorded and therefore deemed an inaccurate recording if data is lost during the translation process. Therefore, editing of the final recorded data was minimal with only initial scanned surface defects being repaired. The surface defects and final file translations on the 3 data recorded were repaired using the accompanying software available with the ZScanner® 700 and GeoMagics© 3D editing programme.

### 4.5 SCANNING RESULTS

The data sheets below illustrate results yielded from this study and the subsequent external and internal conditions in accordance with Bernard et al.'s (2007: 146) definition of a physical object illustrated in figure 3.5. The characteristics and real-time physical data was recorded to detect any material, form, dimensional, lighting, and surface texture features which may cause anomalies in the scanning session. Results are classified as successful, unsuccessful or undetermined with a short commentary concerning the variables of the session.

# RESULTS

## Test Scans

### TEST SCAN 1

ARTIST:
UNKNOWN
TITLE:
UNKNOWN

DATA

MATERIAL: CERAMIC CLAY

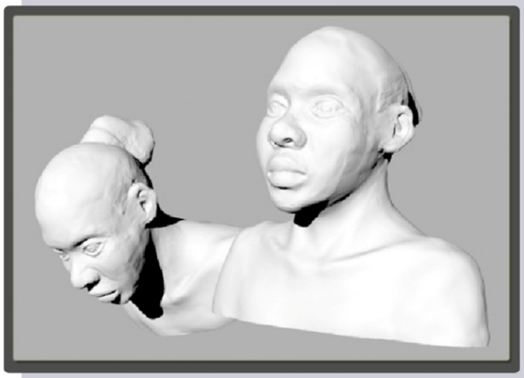
DIMENSIONS: 30cm (Height) X
25cm (Width) X
20cm (Breadth)

SURFACE TEXTURE:
Smooth surface with low reflection

LIGHT SOURCE:
Artificial Fluorescent

FORM: Free-form

### TEST SCAN 1: SUCCESSFUL



SESSION

This artefact has limited detailed areas therefore required minimal calibration. The reduced file size allowed for easy post scanning repairs and speedy .STL file conversion.

SCANNING TIME: 1 hour

# RESULTS

## Test Scans

### TEST SCAN 2

ARTIST:
Anton van Wouw

TITLE:
"Lehmhans-The Postman"
(n.d.)

**DATA**

MATERIAL: CAST BRONZE

DIMENSIONS: 52cm (Height) X
14cm (Width) X
14cm (Breadth)

SURFACE TEXTURE:
Smooth surface with medium reflection and some oxidation

LIGHT SOURCE:
Artificial Gallery Pod Lighting

FORM: Detailed Free-form

### TEST SCAN 2: UNSUCCESSFUL

No Results

**SESSION**

Initial positioning features scanned easily, however the surface area was too detailed even when set at high resolution detection. As a result a minimum default surface size measuring 20cm X 20cm is needed.

SCANNING TIME: 40 minutes

# RESULTS Scanning Sessions

## SCAN 1

ARTIST:
Edoardo Villa

TITLE:
"Torso" (1968)

### DATA

MATERIAL: CAST BRONZE

DIMENSIONS: 44cm (Height) X 24cm (Width) X 26cm (Breadth)

SURFACE TEXTURE:
Smooth surface with medium reflection

LIGHT SOURCE:
Artificial Gallery Pod Lighting

FORM: Geometric Free-form

## SCAN 1: SUCCESSFUL

### SESSION

The positioning points were difficult to detect; this could be due to a combination of lighting source and the limited 32-bit processing power. Gauging the scanning process requires constant eye adjustment between object and monitor.

SCANNING TIME: 1 hour

# RESULTS

## Scanning Sessions

### SCAN 2

ARTIST:
Maureen Vivian Quin

TITLE:
"Genesis II" (1984)

DATA

MATERIAL: CAST BRONZE

DIMENSIONS: 59cm (Height) X
33cm (Width) X
25cm (Breadth)

SURFACE TEXTURE:
Smooth surface with low reflection

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Free-form

### SCAN 2: SUCCESSFUL

SESSION

Scanned areas that joined or formed sharp edges were not detected by the laser. The reflectivity of the fluorescent lighting disrupted the recording process. Areas where the light was more diffused scanned more easily.

SCANNING TIME: 1 hour

# RESULTS

## Scanning Sessions

### SCAN 3

ARTIST:
Rhona Stern

TITLE:
"Abstract Animal Head"
(n.d.)

DATA

MATERIAL: CAST BRONZE

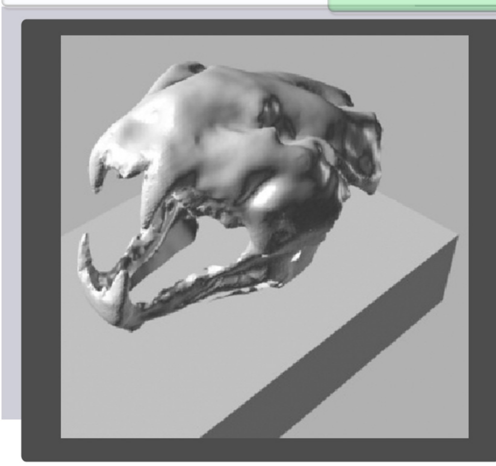
DIMENSIONS: 24cm (Height) X
19cm (Width) X
16cm (Breadth)

SURFACE TEXTURE:
Smooth and rough surface with medium reflection

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Free-form

### SCAN 3: SUCCESSFUL



SESSION

Difficulties arose due to the laser being unable to detect the inside surfaces and deep folds on the skull. This sculpture frequently had to be moved around as surface areas closer to the base were difficult to detect.

SCANNING TIME: 1 hour

# RESULTS

## Scanning Sessions

### SCAN 4

ARTIST:
Sydney Alex Kumalo

TITLE:
"Madala" (n.d.)

DATA

MATERIAL: CAST BRONZE

DIMENSIONS: 47cm (Height) X 14cm (Width) X 16cm (Breadth)

SURFACE TEXTURE:
Rough surface with low reflection and some oxidation

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Free-form

### SCAN 4: SUCCESSFUL

SESSION

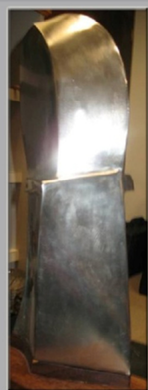
The first scanning session was interrupted by technical difficulties. As a result all information was lost. The second session was successful, but limited surface areas in sections of the sculpture were difficult to detect.

SCANNING TIME: 2 hours

## RESULTS

# Scanning Sessions

## SCAN 5



ARTIST:
Michael Henry Keith Edwards

TITLE:
"Helmet" (n.d.)

