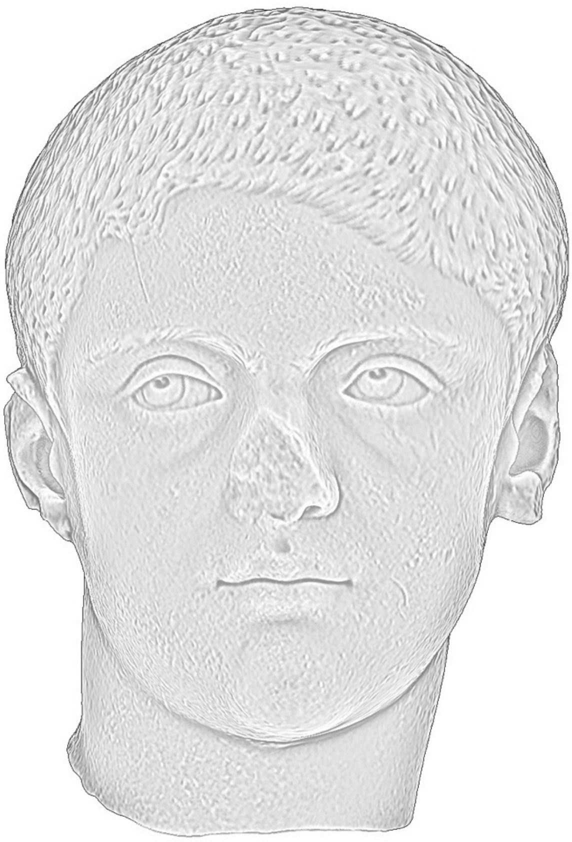
APPLICATIONS OF DIGITIZATION TO MUSEUM COLLECTIONS MANAGEMENT, RESEARCH, AND ACCESSIBILITY



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ABSTRACT

Over the past few decades, digital methods of documentation and exhibition have been becoming ever more popular in museums. As technologies advance, so too do the implications for museum digitization. This thesis provides a glimpse into the current atmosphere of museum digitization, proposes new applications for digital documentation and propagates these themes through the development of a case study. Applications of digital documentation and visualization to collections management, scientific research and dissemination are investigated. Among the foremost objectives of this thesis is to convey the manners in which digitization can give further value to museum specimens and unlock their potential to answer scientific and social questions.

Within this thesis, the capacity for 3D models to make data more accessible, extend research methods and forge new relationships between researcher and subject are highlighted. Applications in museum collections management are also explored, especially how these methods aid collections staff in monitoring and conserving specimens for future study and diffusion. In terms of dissemination, issues of 'universal collections', virtual exhibits and digital repatriation are addressed. The propensity for digital visualizations to convey intangible aspects of cultural heritage and embody personal memories and experiences are duly probed.

The work culminates in a case study, which follows the digital acquisition and creation of a 3D model of a classical Roman portrait from the collections of the Ny Carlsberg Glyptotek in Copenhagen. Both a technical and theoretical work, the case study underscores the potential uses of 3D models as canvases upon which to gather, project and juxtapose different kinds of scientific data. The case study is specifically developed to emphasize and create discourse concerning how 3D models can supplement or surpass current polychromy study techniques.

KEYWORDS:

3D models; digital acquisition; digital cultural heritage; digital documentation; digital repatriation; digitization in museums; intangible cultural heritage; laser scanning; museum collections management; MeshLab; museum research; Ny Carlsberg Glyptotek; sculptural polychromy; universal collections

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PERSONAL MOTIVATION

The purpose of museums is manifold. Most visibly, one of the main functions of museums is to foster education. Museums promote education directly through exhibition and museum-based education initiatives (pamphlets, tours, class activities, on-site discovery rooms, traveling exhibits on wheels, and community outreach—just to name a few). Museums have long been regarded as centers for learning and remain consistently visited by young school groups and established scholars alike. There is no doubt that museums play a large role in educating, capturing the imagination of and inciting critical thinking in society.

When you walk the exhibition halls of a large museum, odds are that you will only gain a glimpse into 10% or less of their holdings. The majority of museums' collections are held in storage. Here fragile and scientifically significant specimens are cared for and maintained by staff focused on their preservation. Museum collections conservation and management is a science battling deterioration caused by light, gravity, and chemical reactions to ensure the continuity of cultural heritage. The collections staff also has the responsibility of making collections available to researchers through either visitation or loan. This encompasses the second main function of museums as repositories for and stewards of cultural artifacts.

For two years following my graduation from college, I worked within the collections and archives of a large natural history museum in New York. At the American Museum of Natural History, I was fortunate enough to tour several different divisions and become acquainted with various collections spaces, staff and systems of archiving, cataloging and housing. Walking among the cabinets and shelves of collections areas nestled in old courtyards and attics, my interest in and passion for collections management and museology was spurred.

I encountered many treasures waiting to be rediscovered: hand drawn maps and fieldnotes yellow with age and laden with a distinct film of dust, cabinets with drawers that hadn't been pulled opened since a researcher had last inspected their contents (and hastily forgotten their notes, newspaper and perhaps an orange peel) thirty years ago, shelves filled with fossils collected by overzealous paleontologists of the early 20^{th} century still cloaked in field jackets waiting to be exhumed...

Despite professional and forward-thinking collections management staff, the potential of collections, for the most part, lies locked up in the cabinets along with the specimens. They are accessible to only as many researchers as a museum's collections staff can accommodate via visit or loan.

My first year in pursuit of a Master's degree at Lunds universitet put my experiences into perspective and led me to grow ever more intrigued by cultural heritage management and preservation. In a course in digital archaeology (ARKN08: Digital arkeologi), I found the means to unlock the potential of the collections to which so few have access. Digital forms of documentation and visualization are capable of standing as implements in the toolkit of collections management staff, enabling them to best organize, preserve and make their collections not only accessible, but also highly functional to both researchers and the public.

My aim in writing this thesis is to make a practical analysis of the multiple applications of digital documentation within the field of museum studies, with an emphasis on collections management, research and dissemination. I will look to recent and current examples of digitization within the museum community and develop a small case study of my own to offer a primary example of the potentialities of 3D models in this arena.

CHAPTER 1.
INTRODUCTION

BACKGROUND

As technology has rapidly advanced, so have many museums endeavored to employ newly available methods of organization, presentation, and education to their exhibits. Museums with extensive exhibition websites and mobile apps are on the forefront of a paradigm shift in the manner of representing collections. Recently, digital initiatives have proven effective in kindling the public's interest in and interaction with museums. Visitors are also taxpayers, proponents, and potential benefactors and therefore standing in a positive light with visitors can help boost museum accreditation in many realms. Digital elements of exhibition serve as a means of communicating with and evoking enthusiasm in a museum's largest target audience (Wachowiak and Karas, 2009; Baker, 2011; Westin, 2011). In the past, the propensity of museums to invest in digital forms of exhibition has been higher than that of digital forms of documentation to general collections for this very reason.

Although digital methods of documenting museum specimens for collections-based scientific research have been less explored, they are certainly no less imperative. The two main functions of museums are not mutually exclusive and digitizing museum specimens and their associated data can only serve to propagate both: cultivating education and preserving cultural history (Baker, 2011). Over the past decade, many museums have taken strides to incorporate digital methods of documenting their collections (Library of Congress, 2002, 2011; Smithsonian Institution, 2007, 2010, 2011; Madden, 2008; American Museum of Natural History, 2011; etc.). Digital documentation in terms of collections encompasses a broad definition depending on collection type. It has proven a blanket term that has been used to describe anything from computer data input (transcribing information from catalog cards into an electronic database), to digital photography to the creation of virtual reality systems and everything in between. Simply put, digital documentation encompasses collection, processing and integration of data through different digital scopes in order to yield a comprehensive representation of an object, the context in from which it originated and the capacity it has to impact to other fields of scientific research (UNESCO, 2003a).

Electronic collections and archive databases are quite common in museums. Entries for specimens are not always complete (containing data from all sources) and as a result strides to fill in the blanks and include digital images and document scans are being undertaken. These kinds of digital projects: data migration, imaging, and georeferencing, are essential steps in the process of building comprehensive digital databases. Such databases connect information originating from many different sources and thus are fundamental in setting a solid foundation upon which 3D models and virtual reality systems can be built to retain the context of the actual object. Digital documentation has multi- and inter-disciplinary implications. It can be applied in every field, from archaeology to ornithology to paleontology to organize collections and forge new frontiers in research (Bates et al., 2010).

In every field of museum science, some of the most important information regarding a find is generated at initial discovery in the field. When a specimen is collected, it is taken from the context that gives it meaning. Digital techniques offer a means to preserve these important contexts (Westin, 2011: 49). One discipline in which both museum and field-based research have embraced digital methods of documentation is archaeology (Evans and Daly, 2006; Campana and Remondino, 2007; Rua and Alvito, 2008; Frischer, 2008, 2009; Doneus et al., 2011; Fanini et al., 2011; etc.).

Archaeology, a mix of science and narrative reconstruction, attempts "to draw a coherent picture that encompasses both human meanings and general processes" (Zubrow 2006: 10). Here digital methods have the ability to operate as a form of mediation between these two contradictory qualities of archaeology. Combining precise scientific data and research based assumption, the development of virtual environments paints a more easily culturally perceived picture of the past than text, figures and tables alone. A new field, digital archaeology, has sprouted from the application of digital methods to the archaeological practice and research.

As will be further explored, the field of digital archaeology provides sound examples of these capacities as well as offers insights into the complications that also arise from conjecture and interpretation common to the science. 3D models in particular hold much potential in this regard. They offer digital carbon copies of specimens, which can be studied, measured, and manipulated in manners that actual artifacts may not. They also present the opportunity for incorporation in virtual reality systems for education, exhibition, and repatriation.

THEORETICAL FRAMEWORK

Museums stand as institutions founded as a means to preserve and convey our natural and cultural history. “As such, they hold a significant part of the ‘intellectual capital’ of our information society. The use of emerging digital technologies to activate, engage, and transform this ‘capital’ is paralleled by shifts in the organizational and practice culture of the institutions entrusted with its care” (Cameron and Kenderdine, 2007: 1). It is equally determined by the attitudes toward what new technologies can yield held by the museum professionals and researchers of the time.

Emerging views of digital developments in the field of archaeology, for example, have been discussed by Zubrow (2006: 11–12). He sums up the situation as being divided into two factions: the first, inhabited by those who view digital developments as methodological and the second as theoretical. The former consider digital methods of documentation as purely another research tool to solve problems “generated by a variety of theoretical narrative concerns” akin to radiocarbon dating, tree-ring dating or the like (Zubrow, 2006: 11). The latter consider digital developments a driving force, inciting and determining the development of new theory. In this vein, technological evolution opens up new realms of possibility never before considered and therefore stimulates new waves of theoretical thought accordingly. To this end, Zubrow (2006: 14) remarks, “Not only is technology relevant for methodology, it is determinative of some aspects of theory.” He also remarks on the opportunity for digital developments to bring us closer to our cognitive past. “Indeed, if one believes that it reconstructs human mental processes it may be a proxy for theory itself” (Zubrow, 2006: 11).

Zubrow (2006: 14–16) offers a discourse on the compatibility of digital technology with archaeological theories. “Post-processual theory and digital technology are incompatible,” he declares (Zubrow, 2006: 14). Where post-processual is interpretive, deconstructive and narrative, he contests that digital is analytical, reconstructive and measured. Here a convergence between cognitive and digital archaeology, with their common reconstructive, hypothetical and experimental qualities can be inferred. The contention that digital archaeology is solely analytical, reconstructive and measured can be argued. Various methods of digital visualization are able to combine the aforementioned characteristics of digital documentation with the interpretive, deconstructive, narrative aspects of post-processual archaeology however. Visualizations present the opportunity for viewers to construct their own cultural meanings and interpretations. "Thus post-processual archaeology provides a context for considering tangible and intangible heritage through new ways of thinking about the landscape context, sense of place, and the embedded nature of the user experience" (Flynn, 2007: 85). Digital visualization can be based on both hard and fast numeric data and on interpretation. In fact, without this interpretive facet it fails to propagate full meaning. What is important to consider is that a balance of the two is what will yield the best results. Interpretive and experimental archaeology, so long as rooted in fact, will always be relevant since archaeology rarely encounters a comprehensive record.

The field of digital cultural heritage is observably still in its formative stages and is not yet served by definitive theoretical underpinnings. Digital cultural heritage has been a subject of much controversy. 3D models and virtual reality systems breach borders and defy conventional definition; in the process they have created quite the epistemological conundrum regarding how knowledge is created, disseminated and regarded. Questions surround the authenticity of digital cultural heritage due to the elaborations and artistic merit taken in the creation of virtual environments and 3D models (Addison, 2000). Scientists have debated what role digital cultural heritage can play in research and education beyond 'edutainment' when the border between observation and elaboration is so easily blurred (Addison, 2000; Lepouras and Vassilakis, 2005; Flynn, 2007).

In fact, the acceptance of digital heritage as a legitimate form of cultural artifact invested with scientific value by those in the field has only just come to fruition.

> It is only recently that digital heritage has accorded status as an entity in its own right. The UNESCO Charter on the Preservation of Digital Heritage articulates this turn by creating a new legacy—the digital heritage: ''resources of information and creative expression are increasingly produced, distributed, accessed and maintained in digital form, creating a new legacy—the digital heritage.'' As a result, digital technology has been largely unmapped in terms of a critical theory for cultural heritage per se, and for heritage institutions. (Cameron and Kenderdine, 2007: 3)

With UNESCO's (2003b) recognition and distinct standards guiding the development of digital heritage, the field's most constructive days lie ahead.

In assessing the role digital forms of documentation, such as 3D models, can play in museum collections management, research and repatriation, one must contemplate how potential users experience these kinds of media and the attitudes they hold toward them. The role of visualization in human cognition and connection has been well documented (Frischer, 2008). This is an important lens through which to view the issue, as it has the ultimate impact on the effectiveness of 3D models and virtual environments. If a user does not perceive the model as practical, the model simply cannot be so.

For a model to be most effective, it must be regarded as an active agent of study and communication, not solely a means of recording. “3D information can be regarded as the core of the knowledge process, because it creates feedback, then cybernetic difference, among the interactor, the scientist and the ecosystem” (Forte, 2010: 11). Here the notions of embodiment, immersion and interaction come in to play (Champion, 2006: chapter 4; Forte, 2010: 9). Forte (2010: 9) considers the success of the model as hinging on the propensity of the model to gain meaning along with the user’s perception; “the object takes shape because of our eco-activity and therefore we and the object take shape together.” Thus the model must be engaging in a way that incites critical and self-reflexive thought. In turn, this cultivates a sense of connectedness between the user and the model, animating it and imbuing it with a whole other dimension.

As discussed, in terms of digital heritage a 3D model should be regarded as an artifact, a true cultural construct, in and of itself. While it retains all of the original significance of the object of which it is a replica, it is also invested with new social and scientific value. A 3D model or virtual reality system is interactive and allows for levels of experimentation and collaborative research not possible with museum objects and most cultural heritage monuments. In that it involves interactive and dynamic objects, digital cultural heritage rouses sentiments on the part of the user distinct from the physical counterparts of which they are a copy. 3D and virtual reality models evoke responses, develop strong impressions and forge new relationships between the user and the cultural material (Flynn, 2007: 85). In this sense digital objects can be viewed as actors influencing human perception and encouraging the formation of new perspectives, interpretations and cultural knowledge.