### DATA

MATERIAL: STAINLESS STEEL

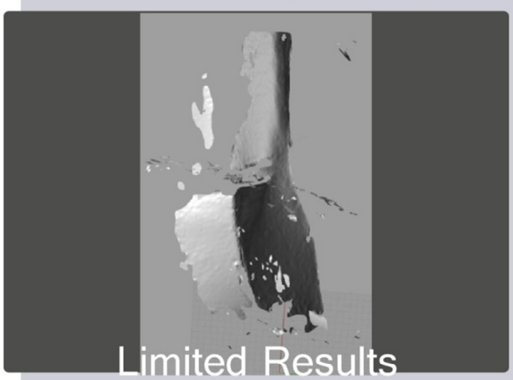
DIMENSIONS: 52cm (Height) X 14cm (Width) X 18cm (Breadth)

SURFACE TEXTURE:
Smooth surface with high reflection

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Geometric Form

## SCAN 5: UNSUCCESSFUL


Limited Results

### SESSION

The high reflective surface of this sculpture disrupted the scanner's laser detection. Light infractions from the reflective surface caused some surfaces to be misplaced.

SCANNING TIME: 1 hour & 30 min

# RESULTS
## Scanning Sessions

### SCAN 6

DATA

ARTIST:
Maureen Vivian Quin

TITLE:
"Shackled Man" (1985)

MATERIAL: WOOD

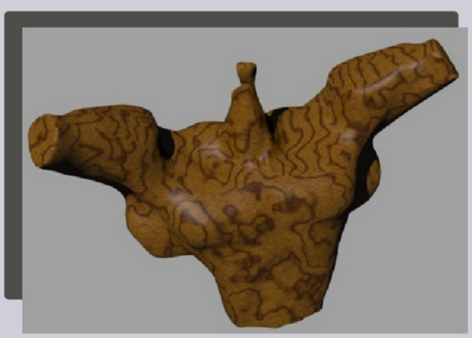
DIMENSIONS: 30cm (Height) X
20cm (Width) X
16cm (Breadth)

SURFACE TEXTURE:
Smooth surface with low reflection

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Free-form

### SCAN 6: SUCCESSFUL



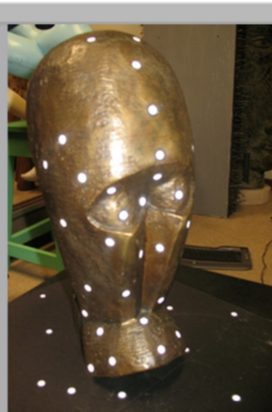
SESSION

Fluctuating surface areas and deep recesses were difficult to detect.Moved the artwork around, and this proved to be a productive method of scanning. The movement has to be done between activations of the scanner.

SCANNING TIME: 2 hours

## RESULTS Scanning Sessions

### SCAN 7



ARTIST: Ezrom Kobokanyo Sebata Legae

TITLE: "Head of a Wise Man" (1938)

**DATA**

MATERIAL: CAST BRONZE

DIMENSIONS: 37cm (Height) X 17cm (Width) X 54cm (Circumference)

SURFACE TEXTURE:
Slighty rough surface, somewhat reflective.

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Geometric Free-form

### SCAN 7: SUCCESSFUL

**SESSION**

In this scan the positioning features were placed all over the artefact and moved when needed. This process seems to work when a particularly difficult curve or undercut is scanning difficultly.

SCANNING TIME: 1 hour

## RESULTS

## Scanning Sessions

### SCAN 8

ARTIST:
Laura Rautenbach

TITLE: "Hamlet"

DATA

MATERIAL: CAST BRONZE

DIMENSIONS: 52cm (Height) X
34cm (Width) X
67cm (Circumference)

SURFACE TEXTURE:
Slighty rough surface, somewhat reflective.

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Free-form

### SCAN 8: SUCCESSFUL

SESSION

The surface areas of this artwork varied greatly. Detailed areas around the face had to be scanned in high resolution which left very little calibration space for the larger areas.

SCANNING TIME: 1 hour, 40 minutes

# RESULTS

## Scanning Sessions

### SCAN 9

ARTIST:
Louis Le Sueur

TITLE:
"Grenade Head"

**DATA**

MATERIAL: CAST BRONZE

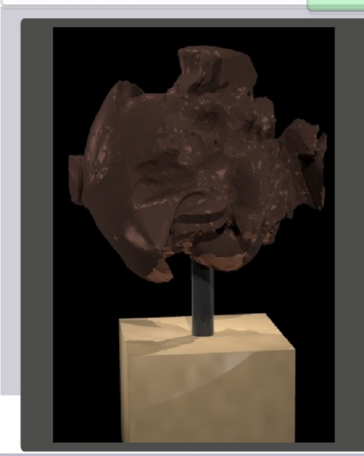
DIMENSIONS: 22cm (Height) X
16cm (Width) X
48cm (Circumference)

SURFACE TEXTURE:
Rough surface and oxidation somewhat reflective.

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Free-form

### SCAN 9: SUCCESSFUL



**SESSION**

This artefact contained areas with irregular joints and deep set surfaces. Despite these anomalies, the scanner was able to detect most of the surface grooves and roughness. Deep set surfaces were detected separately.

SCANNING TIME: 2 hours

# RESULTS

## Scanning Sessions

### SCAN 10

ARTIST:
George Jahdkowshi

TITLE:
"Mask" (1962)

DATA

MATERIAL: COPPERPLATE

DIMENSIONS: 12cm (Height) X 22cm (Width) X 32cm (Length)

SURFACE TEXTURE:
Smooth surface with oxidation minimal reflective qualities.

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Geometric shapes

### SCAN 10: SUCCESSFUL

SESSION

The joints in this copperplate piece were extremely sharp. These were hard to detect with the scanner.

SCANNING TIME: 1 hour

# RESULTS  Scanning Sessions

## SCAN 11

ARTIST:
Rhona Stern

TITLE:
"William"

### DATA

MATERIAL: BRONZE CAST

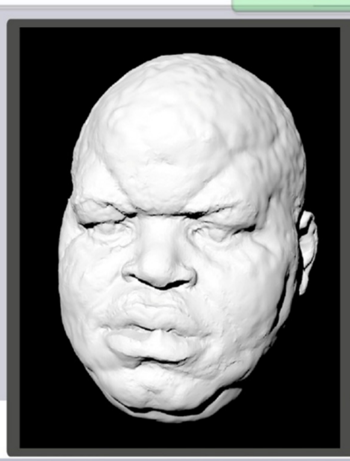
DIMENSIONS: 25cm (Height) X
19cm (Width) X
90cm (Circumference)

SURFACE TEXTURE:
Rough surface with oxidation and minimal reflective qualities.

LIGHT SOURCE:
Artificial Fluorescent Lighting

FORM: Organic Form

## SCAN 11: SUCCESSFUL



### SESSION

This artefact scanned very successfully despite its rougher texture. Areas where joints interacted needed some post-scanning re-engineering. The texture was captured by scanning in high resolution.