Cameron and Kenderdine (2007: 1) discuss how media theorist, Marshall McLuhan “argued that new ways of perceiving the world, embedded in knowledge structures and societal transformations, enable the development of tools that emulate new social and theoretical ideas. Thereafter these tools, through technological innovation, have the ability to offer a range of possibilities beyond those originally imagined." Without a doubt, this is the case in digital cultural heritage. Technologies originally created for a myriad of other uses have found relevant uses in the field of cultural heritage management. Likewise, more and more uses are becoming evident of the 3D models and virtual environments produced using these technologies.

Digital culture is a young, rapidly expanding and increasingly practical field. Applications of digital documentation through 3D models and virtual environments are pertinent to research across all disciplines of museum science. As such, it is worthwhile to analyze the application and efficiency of digital culture using viewpoints that take into consideration human perception, scientific authenticity, knowledge transmission and collections care. With the aforementioned theoretical perspectives setting the scope of the study, the subsequent examples of museum and research based digital documentation can be understood in context.

OVERALL OBJECTIVES

It is among the main objectives of this study to analyze examples of digitization specifically for the purposes of museum collections management, research and educational outreach. Central to this thesis is the conveyance of the manners in which digital documentation allows for transmission of information three-dimensionally in a digital format accessible to museum collections staff and researchers. Another aspiration of this thesis is to create an ongoing dialog on further and future uses of 3D models and virtual reality to this end.

In pursuit of this ambition, a case study comprising digital acquisition of one of the Ny Carlsberg Glyptotek's Roman portraits and analysis of its applications is presented. The subject was chosen for the role it has the capacity to play in current, significant, and time sensitive archaeological research, which makes it an appropriate exemplar. This specific Roman portrait, IN 821, is the subject of ongoing polychromy studies by The Copenhagen Polychromy Network. It is in a group of objects of particular scholastic interest for the high level of craftsmanship demonstrated by the highly refined polish finish of the skin and subtle detailed texturing of the eyebrows and along the hairline. In this instance, the processes of creating and applying a 3D model are described in order to highlight the implications of digital documentation to preservation of collections, capture of fading data and accessibility to the research community.

RESEARCH QUESTIONS

Questions central to this study concern digital documentation at different stages of creation and for different uses within the field of museology. These questions gave direction to general research, the development of the case study and the course of the thesis as a whole.

On the processes of digital documentation, 'How can specimens be digitally documented authentically in three dimensions?' was asked. This question led to the formation of the case study. It was deemed best answered through a digital acquisition project and creation of a 3D model to demonstrate the manner in which a specimen can be replicated digitally. The case study is regarded as quite imperative in substantiating many of the main points of the thesis.

Although the processes of capture and creation of digital documentation are quite important, most questions relate to the application of these models. An overall guiding question asked was, 'What roles can 3D models play in the field of museology?' This question is answered in many parts related to management, research and outreach. In this vein, 'What opportunities can digital methods provide to specimen documentation and organization of associated data?' and 'How can digital acquisition be considered a method of museum collections management?' were asked. The manner in which 3D model creation and other forms of digital documentation are able to act as collections management strategies is an exciting prospect since the persistence of collections propagates the future of scientific research.

On that subject, 'How can researchers use digital documentation to study museum specimens?' was a question that guided research, independent thought, as well as case study subject selection. This led to the question of 'What audiences can 3D models of museum collections serve?' the answer of which extends far beyond just the scientific community. Lastly, 'What does the future hold for museum documentation?' was a question asked in order to forge a path for future discussion.

RESEARCH METHODS

Investigation of the aforementioned questions was carried out through research of pertinent publications, development of the case study and drawn from personal discussions and experiences. In this thesis, both the top-down and bottom-up research approaches were employed: information was collected, accessed, experienced and analyzed, while a 3D model was created and applied. Both of these research methods were necessary because context and meaning are found to lie at the convergence of the two. The processes of research and model creation were simultaneous and had an impact on the manner in which the other was carried out.

Specifically, literature in the fields of digitization, museum collections management, digital archaeology, 3D models, virtual reality, repatriation and virtual exhibition were assessed. Prospects and prerequisites of digital collections management and scientific research were discussed with former colleagues and mentors. Examples of virtual environments and digital exhibitions mentioned in literature, were explored, experienced and investigated if available online. An attempt to experience as much of the aforementioned kinds of digital culture first hand was considered a vital manner of putting research into context.

The most demonstrative aspect of the thesis and the proverbial binding to the book lay in the case study. The case study serves as the author's interaction with the audience and the modus of connecting the dots for the reader. Through the case study, connections to the main themes of the thesis can be understood firsthand. For this reason, the case study has been designated its own chapter, 'The Roman Boy (IN 821): digital acquisition of a Classical polychrome portrait,' complete with a historical background on the museum specimen modeled and archaeological information documented, distinct methodology applied to the project, immediate applications of the model and further analysis.

RESEARCH HISTORY

While the advent of collecting is not new the relationship between collecting and documenting is considerably younger. It was not until a certain culture of conservation took hold in the early 1900s that the importance of documenting contexts, backgrounds and conditions of finds was deemed imperative. A find without documentation is of little scientific value because it cannot be easily connected to the environment or cultural context in which it existed. In this day and age, digital forms of documentation and visualization (GIS recordings, total station measurements, advanced digital imaging, digital acquisition, relational databases) can nearly replace the hand drawn maps, fieldnotes, and sketches. These methods are vital in creating precise documentation and means of disseminating this information.

However, as the subject is a newly formed and quickly developing one, there is no long-standing tradition of research on the topic of digital heritage management. The majority of literature on the matter gives detailed technical accounts of the methods and outcomes of digitization from the time written. The literature referred to herein must relate to concepts and procedures still relevant in contemporary digitization and as a result is therefore, for the most part, from the past decade. Contradictory to the situation in fields with which it is so intimately connected in this account, this amount of time is an eternity in the world of computation and digitization!

The outcome of recent and current digitization projects have much influence on the future course of the field. These examples shed light on the manners in which digital forms of documentation and representation (3D models and virtual reality systems especially) can aid collections staff, researchers and outreach teams, as well as what steps must be taken to better meet the needs of these audiences (Bruno et al., 2010; Baker, 2011).

Baker (2011) presents a thorough look into the push to bring collections online in the United States as funded in-house, by the National Science Foundation or United States Congress. The Smithsonian Institution in Washington, D.C., which is mostly federally funded, provides a fine example of the direction digitization is heading having, for the first time, created a line item for digitization in their budget report (Lipowicz, 2012). “The Smithsonian Institution expects to spend $8.7 million to engage in digitization, social media, mobile and Web efforts in fiscal 2012, according to an agency official” (Lipowicz, 2012). A new project to digitize and promote the Smithsonian’s collections is well underway with plans for digital capture and 3D printing of some of their 137 million specimens (Pfeifle, 2012). To date, most notably a life sized replica of a Thomas Jefferson statue was created via laser scanner and 3D printer and installed in the ‘Slavery at Jefferson's Monticello: Paradox of Liberty’ exhibit at the National Museum of African American History and Culture in late

January of 2012 (Pfeifle, 2012). This initiative may very well set the bar for future standards of museum digitization.

CHAPTER 2.
DOCUMENTED & PROPOSED APPLICATIONS OF SPECIMEN DIGITIZATION

OVERVIEW

In this chapter, specific examples of the applications of digitization, in terms of documentation, visualization and dissemination, will be proposed, cited and discussed. Through analysis of digitization projects, this chapter aims to articulate just "what it means to develop both scientific objects and interpretive products for cultural heritage using the modalities offered by virtual reality" (Cameron and Kenderdine, 2007: 11). Various tools and techniques behind the forms of digitization that bring specimens to life will also be described to provide background into the many possible forms of digitization. Concluding remarks on digitization—its potentialities, drawbacks and future commence in the fourth chapter.

What methods of digitization exist?