SCANNING TIME: 1 hour,30 minutes

# RESULTS
## Scanning Sessions

### SCAN 12

ARTIST:
Joel Noosi

TITLE:
"Old and Young"

**DATA**

MATERIAL: JACARANDA WOOD

DIMENSIONS: 130cm (Height) X
28cm (Width) X
57cm (Length)

SURFACE TEXTURE:
Smooth and rough areas with medium to high reflection

LIGHT SOURCE:
Artificial Gallery Pod Lighting

FORM: Organic Free - Form

### SCAN 12: UNDETERMINED


**SESSION**

Due to the size of this artefact the scanning had to be divided into several sessions and pieces. Ideally the area of the artefact chosen for scanning should be within a certain cubic measurement, i.e. 50cm X 50 cm.

SCANNING TIME: 7 hours (13 sesions)

### 4.6 Oliewenhuis Art Museum's Sculptural Artefacts

This project was launched in conjunction with Oliewenhuis Art Museum, the National Research Fund of South Africa and the Central University of Technology, Free State, to promote the use of 3D scanning technology in the documentation of sculptural works of art by a single user with the eventual goal of promoting 3D data acquisition as a viable tool in future Cultural Heritage applications; i.e. the development of a web-based interactive platform and archive.

**Figure 4.6)** The 13 sculptures selected from Oliewenhuis Art Museum for 3D data acquisition, processing and preservation.

As mentioned in chapter 3, the development of scanning technology has been vast since the above projects were launched in 1997, 2002, and 2001 respectively. Scanning systems are still being developed by research teams with specific data acquisition needs, but overall the commercial market has produced a range of reliable, state-of-the art 3D data capturing instruments which are predominantly meeting project goals according to Pezzati et al. (2009: 2). With the acquisition of the ZCorporation Z Scanner® 700, the Central University of Technology (CUT) recognized the important archival implications which can be performed using a 3D scanner known for its ease of use and portability. As with the Minerva project discussed in chapter 3, this project aimed to create a general awareness amongst CH institutions and establishments and provide them with relevant information to stimulate the growth of 3D data acquisition use. Ten sculptural works were chosen, with the addition of 3 test cases, to represent the technical challenges and limitations of the technology as well as experimenting with structural complexities and the different surface qualities of the art works.

The first scan of this study was performed as a test case in a laboratory environment (see figure 4.23). The procedural process for the scanning system setup were also divided into six  steps during this scanning session as it was a preparatory exercise before attempting the scanning procedure in a gallery environment. It is important for an individual user to record each process as no team correspondence or support will be available in terms of technologies and procedures. The setup steps were divided as follows;

- Step 1: Connection from scanner to computer to power supply via fire wire and power cable. (The order of connection is imperative.) The scanner may also require calibration before a scan can be executed.
- Step 2: Ensure 360º of movement space around target object.
- Step 3: The placement of positioning targets 2 – 4 cm apart in a triangular pattern on the surface of the sculptural artefact.
- Step 4: An initial scan of the positioning features – a setting activated within the scanner's accompanying software and then performed by the user. Maintaining a distance of approximately 50cm from the object whilst rotating around and moving the scanner up and down. This motion is continued until all positioning features (targets) appear on the screen.
- Step 5: Main surface scan of the sculptural artefact – a setting activated within the software and then performed by the user. A distance of approximately 40cm from the object is maintained with the scan first performed in low resolution and then the surface detail is captured in high resolution. When the scan reaches roughly 60% calibration it is discontinued to preserve memory space. If the object is not scanned in its entirety, another session is engaged and the scanning is continued in parts.
- Step 6: The editing and smoothing of recorded facets – an editing feature activated within the scanner's accompanying software. A preliminary data fix is performed and the facets are saved as an STL (stereolithography file).

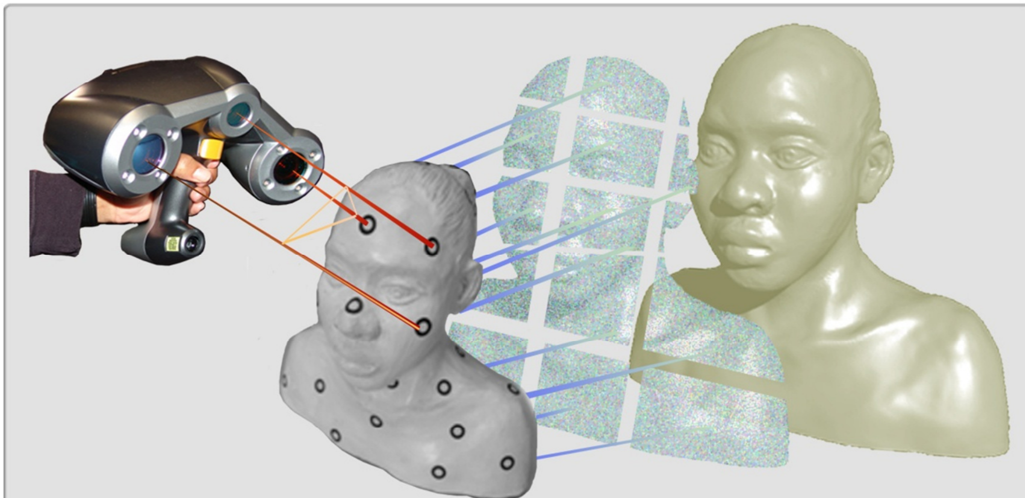


**Figure 4.7)** The procedural steps as developed on Test Scan 1.

### 4.6.1 Case Study 1: Edoardo Villa – “Torso”

Edoardo Villa’s “Torso” was the first sculpture selected for the project and is perhaps the most recognizable piece. Its geometric composition and size presented a good platform for procedural experimentation in a gallery environment. An initial recording failure due to limited RAM led to a second recording session which proved that a sculpture within the scanning software’s boundary box of 50cm X 50cm can be recorded in one session. More importantly, the age of the sculpture warranted a closer analysis of the surface to verify the artist’s tool marks and process as with Rushmeier et al. (2002: 60). Historical sculptural pieces such as “Torso” also require Pezatti et al.’s (2008: 8) surface analysis to determine how the aging process is compromising the integrity of the artefact. 3D recording at this stage also provides a restoration ‘check point’ to preserve the surface quality for future restorations. In total, this session attributed two and a half hours to the projects total of 22 hours of scanning time and 5 hours to the project total of + - 60 hours of post-scanning processing time.

**Figure 4.8 a)** Edoardo Villa – “Torso”1920 (bronze on wooden stand) **b)** Rendered model of “Torso”.

### 4.6.2 Case Study 2: Rhona Stern – "Abstract Animal Head"

The complex surface folds and smaller detail evident in "Abstract Animal Head" presented the prospect of proving the efficiency of using a handheld device such as the ZCorporations ZScanner800©. This portable 3D scanner is able to reach the complexities apparent in a free-form surface without the obvious physical constraints of automated scanning systems. Automated scanning systems such as the one used in the *Digital Michelangelo Project* requires a second scanner mounted on a digitized arm with a pre-determined path. The scanner mounted to the digitized arm also proved very sensitive to vibrations according to Pezatti et al. (2008:8) and the technicians had to evacuate the immediate area in order not to disturb the scanning process. Handheld, portable 3D scanners offer the researcher a larger experimental scope which is fully controlled by the user. In this scanning session the more detailed sections had to be scanned several times in various directional strokes to capture all the angles of the smaller features. The detail also had to be captured in High Definition (HD) which required more RAM and storage space. This session contributed 1 hour to the project total scanning time and 4 hours to the processing time.

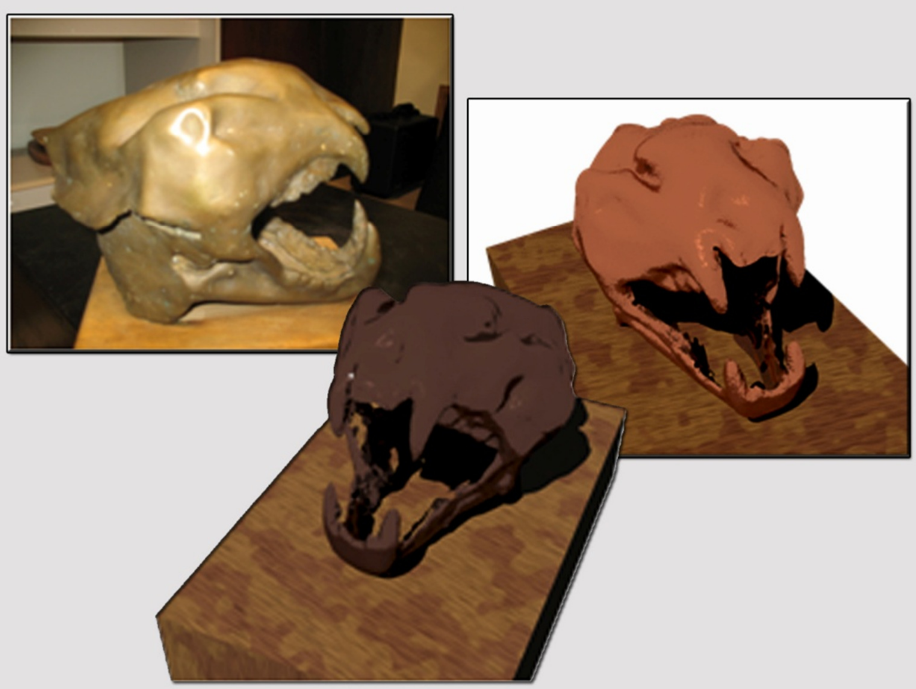


**Figure 4.9 a)** Rhona Stern – "Abstract Animal Head" (bronze)
**b & c)** Rendered model of "Abstract Animal Head".

### 4.6.3 Case Study 3: Sydney Alex Kumalo – "Madala"

The light sensitive sensor attached to 3D scanners acquires the detail of an object by illuminating the object and determining the shape of the object by measuring its location in relation to its baseline and angles according to Rocchini et al. (2001:4). The surface area, material and reflectivity in a sculpture such as Sydney Alex Kumalo's "Madala" (figure 4.26) provides a good control specimen to determine which objects consisting of specific material characteristics causes the indistinct return of the scanner's initial illuminating light source because of elevated reflectivity. These objects often require multiple scanning sessions under varying lighting conditions to capture surface detail. In the case of "Madala", the solid nature of the sculpture allowed for it to be moved circularly during the scanning session and therefore avoiding problem surface reflectance areas colliding with problem lighting. The photo capture in the figure below reveals slight areas of reflectivity as light returns from the surface.  These reflectance anomalies of the sculpture attributed to the scanning session's overall time which amounted to two hours. Processing of the scanned data revealed that the simple base of the original sculpture is easily recreated by 3D modelling to the specific measurements.

**Figure 4.10 a)** Sydney Alex Kumalo – "Madala" (bronze on wooden stand) **b & c)** Rendered model of "Madala".

### 4.6.4 Case Study 4: Maureen Vivian Quin – "Genesis II"

The complex surface variants evident in Maureen Vivian Quin's "Genesis II" (figure 4.27 below) and the composition of two figures allows for a similar analysis of the artist's process and the development of the artwork as with Rushmeier et al. (2002: 59)'s analysis of Michelangelo's Pieta. The figures can be separated and the sections overlapping can be separated within the virtual environment of the digitized object. In a digital capacity, the artwork can be viewed from angles not physically possible in a traditional gallery environment. The artist process can also be digitally mapped or recreated (Rushmeier et al. 2002). In terms of the scanning process, however, the overlapping figures proved problematic and various directional scans were operated in high definition. In total the session required 2 hours of continual scanning and later processing required a significant amount of surface correction.

**Figure 4.11 a)** Maureen Vivian Quin – "Genesis II" 1934 (bronze on wooden stand) **b & c)** Rendered model of "Genesis II".

### 4.6.5 Case Study 5: Maureen Vivian Quin –"Shackled Man"

Rushmeier et al. (2002: 60) describes the scanning process as the acquisition of multiple, overlapping surface scans; these individual scans are then registered together and re-meshed to obtain one seamless geometric model. With a handheld scanner such as the Z Scanner® 800, this process still applies, but is accelerated to occur in one process of data acquisition, activated and controlled by the user. Multiple overlapping scans are therefore necessary to filter out small high frequency components evident in more complex or larger surfaces assembled in a structure such as Maureen Vivian Quin's "Shackled Man" (figure 4.12). The whole process is controlled by the user and a scanning 'path' can be coursed or altered as the data appears on the screen. The "Shackled Man" has seamless relatively smooth surface features and scanning was unproblematic. The session lasted 45 minutes and processing amounted to one hour and 30 minutes.