"The first challenge in heritage work, whether virtual or real, has always been to gather data of existing conditions" (Addison, 2000: 22). Digitization affords some of the best techniques for documenting and representing a specimen with the highest precision possible (Addison, 2000; Arnold, 2007; Frischer, 2009; etc.). Digitization cannot replace all other forms of documentation, but it can serve to connect them and make them more effective for research in relation to one another.

Depending on the material, some forms of digitization may not capture certain details as well as traditional methods, such as hand-drawn specimen sketches (for examples, please see Boehler and Marbs, 2004: 294, 296; Kelly, 2011: 6, 10, 14). Therefore in order to gain precision, methods and means of digitization must be tailored to carefully correspond to specimen type, intended uses of the digital artifact (model, image, virtual reality environment) and prospective audience. As a result, there are many different systems of digital capture and creation with different aims, scopes and implications (table 2.1). Likewise, digitization has a large range of expense. Some institutions have in-house digitization units equipped with scanners, microscopes and cameras, while others commission companies specializing in digitization and 3D printing to complete projects on their behalf.

TABLE 2.1
METHODS OF DIGITIZATION

TECHNOLOGICAL METHOD	DESCRIPTION	OUTCOME
3D IMAGE BASED MODEL CREATION TECHNIQUES	acquisition of 3D surface data from photography taken 360º around an object with either calibrated camera positions (photogrammetry) or uncalibrated cameras (computer vision)	dimensional data (point clouds, 3D models, elaboration of CAD data)
LASER SCANNING	capture of points with coordinates in 3D from the surface of an object with a laser and sensors	
WHITELIGHT SCANNING	projection of light patterns onto objects to capture surface topography with a sensor	
COMPUTED TOMOGRAPHY (CT)	capture of 2D cross-sectional images of the exterior and interior of an object based on variable absorption of X-rays and construction of 3D model	dimensional data (2D still images, volumetric 3D representations 3D)
SCANNING ELECTRON MICROSCOPY (SEM)	imaging to 6 orders of magnification of the surface of an object through the emission of electrons in a raster scan pattern. capture of chemical data from small areas.	visual and material data (2D still images)
MULTI SPECTRAL IMAGING	acquisition of images taken at different wavelengths of light to uncover specific spectrums for unique data on/in the object	visual data (2D still images of content not visible to the eye)
DIGITAL RADIOGRAPHY	digital capture of the internal make-up of an object through electromagnetic radiation (X-ray)	material data (2D still images)
CONFOCAL LASER SCANNING MICROSCOPY (CLSM)	imaging of diminutive, transparent, fluorescent objects in 2D and construction into 3D	visual and dimensional data (2D and 3D visualizations)
VIRTUAL REALITY	incorporation of 3D models into a virtual environment to be experienced and guided by a user. opportunity for cultural dissemination through a storyteller	dimensional data (3D environments with cultural backdrops)
GEOGRAPHIC INFORMATION SYSTEMS (GIS)	software wherein cartographic, topographic, CAD information can be overlaid, georeferenced and analyzed	spatial and locational data (2D and 3D visualizations)
STANDARD PHOTOGRAPHY	capture of an objects surface color and general shape	visual data (2D still images. digital or film)
VIDEOGRAPHY	motion capture	visual data (moving images)
(Boehler and Marbs, 2004; Remondino, 2006; Santanna- Quintero and Addison, 2008; Wachowiak and Karas, 2009)		

What audiences can 3D models of museum collections serve?

> The recent proliferation of commercial three-dimensional digital scanning devices has made 3D scanning, and virtual and physical replication, a practical reality in the field of heritage preservation. 3D scanning produces a high-precision digital reference document that records condition, provides a virtual model for replication, and makes possible easy mass distribution of digital data. In addition to research, documentation, and replication, 3D data of artifacts are increasingly being used for museum collections storage and packing designs.
> (Wachowiak and Karas, 2009: 141)

Museum culture is firmly rooted in the notion of collecting and caring for physical objects. It is therefore generally a bit wary of the impalpable nature of the digital information. Despite this reserved attitude, the benefits of instituting advanced forms of digital documentation in museums have been embraced by many and lauded for their far-reaching effects. Digital replicas have been used to supplement collections and imbue them with meaning. 3D and virtual reality offer methods of documentation with more additional dimension than depth alone; they have the ability to completely change the way objects and data can be archived, investigated and understood and by whom. As a result, changes in research strategies incite the creation of new knowledge, which increases the cultural relevance and scientific worth of specimens.

Digitization also aids in collections management, conservation and accessibility. These, in turn, have implications in the realms of scientific research, exhibition and epistemology. Digital documentation perpetuates all of the positive facets of collections and helps ensure their continuity. Without digitization, collections can lie forgotten, invisible, and decaying, leaving all questions that they may resolve unanswered. Digitization has the capacity to broaden a museum's audience greatly, giving access to people of all geographic and educational backgrounds. Approaches to research, management, exhibition and repatriation have been altered by the adoption of digital documentation and so, therefore, have relationships between researchers, objects and the public at large.

"Digitization isn't meant to replace the physical specimens, it's meant to cause them to be more valuable and worth keeping…" (Brent Mishler, Director of the University and Jepson Herbaria at the University of California, Berkeley, quoted in Baker 2011: 659). In the way that digitization paves the way for new research and illuminates undetectable aspects of specimens it unlocks the potential of specimens and makes them more scientifically or culturally pertinent.

The rest of this chapter takes a look at the ways digital documentation appreciates the value of specimens and serves museum collections staff, researchers, the public and groups with a claim to specimens.

COLLECTIONS MANAGEMENT

> “I can give you example after example," says Rick Bennett, who heads the department of plant pathology at the University of Arkansas in Fayetteville. "A lot of collections are not documented or backed up. After someone retires, someone opens the freezer, says, 'hey what's this stuff?' and it gets tossed. There's no transition planning in many cases, no back up, no database, other than the researcher's notebook."
> (Baker, 2011: 659)

Without doubt, this has certainly been the case even in the most professional and well regarded of cultural institutions. When a curator or collections manager organizes the collection in a manner that makes sense to them, they can end up leaving a seemingly disorganized legacy if they do not leave information that can put their reasoning into an ordered context for their predecessors.

Digital forms of documentation allow collections management staff to organize collections data in a transparent manner and make their collections accessible. Central to the main pillars of a museum are registration, organization of metadata, storage, and maintenance of collections (Cameron and Kenderdine, 2007: 11). The digital techniques of capture, documentation and visualization present an effective way to achieve these ends.

How can digital acquisition be considered a method of museum collections management?

Although digital replicas cannot replace specimens, they can help to make them more accessible without incurring the subsequent wear and tear. 3D models digitally present specimens to researchers, which alleviates much of the stress placed on objects through constant handling. Giving researchers the ability to view a model of an artifact digitally enables them to make better-informed decisions of which specific artifacts they would like to physically study. This means collections staff will have to pull fewer specimens for visiting researchers and send fewer specimens out on loan.

This saves both researcher and collections staff time, and the institution money on expensive packaging supplies. When specimens do need to go out on loan or with a traveling exhibition, 3D models can aid in creating the most efficient packaging. The data obtained through scanning can be applied to packaging material to a yield custom fit (Wachowiak and Karas, 2009: 142, 144). Digital negatives of the model can be cut from archival foam or created from other materials. Likewise, this can be used in storage facilities as well, especially in fragile or important collections.

3D models present an alternative to physical study of an object. The museum may provide researchers with 3D models for study within open source software. This offers a researcher unprecedented access to a specimen, as well as the ability to study an object on an entirely new level. These scenarios cut down on the handling of specimens, which leave them secure in archival storage with less chance of degradation.