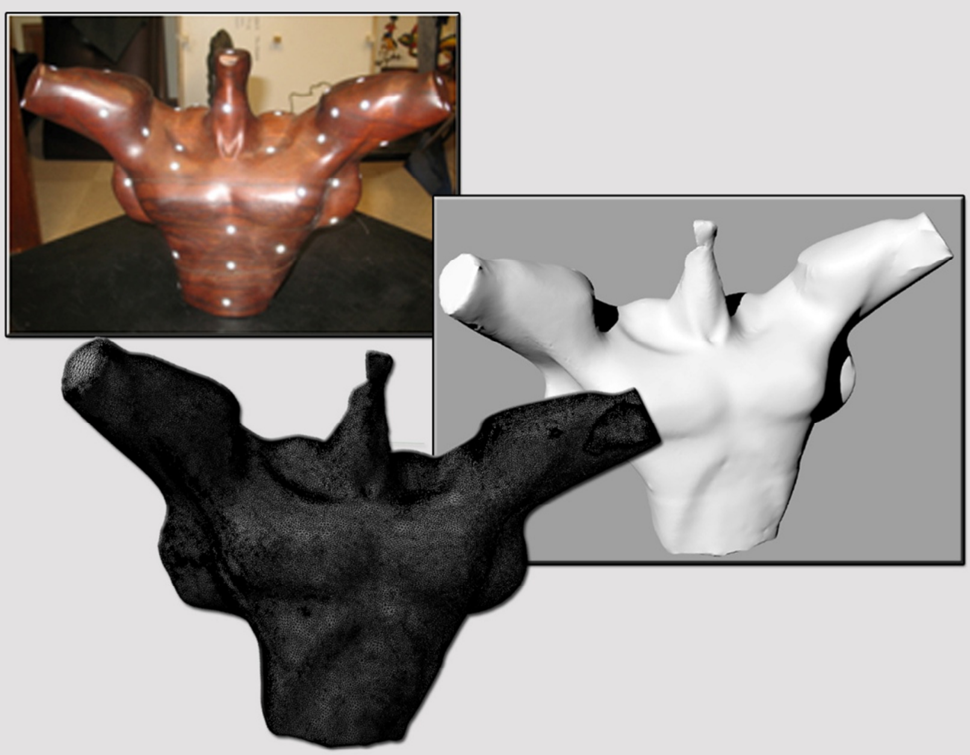


**Figure 4.12 a)** Maureen Vivian Quin –"Shackled Man" 1934 (wood section) **b & c)** Rendered model of "Shackled Man".

#### 4.6.6 Case Study 6: Ezrom Kgobokanyo Sebata Legae –"Head of a Wise Man"

As with Dellepiane et al. (2008: 2185)'s digital models, each session in this study proved methodological in as much as planning and adopting innovative ways to digitally record and create a digital recording process. Models such as Ezrom Kgobokanyo Sebata Legae's "Head of a Wise Man" can be used in comprehensive art-historical studies, including the artistic significance, the historical reference, and the scientific data. In this session, "Head of a Wise Man" was placed on a base or target mat consisting of an opaque surface board with positioning targets already permanently placed and forming the base of the scan. Positioning targets were also conserved on this scan as the session was paused to reposition the targets after every routed 'sweep' of the scanner. This method proved highly effective for the sharper edged surfaces evident in the figure below. When a problematic area was identified the session was paused and targets moved to re-address the area. Although more time-consuming, the process offered effective results. The total scanning time was 2 hours with an addition hour for target re-positioning.

**Figure 4.13 a)** Ezrom Kgobokanyo Sebata Legae "Head of a Wise Man" 1938 (bronze) **b & c)** Rendered model of "Head of a Wise Man".

#### 4.6.7 Case Study 7: Laura Rautenbach – "Hamlet"

The surface of Laura Rautenbach's "Hamlet" represents a very archetypal case. With most bronze surfaces, the chromatic variations may cause slight disturbances with the laser scanner's illuminating sensor. These surface reflectance anomalies can be avoided to some extent by locally adjusting the light source intensities and varying the positions of the physical artefact. A bronze surface does however translate well into a digital model if it is recorded successfully. The Digital Michelangelo Project afforded Dellepiane et al. (2008:2182) an opportunity to report on the traces of Michelangelo's workmanship on David. The success of the "Hamlet" scanning session also proved illuminating in regards to deposits and strains on the surface of the sculpture demonstrating Laura Rautenbach's creation process and giving the digital model a very authentic aspect. This session lasted 1 hour in continual scanning time.

**Figure 4.14 a)** Laura Rautenbach – "Hamlet" bronze)
**b)** Rendered model of "Hamlet".

### 4.6.8 Case Study 8: Louis Le Sueur – “Grenade Head"

The complex detail of “Grenade Head” (figure 4.31) not only proved exigent when scanning, but the oxidation manifesting on the bronze statue may lead to some detail erosion and prove compromising to the physical artefact in the future. A digital replica at this point of the sculptures lifespan may prove very beneficial to future restoration and documentation. Most of the detail had to be scanned in high definition which contributed to storage memory. The asymmetry of the surface compositional characteristics of the sculpture was part of the reason for its selection into the study and proved very edifying in terms of the scanner’s detection of surfaces at different levels of distance. It was also found that when a surface was not detected properly positioning features can be moved around and will still be detected even after the designated positioning feature scan. “Grenade Head” was also the smallest sculpture in the study and a prime example of the benefits of handheld, plug-and-play scanning without a pre-determined path. This session contributed 1 hour to the project’s total scanning time and processing amounted to 3 hours due to the high definition data acquired.

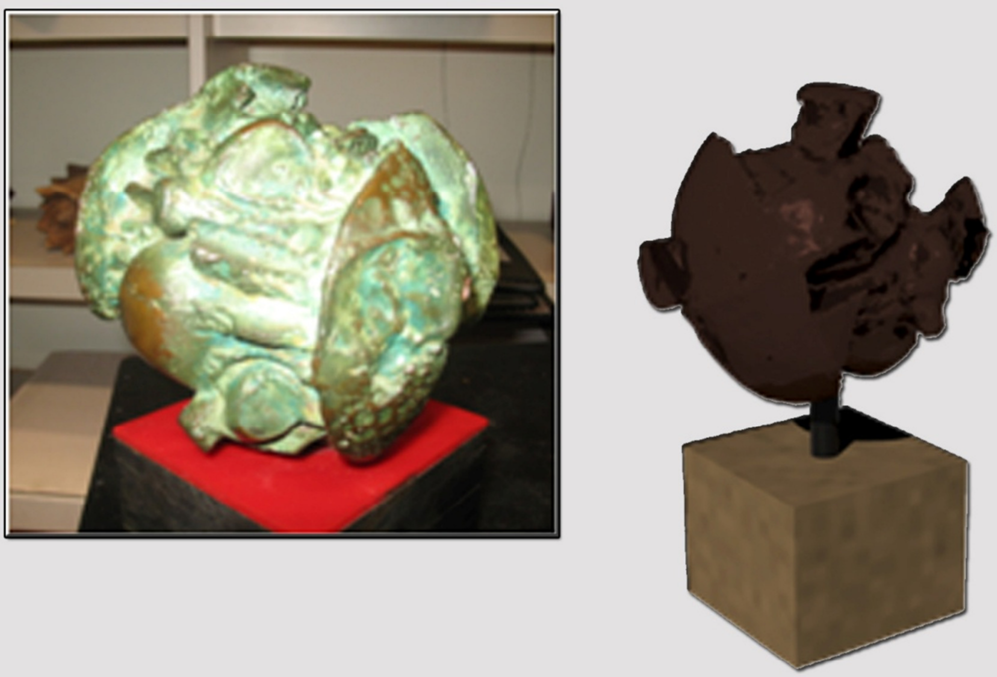


**Figure 4.15 a)** Louis Le Sueur – “Grenade Head” (bronze)
**b)** Rendered model of “Grenade Head”.

### 4.6.9 Case Study 9: George Jahdkoshi – “Mask”

George Jahdkoshi’s “Mask” was chosen for the project because of the planar constraints in terms of the inhibited space of the artwork. As with Ezrom Kgobokanyo Sebata Legae’s “Head of a Wise Man”, Jahdkoshi’s “Mask” was placed on a base target mat. The mat forms part of the scanned information acquired and is later edited out in post-processing. Adding a target object or mat to the intended object allotted for scanning is a technique often used to capture levels of detail or LOD at the edge or precipice of the goal artwork. The process of eliminating the unnecessary scanned information generated from a target object should be minimal and the target object is usually geometrically simple in shape to assist the process. Jahdkoshi’s “Mask” did however have a pointed fold at the assembly point between the target mat and artwork which resulted to the subsequent loss of surface detail. Sharp variants in surfaces can cause this difficulty. This scanning session lasted 1 hour in total.

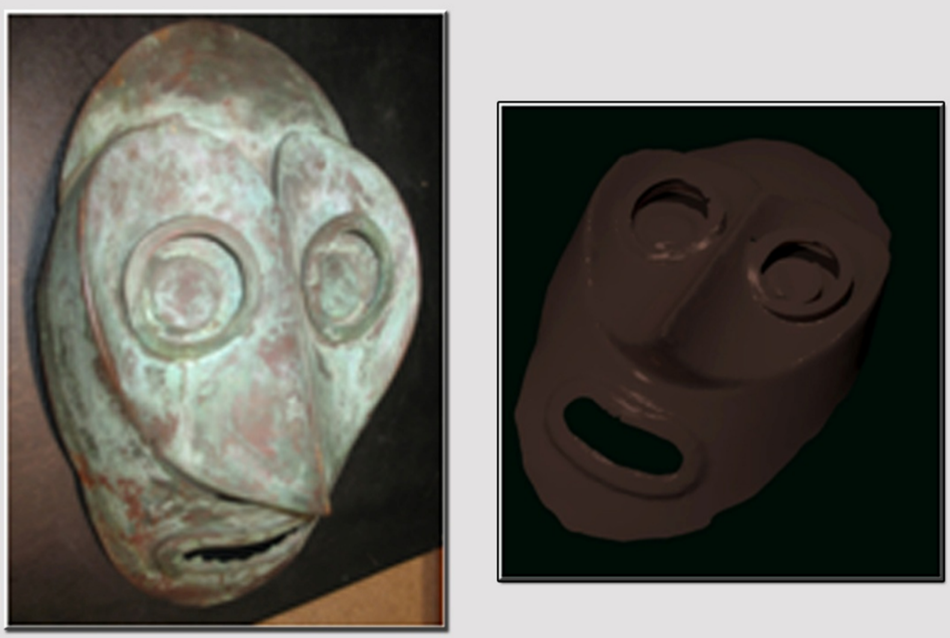


**Figure 4.16 a)** George Jahdkoshi – “Mask” 1962 (copperplate)
**b)** Rendered model of “Mask”.

### 4.6.10 Case Study 10: Rhona Stern – "William"

Berndt et al. (2010: 170) suggests that most 3D objects are related to further metadata, describing the 3D content or its context more precisely. This is specifically the case with Rhona Stern's "William" (figure 4.33) where users viewing the digital replica of the scanned artwork benefit from both a 3D visualization and additional information related to the presented 3D content, for example, a magnified view of the surface LOD. The digital replica does not replace the physical counterpart, but enhances it. Rhona Stern's artistry is very integral to the conceptual content of "William". A digital replica adds to the sustainability and flexibility of the artwork. "William" was specifically chosen for the marked texture of the sculpture. The digital replica of this surface texture allows for scientific analysis and therefore widens its original intention. Scanning time was longer in this session because of the surface detail and was a total duration of 2 hours.

**Figure 4.17 a)** Rhona Stern – "William" (bronze)
**b)** Rendered model of "William".

### 4.6.11 Test Case Studies

The following test cases were selected to test the methodology and technological limited of the project. Remondino et al. (2010: 85) suggests that the technologies and methodologies used for cultural documentation need to allow the generation of very realistic 3D results. This includes quality scans that are as accurate as possible in terms of general geometry and surface texture and LOD.  The models generated need to be versatile and qualitative to be used for many scopes, i.e. archaeological documentation, digital conservation, restoration purposes, VR/CG applications, 3D repositories and catalogues, web geographic systems, and visualization purposes. Conducting test cases prove just as crucial as performing the selected case studies. Test cases demonstrate which areas of research are still open for further development and experimentation. Results yielded may also prove beneficial to the wider spectrum of further applications.

#### 4.6.11.1 Anton Van Wouw – "Lehmhans-The Postman"

**Figure 4.18 )** Anton Van Wouw – "Lehmhans-The Postman" exhibited in Oliewenhuis Art Museum.

Anton Van Wouw's "Lehmhans – The Postman" (figure 4.34) and Joel Noosi's "Old and Young" (figure 4.35) represent the two scale tests performed for this project. In this session 4 positioning features were placed approximately 3cm apart on the head of the figure. The positioning features were scanned, but unfortunately the surface proved too small for recognition by the scanner's illuminating sensor. The scanner's high resolution setting also proved unsuccessful in capturing surface data. With this sample, it was determined that a default size of approximately 20cm X 20cm should be achieved before scanning can commence.

#### 4.6.11.2 Joel Noosi – "Old and Young"

The size tests performed concluded that this specific scanner performs at its maximum technically within an exact size parameter. The scanner's accompanying programme indicates the optimum size of a scan by showing a boundary box. This box measures to roughly 50cmX50cm. Due to the size of this artefact the scanning had to be divided into several sessions and pieces. The detail and curvature of the artefact also determined how large each scanned section should be. In total there was 13 scanning sessions totalling to 45 minutes per scan. The positioning features were constantly moved from section to section as the scan progressed. All facial features, as well as the hands and feet, and the objects held by the figures were scanned in high detail. The assembly of the scans in the processing stage proved problematic as an exact point of meeting between the 3D surface patches should be determined before the 3D content is virtualized. In structured scanning systems, the scanner's path is designed to survey the entire artefact in pre-determined patches. A physical boundary, for example - laser marked points, may need to be included in the setup of a handheld scanning process to assist the user in future alignment.  Careful planning is essential in handling large sculptures in order to protect the integrity of the artwork being portrayed digitally. Large sculptures also signify large data sets which may require additional technological equipment and support.