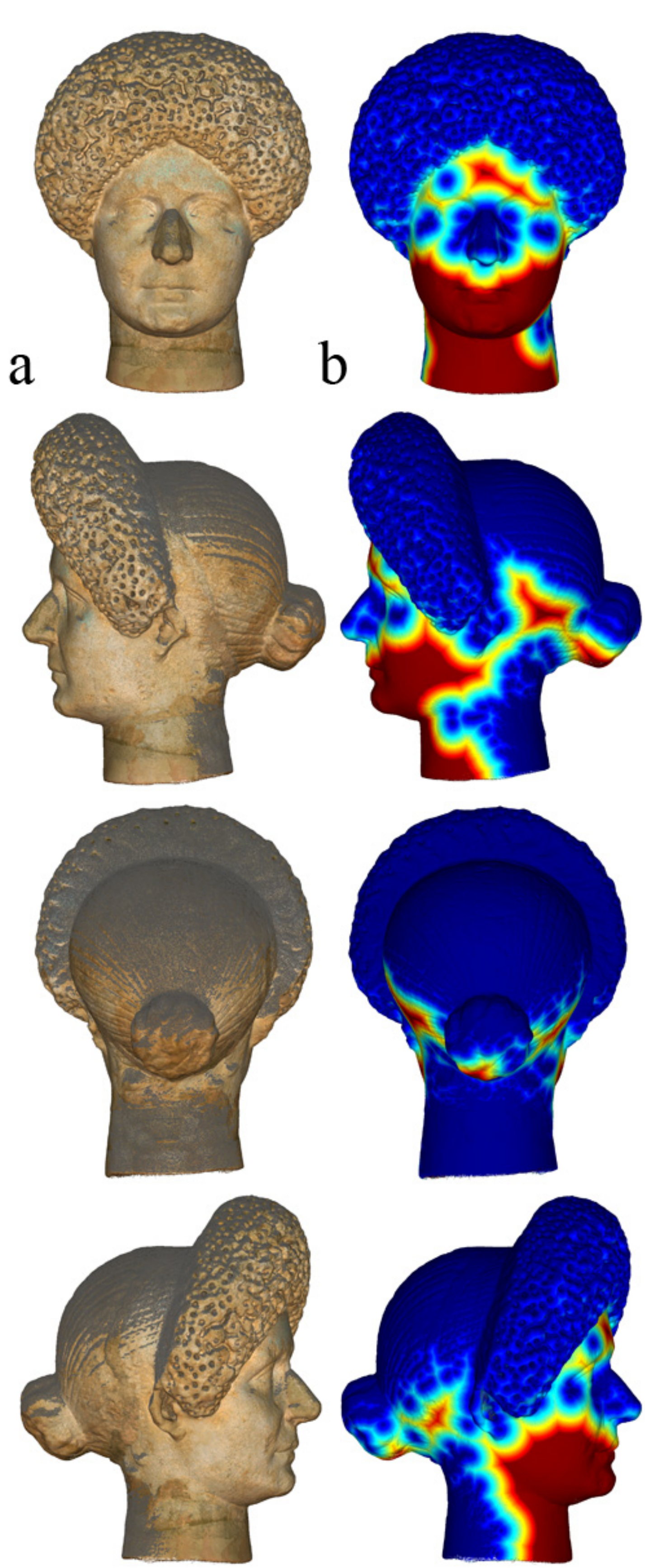
Among the specimens afforded the highest priority in museums are type specimens (Jerve et al., 2007). Type specimens are findings upon which new categorizations have been made. The maintenance and continuity of these specimens is extremely important to science. Often, as an act of preservation, access to fragile or extremely valuable specimens (scientifically or monetarily) is strictly limited or downright denied. Here, one session spent digitally acquiring the specimen can substitute multiple future handlings and can enable the creation of custom housings. In these cases, digital copies allow a form of access to specimens that is rare or impossible to achieve in the physical world. The creation of 3D models is a form of collections management in that it makes collections better understood by staff and more accessible to researchers, thereby reducing stress placed on specimens by unnecessary handling. The inclusion of 3D models in digital relational databases helps create a complete picture of a specimen, its provenance, history and condition.

What opportunities can digital methods provide to specimen documentation and organization of associated data?

In cases where museum's conservation labs may not be able to pinpoint the cause nor retard the decay of certain museum specimens, digital acquisition provides the opportunity to preserve an object as it is in a precise moment in time. From these visualizations researchers can conduct studies that shed light on the source of deterioration. This is relevant in all fields along different lines—fragile fossils, decomposing fibers, fading pigments (please see chapter 4), and the list goes on. In the case of living specimens, digital capture through 3D creation can provide a glimpse into the behaviors and development of a specimen over time.

This sort of tracking through time can be applied to all different kinds of collections. Digital documentation on a consistent basis can reveal trends related to deterioration of specimens, patinas acquired from falling dust particles, stress points created by certain manners of storage or exhibition, etc. (Dellepiane et al., 2011: 55–58; please see figure 2.1 and appendix A for a dust accumulation simulation carried out on a 3D model of a classical portrait digitally acquired and created for this thesis). Structural analyses through digital documentation, especially 3D model creation, can incite the adoption of new storage techniques and prevent specimen damage and destruction. Digital methods provide a manner of monitoring slowly accruing harmful impacts on collections that could otherwise escape notice.

Dellepiane et al. (2011: 58) describe the role 3D models can play in monitoring specimens, citing an example undertaken during a 2006 restoration of Michelangelo's David. In this project, 3D models were applied in restoration and conservation capacities. They were also used to evaluate the structural status of the statue, especially in terms of cracks in David's ankles. Conservators and curators wondered if the cracks were naturally occurring or the result of improper placement. They also wondered if the cracks were continuing to grow or had since been stunted. It was believed that the cracks could have been spawned by an imbalanced distribution of the statue's mass resulting from an original base that was not level. This slanting planar base would have caused the statue to lean forward at a slight angle, thrown off the intended center of gravity and as a consequence produced stress points at points not made to bear certain proportions of weight. For their structural examination, "the mass properties of volume, center of mass, and the moments and products of inertia of the center of mass" were considered. These were "computed directly on the 3D model using an algorithm that exploits an integration of the whole volume assuming constant density of mass" (Dellepiane et al., 2011: 58). Structural information generated from the models can be used to determine best practices of specimen storage and display to prevent further cracking and eventual breaking. In this way, digital methods prove essential to the development of collections management practices.



2.1. SIMULATING DUST ACCUMULATION DIGITALLY (UNDER MAXIMUM ANGLE OF RANDOM FALL SET AT 5° IN MESHLAB) *a. projected dust layer in gray, b. projected intensity of dust accumulation: from blue, representing the highest, to red, representing none*

They are also instrumental in guiding restoration practices. An Italian project initiated in the wake of a 2009 earthquake in the Abruzzo region presents an appropriate example (Callieri et al., 2011; Scopigno et al., 2011; Dellepiane, 2012). The reconstruction of Madonna di Pietranico, a Renaissance era terracotta statue, brought specialists together from the realms of art history, archaeology and computer science. The goal of the project was to use "traditional materials and techniques supported by advanced technology" to reconstruct the statue and return it to public exhibition (Ministero per i Beni e le Attività Culturali, 2011). All of the recovered pieces of the statue were laser scanned. The resultant 3D models guided regeneration of missing parts and reassembly of the statue. Conservators needed an invisible means of keeping the fragments of the hollow head and bust together, while conforming to their unique shapes and supporting their weight. The remedy to this quandary came in the form of supports created through rapid prototyping technology (3D printing) from the internal cavity of the 3D model. The fragments of the statue were adhered to specific points of contact on the supports for reinforcement (fig. 2.2).