**Figure 4.19 a)** Joel Noosi - "Old and Young"  **b,c & d)** section of the scanned material of "Old and Young".

#### 4.6.11.3 Michael Henry Keith Edwards – "Helmet"

With active non-invasive optical techniques, the object – in the case Michael Henry Keith Edwards' "Helmet", requires the object to be actively illuminated. As mentioned in chapter 2 laser scanning and active sensors often have difficulty recording an object material which has a significant influence on the acquired data, causing penetrations and bad reflections. The stainless steel surface of "Helmet" coupled with its smooth contours mirrored the scanner's sensor laser beam and led to a scattering of 3D data evident in the collected data snapshot in figure 4.36b.

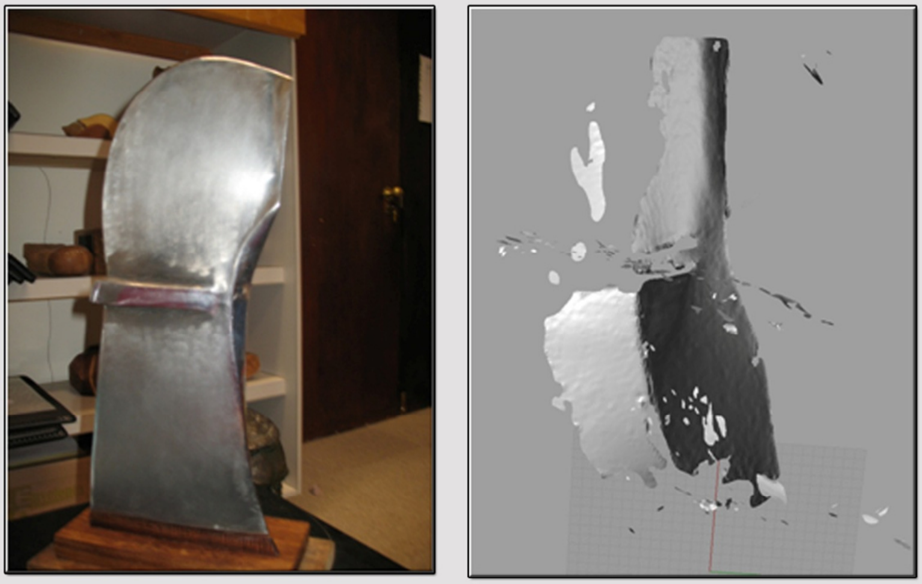


**Figure 4.20a)** Michael Henry Keith Edwards – "Helmet" **b)** Image of the resulting material scanned.

**4.7 Concluding Remarks**

According to the Remondino et al. (2010: 86) new sensors, data capture methodologies and multi-resolution 3D representations are continuously being developed and contribute to projects following these changes. The diagnostic applications in the international projects mentioned in chapter 3 formed a basis for the methodology developed in the Oliewenhuis Art Museum scanning sessions. In contrast to the international cases, the latter scanning sessions solidify non-invasive optical techniques as being particularly suitable for CH artefact virtualization. Pezzati et al. (2009: 14) concludes that the commercial technology available such as the Z Scanner® 700, allows for faster measurements of the shape of artworks with both the high accuracy and high resolution which would make it even more relevant in content for CH applications. These new methods and techniques, together with new modelling software tools also provide researchers with more options. The collaborations founded between traditional preservation methods and 3D data acquisition by the earlier CH 3D projects, namely surface analysis, procedural experimentation, surface alignment, and creating digital preservation checkpoints only strengthen future projects. In addition, Pezzati et al. (2009:14) refers to the models acquired by the 'wisdom' of the past and the technology of the future as high resolution digital objects that are taking a step further into possible 3D archives, virtual museums, or reproduction by means of fast-prototyping (stereo-lithography or electro-erosion). Therefore the knowledge gained through CH projects builds an informative resource not only in 3D model content, but also in 3D data acquisition methodologies and the associated processes.

Case studies reveal that using the ZScanner® 700 for the digital archiving of sculptures presents a plausible portable 3D scanning activity for the museum-based user's archiving activities. An exploration of set parameter variants such as texture, scale, surface detail and light largely determined successful results. The use of a plugged device required some manoeuvring from the user and a cordless scanning device weighing less could in the future facilitate the process. With the average scanning session lasting between 40min and 2hrs guiding a 1.25kg weight became tiresome. The recent launch of Z Corporations 24 bit colour mobile ZScanner® 700 CX presents potential for the improved virtual recording of 3-D artworks destined for digital database development and similar recording applications. However, at present this heavier 1.3kg scanner with improved 50-micron accuracy in the XY axis offers a low colour texture resolution of 250 dpi, which could present difficulty when scanning detailed colour texture surfaces. Therefore, although the ZScanner® 700 CX is destined for the archiving of artworks; its limited colour resolution capabilities and 10-micron improved surface detection does not deem the ZScanner® 700 redundant, as most CAD applications are able to replicate and wrap surface colour and textures (namely, photogrammetry) in preparation for the virtual environment.

Each case study was specifically chosen to introduce data recording variables that challenged the stability of the 3D scanning environment. The exploration of variables such as texture, scale, surface detail and light introduced new strategies to the already complex task of "digitizing reality". Among others scanning strategies such as; logistical environment setup, constant monitor viewing, scale limitations, calibration failure, accurate positioning feature placement, inaccessible internal volumes, sharp edges, complex joins, artefact handling and various surface anomalies were addressed and in most instances overcome.

Currently the market offers a range of 3D scanning technologies suited to various archival or reverse engineering industry applications (discussed in Chapter 2). 3D Scanning technology therefore becomes renewed territory for further product development thereby, introducing various arenas to a diverse range of digital data recording infrastructures.

# CHAPTER 5

## Conclusion and Recommendations

### 5.1 Chapter 1

The research presented reveals the development of 3D scanning technology from large, complex CMM's (Coordinate Measuring Machines) to the current era of image-based portable 3D surveying (Gagne 2006: 66). The accumulative features and properties present in 3D scanning technologies proved pivotal by drawing the awareness of its accuracy, portability, low cost and fast data acquisition (Pezzati et al. (2009: 7) and as a result a number of international projects followed. According to Pezzati et al. (2009: 5) the latest commercial availability of 3D acquisition technologies have made it even more vital for Cultural Heritage diagnostics as it is safe and effective to use on artefacts marked for preservation. The 3D models generated from the acquired data not only protect its physical counterpart, but becomes an enhanced platform for communication through web-based interactive virtual reality applications. All these factors validates 3D scanning as crucial technology for institutions like Oliewenhuis Art Museum who present a need to document and enhance the communicative strategies of their collections. Research presented by Pitikakis et al. (2009: 13) and Remondino et al. (2010: 90) does however; show a general lack of interest from Cultural Heritage organizations that should be viewing 3D data acquisition as a future default approach to documentation. This lack of interest presented an optimal opportunity for the researcher to collaborate with Oliewenhuis Art Museum and the Central University of Technology, Free State and present a basic overview of the developments and technical challenges associated with 3D scanning whilst using state-of-the-art equipment (ZCorp's ZScanner® 700). The ten sculptures selected for scanning have proven the hypothesis. The methodology presented supports the development of 3D scanning technologies by adhering to objectives which ultimately promotes the international collaborative effort of accumulating an unambiguous body of information characterized by the shapes of the artefacts which might be passed down to future generations (Paquet et al. 2006: 3).

### 5.2 Chapter 2

Chapter two presents research to validate the use of 3D scanning technologies across various global Cultural Heritage preservation initiatives. An in-depth overview of 3D data acquisition, processing, and preservation supports the advancement of 3D digitalization in an inter-disciplinary capacity. By examining each facet of 3D scanning, this chapter provided an informative view whilst characterizing the anomalies associated with the various aspects. Four notable global initiatives namely; UNESCO (United Nations Educational, Scientific and Cultural Organization), FLAAR (Foundation for Latin American Anthropological Research), CyArk (part of Ben Kacyra's Family Foundation), and Canada's NRC (National Research Council) were presented as well as their associated projects to offer an international perspective. The future 3D archivist is also made aware of Rizzi et al's. (2010: 88) optimum data acquisition technique properties; i.e. accuracy, portability, low cost, and fast acquisition. The geometric accuracy, photo – realism, automation, low cost, portability, and flexibility of the modelling technique presented by Remondino et al. (2007: 270) as warranted requirements of 3D data can only be established by exposure to efforts portrayed in previous projects. This chapter embodies Koutsoudis et al.'s (2007:8) principle of communication to exchange and discuss methods in order to strengthen and provide guidelines for the future of 'virtual heritage'.

### 5.3 Chapter 3

Chapter three focussing distinctively on the diagnostics of 3D scanning projects, this chapter endeavoured to discuss examples of the virtual documentation of Cultural Heritage (CH) sites. Three international projects, namely; the digitizing of Michelangelo's "David" and "Pieta", and "The Minerva of Arezzo" were analyzed. These cases represented were chosen to demonstrate the significant use of optical 3D scanning techniques and their employ on renowned historical artefacts thus emphasizing their importance, safety and effectiveness. More importantly, however, a parallel was drawn between the abovementioned projects, to emphasize the contrast in time, procedures, subject matter, and technology. The cases presented proved Remondino et al.'s (2010: 86) proposal that the new sensors, data capture methodologies and multi-resolution 3D representations that are continuously being developed contribute to the projects following those developments. Conclusively, this chapter reveals Pezzati et al.'s (2009: 14) finding that the commercial technology available allows for faster measurements with both the high accuracy and high resolution which makes it even more relevant in content for CH applications.

### 5.4 Chapter 4

This chapter aimed to outline a procedural scanning process using the portable ZCorporation Z Scanner® 700, whilst presenting the technological limitations. Results reveal that valuable procedural 3D scanning information was recorded, although portable scanning using the Z Scanner® 700 still presents technological limitations for the digital archiving of sculptures. The plausibility of using 3D scanning technology for a museum-based user was proven. The sculptures chosen for the project not only represented diverse variables such as texture, scale, surface detail and light, but also presented an opportunity for the user to explore scanning strategies such as; logistical environment setup, constant monitor viewing, scale limitations, calibration failure, accurate positioning feature placement, inaccessible internal volumes, sharp edges, complex joins, artefact handling and various surface anomalies. This chapter proves that with each recorded 3D scanning project, the technology becomes renewed territory for further product development thereby introducing various arenas to a diverse range of digital data recording infrastructures and provides access to previously inaccessible arenas.

### 5.5 Recommendations

In the commercial or public environment 3D virtualization translates as a practical goal; a virtual digital model of a Cultural heritage object or site can be interacted with outside of its habitual surroundings. The development of 3D digital archives and virtual museums that can be created by using 3D data acquisition promises the Cultural Heritage researcher of future generations' easy access to a long-lasting virtual inventory of digital models for continuous study long after possible erosion or destruction. The different contexts that can be introduced within this 'reliable' virtual setting allows for treatments pertaining to Computer Aided Restoration (CAR) and over time, it is also possible to obtain data on the object's previous alterations and restorations, which would relate more to scientific research. In a HCI environment, mechanical stresses can be located, the effects of microclimatic variations can be quantified, surface degradation and shape variations can be monitored, and the restoration process can be measured.

Despite all these prospects, Vavalis (2010: 175) from the FOCUSK3D initiative and contributing author of *Heritage in a Digital Era* (2010) predicts that the Cultural Heritage industry may in the near future face a possible hindrance known in computer science as a 'data grave'. A data grave refers to information that is physically present, but nevertheless lost because it is simply not accessible through reasonable efforts. The implementation of more effective ways to handle not only the acquisitioned data, but also the metadata of an object which has been virtualized is an area of research which can only be remedied with awareness. Berndt et al. (2010: 177) suggests that although some CH projects have become aware of the semantic gap and added this information to their workflow, these semantics are not structured around ontology. An open source system of knowledge management (semantic web technology) will provide major benefits in advanced research and reasoning according to Vavalis (2010: 176). Applying this ontology-based semantic metadata paradigm might provide the critical incentives foreseen by Vivalis (2010: 179);

- Boost new research and innovation via the set up of new ways that allow creating, processing, and re-using 3D scientific resources and the convergence of the research agendas in the scientific communities.

- Increase synergy between the scientific community and the professional users of 3D content in applied sectors, to enable a better knowledge transfer to industry and society.

- Help to involve individuals as active creators, mixers and promoters of 3D media.

## 5.6 Conclusion

Impressive levels in realism and possible personalization are constantly being reached by 3D computer graphics according to Dellepiane et al. (2008: 1719) researchers from the Visual Computing Lab in Pisa, Italy. Computer graphic research is constantly improving in the degree of visual fidelity and interactivity capabilities. The above case studies and subsequent research has proven that the Cultural Heritage diagnostic applications have been infinitely amplified and its implications widened with the advent of 3D data acquisition and scanning technology. Results from the projects discussed in this research concluded and concurred with Remondino et al.'s (2010: 98) proposal that image-based 3D documentation with active optical sensors, spatial information systems, 3D modeling procedures, visualization, and animation software is still in a developmental stage presenting even greater prospects for the future of 3D surveying in Cultural Heritage applications. The potentialities of 3D scanning technologies for the documentation, preservation, and virtualization of our heritages therefore warrant its continual research.

A basic overview of the developments and technical challenges surrounding 3D scanning was provided with the appropriate research applied to the ten case study sculptures from the Bloemfontein Oliewenhuis Art Museum's permanent collection. The selection represented a sample of textures, surface qualities, scale and complexity of shape. The results focussed on metadata diagnostics and 3D data acquisition. This overview promotes the exposure of various industries to the use of scanning technology and its relevancy in future trade collaborations (i.e. concurrent engineering, design and manufacture).

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