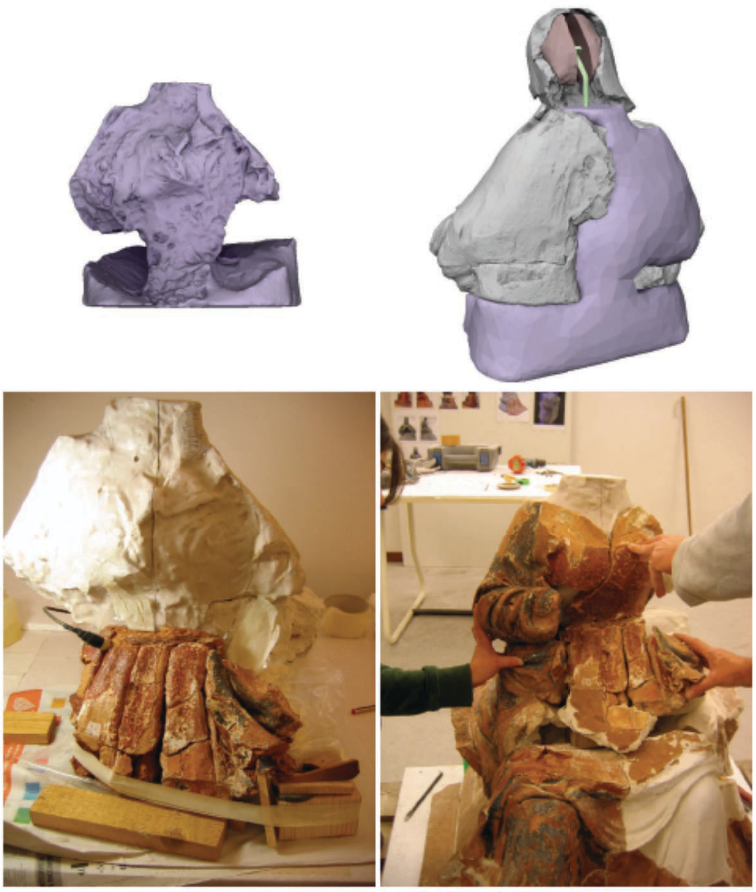


FIG. 2.2. 3D NEGATIVES USED TO FORM SUPPORTS FOR RECONSTRUCTION OF MADONNA DI PIETRANICO (*published in Scopigno et al. 2011: 53 as figure 7, ©2011 IEEE, for usage permission, please see appendix I*)

Along with digital acquisition, the institution of digital relational databases presents collections staff with the opportunity to organize and connect data associated with their physical specimens in one place (table 2.2). GIS (geographical information systems) can be used to georeference different forms of documentation, for example, modern topographic information or historical maps from a specimen's point of origin. Through digitization and integration into relational databases, collections data, georeferencing information, collector's journals, maps, 3D models, digital images and bibliographies of published articles can all to be culled together.

TABLE 2.2
CONNECTED METADATA IN RELATIONAL DATABASES

FIELD	**DESCRIPTION**
CATALOG NUMBER	specimen catalog number
DESCRIPTION	description of taxonomy, material, creators, dimensions, etc
PHYSICAL LOCATION	specimen location in collections space or museum hall
COLLECTION SITE	general location, context of discovery
COLLECTION DATE	collection date, field season, expedition
COLLECTOR	collector name
GEOREFERENCING	georeferenced coordinates of collection site
IDENTIFIER	identifier name and date
CATALOGER	cataloger name and date
ACQUISITION HISTORY	date acquired, means of acquisition, past owners
CONSERVATION	condition reports, history of conservation treatments
LICENSES & RIGHTS	copyright ownership, licensing information
LOAN HISTORY	history of loans with date, recipient, purpose
ACCESS	restrictions on access granted to researchers
ASSOCIATED OBJECTS	other specimens or archival material connected to specimen
ASSOCIATED PUBLICATIONS	publications information for sources related to specimen, site, collector, or expedition
INSURANCE	valuation, risk management, insurance particulars
MULTI-MEDIA	images, audio or video recordings, document scans, 3D models, GIS files and virtual reality systems connected to or of the specimen
(Museum of New Zealand Te Papa Tongaerwa, 2003; American Museum of Natural History and The Paleontology Portal, 2012)	

This tidies up collections information and saves museum staff time spent tracking down different fragments of information about a specimen from countless sources: catalog cards, the specimen itself, archives, hand-written ledgers, etc. Databases can be made accessible to distant researchers with the appropriate credentials via password. With all information in one place, researchers can make better-informed assessments of the pertinence of an object in their research without the assistance of collections staff, or a visit to the museum itself. They can also detect connections between specimens and larger trends within the data, for example migration patterns of humans, flora and fauna, trade networks, cultural diffusion, technological evolution, etc. Collections management perpetuates research. (For a discussion of the implications of such databases in research collaboration, please see *How can digitization lend itself to virtual collaboration?*)

SCIENTIFIC RESEARCH

Museum collections hold infinite scientific potential, far beyond the original intention of their collectors.

> Early collectors never dreamed that their dried leaves or flowers would someday be analyzed for DNA sequencing. “That was unthinkable,” says [Michael] Mares [director of the Sam Noble Oklahoma Museum of Natural History]. “Before they were just specimens—now they're like living objects, because we keep learning new things we can do with them. There’s really unlimited use in the future for these specimens. If the past is a prelude, their value will increase enormously.” (Baker, 2011: 658)

Digital acquisition, advanced imaging and the point where these visualization techniques intersect have major applications in raising the value of specimens through digital documentation, scientific research and conservation.

How can researchers use digital documentation to study museum specimens?

Researchers can truly interact with collections in innovative manners through digital documentation. All of the aforementioned collections management techniques have implications that promote scientific research in that they make collections available to research. The key factor though is that they also allow researchers to combine, overlay and visualize specimens in new ways. These new visualization techniques enable researchers to make new connections between data. 3D models, for example, can be viewed as blank three-dimensional canvases upon which images can be projected and compared to geometry and in relation to each other. 3D models serve as points of convergence for concurrent analysis of different media and data.

Tools within open source software, such as digital calipers, render taking isometric measurements and making surface analyses virtually a possibility. Besides being studied virtually, digital documentation can be studied physically through replication and printing. Laser scanning yields 3D models that may be printed in three dimensions through rapid prototyping technology at any scale. Besides research and restoration purposes, 3D prints can be used in dissemination and exhibition (Pfeifle, 2012).

Digitization, projection of technical images and manipulation of 3D models can serve research of different specimen types, including skins, bones, fossils, and artifacts. Broken or incomplete specimens are particularly common to the field of archaeology. In these numerous occasions, 3D models and virtual reality can be used to visualize an incomplete artifact based in part on documented findings and in part analogous material and hypothesis. Researchers can herein elaborate 3D models created from what exists of the artifact. They can use software to build additional geometry to envision aspects missing from an incomplete artifact or specimen.

It is especially in these cases when the line between elaboration and observation must be defined and clarified. It is always important to state why a model has been interpreted in a certain manner, especially when incomplete. Researchers should clarify how they have reconstructed an artifact, what they have added and on what grounds. As in traditional analyses, visualizations ought to be accompanied by a write-ups detailing how this line has been walked. Researchers may also digitally reassemble specimens broken into multiple pieces, putting together the pieces of a complex puzzle that may only have a chance of existing digitally.

In the same vein, cultural and scientific information related to museum specimens that are degrading, incomplete or broken can be documented digitally to aid research. Digital techniques allow scientists to delve into specimens without destroying them. The American Museum of Natural History in New York's exhibit, 'Picturing Science: Museum Scientists and Imaging Technologies' (American Museum of Natural History, 2011) is a relevant example of how new digital technologies can be applied across disciplines. The images exhibited were taken via Scanning Electron Microscope, Computed Tomography Scanner, X-ray, ultraviolet fluorescence and biofluorescence to obtain extremely detailed high definition images. Two of the images convey how a predicament facing assistant curator in the Division of Anthropology, Alexander de Voogt, was solved. de Voogt was curious to see the ornamentation on an Egyptian blade that was collected in the 1930s and since stuck in its shrunken leather sheath. Using Computed Tomography, scans were taken and processed to create a 3D model. Layers were then removed to digitally unsheathe the blade, making it visible for study (fig. 2.3). This is a prime example of how digital documentation can present a non-destructive solution to studying cultural material.

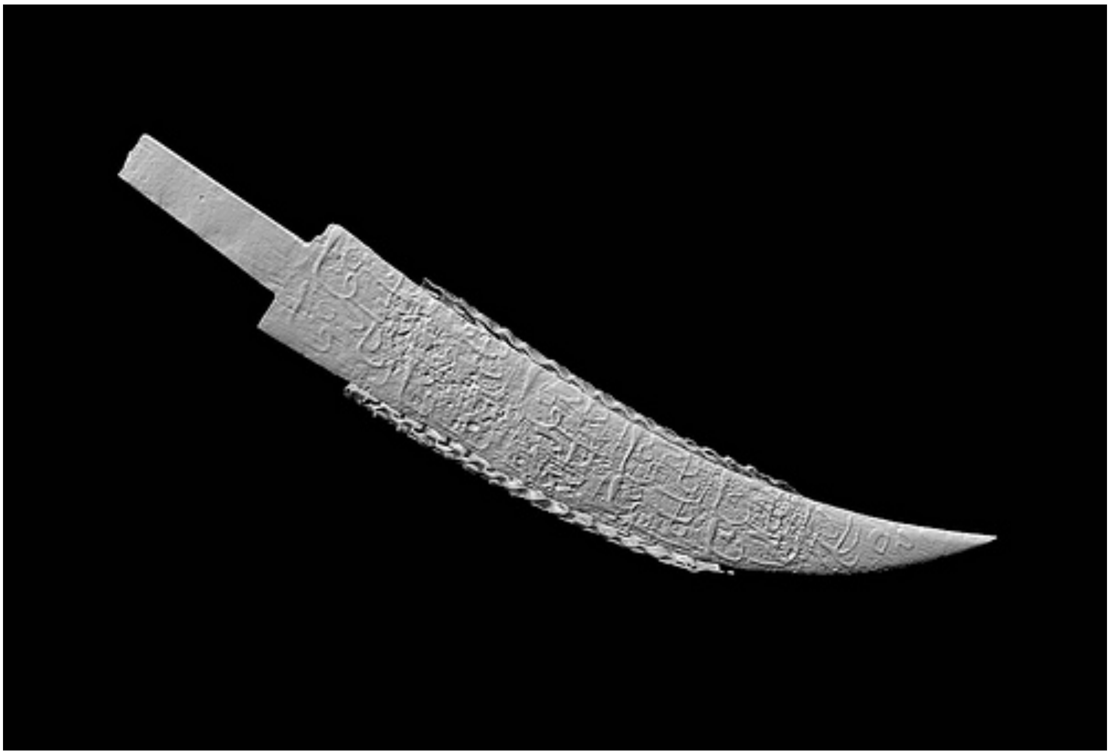


FIG. 2.3. EGYPTIAN BLADE UNSHEATHED BY COMPUTED TOMOGRAPHY
(*AMNH Anthropology Catalog # 90.2/6422 A, ©2011 AMNH/A. de Voogt, for usage permission, please see appendix I*)

How can advanced digital imaging techniques be applied to museum conservation?

Another example from this exhibit pertains to the museum science of conservation. Conservators are scientists who study the materials specimens are made from, what will cause them to decay and how to prevent or stop decay. They then put this knowledge to use in special conservation labs within the different disciplines of museums, working to clean and preserve specimens from a range of materials. Conservators work in scientific research and their results ensure the continuance of museum collections; in this way they can be viewed as an extension of the collections management staff with deeply scientific background. Another set of images from the exhibit focuses on the composition of a Tibetan bronze figure. These X-ray images were used by the Division of Anthropology's conservators, Judith Levinson and Karl Knauer to assess the condition of the figure and can also be used comparatively with future images in the same regard. Through the images, the conservators were able to detect differences in construction method and material in a non-invasive manner, the hands and feet being solid and cast while the body is hollow and constructed of sheets of bronze (fig. 2.4). In the future, along with providing knowledge of the material of a specimen, digital techniques will be able to help conservators uncover or anticipate and remedy or retard the reasons for decay via simulations rooted in scientific knowledge of material weathering and chemistry.

FIG. 2.4. TIBETAN FIGURE CONSTRUCTION REVEALED BY X-RAY
(*AMNH Anthropology Catalog # 70.0/7428, ©2011 AMNH/J. Levinson & K. Knauer, for usage permission, please see appendix I*)

How can digitization lend itself to virtual collaboration?

Different scientific organizations have begun to sprout up around the digital movement to promote digital documentation in museum collections research. One instance is the biological collections community in the United States, which has developed a codified strategic plan to “transform the practice of collections-based biological research, scientific achievement, and international research collaboration” (Baker, 2011: 657). Digitization has many positive collaborative consequences.

The digital movement has provided researchers with an increased accessibility to each other’s projects despite busy schedules and long distances. This accessibility of information has not come without certain drawbacks since the openness of information can easily be exploited. However, it can also be secured. With password-protected spheres of influence, museums can choose which information should be exposed to which audience. A museum’s online exhibitions, for example, can be divided into different areas with permissions and access depending on the status of the user. A limited exhibit can be presented online for the public to view, while password-protected areas of the webpage can be made available solely for accredited researchers within specific fields to access, download, modify and discuss models and data. These areas may serve as digital repositories for models, archiving and maintaining them in a place where they may be accessed, reviewed and edited as new insights become available to the research community (Frischer, 2006: 7; Skovmøller, 2012). Institutions could also come together to form virtual partnerships manifested through research websites with examples pertaining to specific specimen types or research questions. These examples create interdisciplinary forums for scientists to share insights, correct misidentifications, solve mysterious cases, offer peer review and form vital virtual collaborations.

The Ny Carlsberg Glyptotek (2012a) in Copenhagen has been developing a website for their ‘Tracking Colour’ project since 2010. Their main goals are to create sculptural and bibliographic databases, as well as to foster a forum for discussion and collaborative research between scholars (Skovmøller, 2010, 2012). Here involvement is planned to serve as a key to access. In order to gain a professional user account, one must agree to upload the research their access makes possible. The website (fig. 2.5) has gone live in late April of 2012 and is still in development.

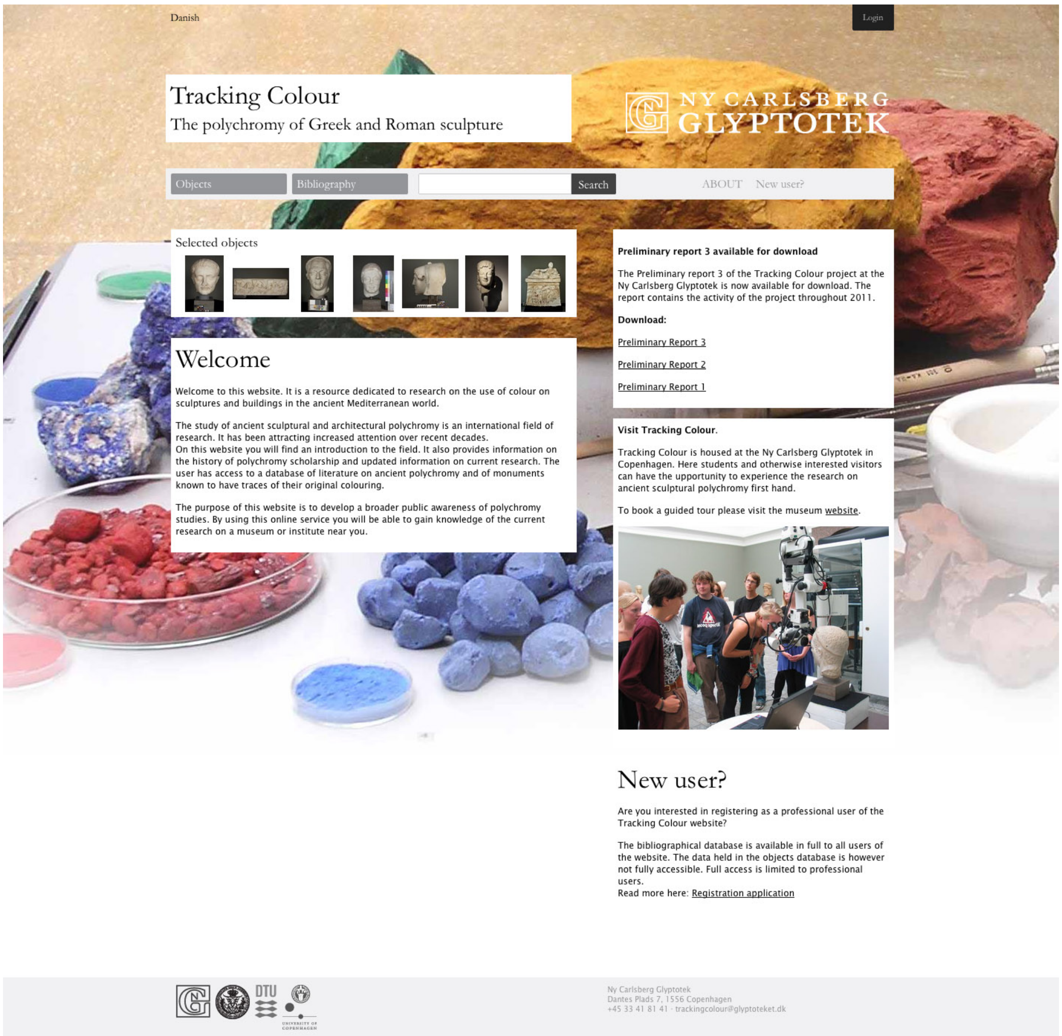


FIG. 2.5. THE GLYPTOTEK'S TRACKING COLOUR WEBSITE

Another database example from the Smithsonian Institution's Museum of Natural History in Washington D.C. illustrates the way digitization of specimens can extend beyond borders (Smithsonian Institution, 2011). Their joint venture between the Division of Mammals and Human Origins Program involves the creation of 3D models of type orangutan, chimpanzee and gorilla skulls. Baker (2011: 660) remarks how these very models can be applied in Africa where researchers do not have regular access to extensive collections and literature. The result of these virtual collaborations is a symbiotic relationship for the institutions and researchers involved and a promotion of science in general.

A museum professional interviewed by Baker (2011: 659) provides a specific example of how such an online research community can benefit collections' identification in the realm of botanical research. Amanda Neill says,

> One of the biggest problems [of] doing biodiversity surveys in tropical places is that it takes the entire world of taxonomists to help you identify organisms. So in the old days, we used to make specimens, dry them, send them to one institution, and they'd send out duplicates or gifts. They might send specimens to England or China, where they'd sit around on a shelf for 5 or 10 years, before they'd have time to identify them.

Unattended specimens taking up space on shelves, waiting to be studied are a problem common to many museums. Cultural material is expensive to maintain and museums simply cannot afford the manpower necessary to give each specimen due attention. If all expeditions and excavations were called off for the foreseeable future, discoveries would still be made for hundreds of years just from the collections museums hold. Unstudied specimens, clad in their original field jackets and packaging would account for a large percent of the findings. Still greater, much knowledge would be gained from the application of new technology and perspectives on previously studied materials. Digitization provides the opportunity to open up the size of the research community and give museum collections their due attention.

‘UNIVERSAL COLLECTIONS’

Digital acquisition and 3D model creation of museum specimens open the door to endless possibilities where the public is concerned. The establishment of ‘universal collections’ stored online and presented for the public to experience remotely within a browser is a natural next step. ‘Universal collections’ are essential outlets through which a museum can communicate directly to their target audience and encourage critical thinking.

How can ‘universal collections’ benefit museums, the public and the scientific community?

For federally funded institutions creating ‘universal collections’ can serve as a method of sharing their collections with taxpayers who are not able to physically visit the museum yet still fund the functions of a museum in supporting these collections. For institutions funded by internal revenue and endowments, the interest and attention ‘universal collections’ have the ability to bring to the museum can only beckon more paying visitors to the halls of the museum and prompt more bestowments. Well executed, the establishment of ‘universal collections’ can garner prestige and support for a museum, make them personally relevant to the public and attract partnerships from interested entities.

Some institutions, like the Smithsonian Institution in Washington, D.C., have begun projects in this vein. On one of their webpages, the Smithsonian Institution (2011) presents a collection of artifacts from the David H. Koch Hall of Human Origins in 3D. The webpage (fig. 2.6) plays host to flash enabled 3D models created from laser and CT scanning. Models of primate skulls, fossilized skulls, and artifacts can be viewed and rotated by anyone with access to the Internet. Files are also available for download and view in different preset views. This expands the distribution of the models even further that the reaches of the Internet. Although this content is non-downloadable in a format that allows for in-depth analysis by the general public, the specimens are available to the public via an interactive interface that encourages hands-on exploration and inspires analytical thinking.

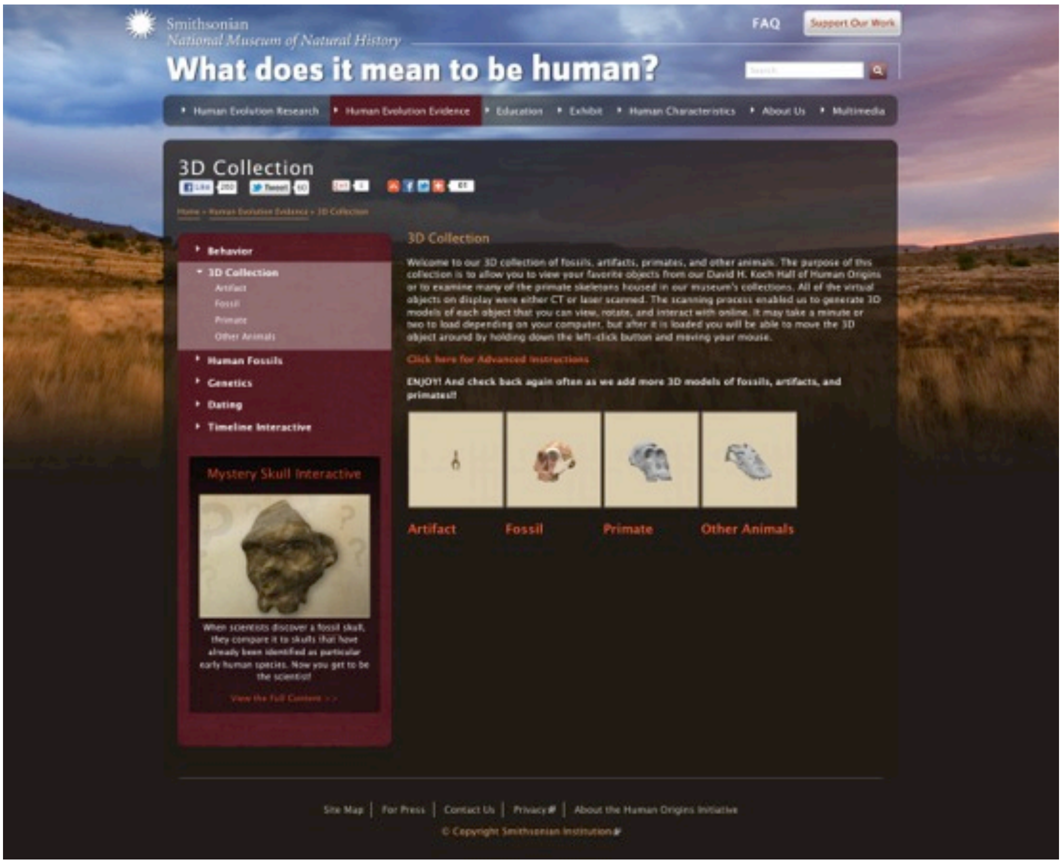


FIG. 2.6. THE SMITHSONIAN'S HUMAN ORIGINS PROGRAM WEBSITE

As times change, so do the trends that govern what is considered culturally significant to be displayed. 'Universal collections' open up the possibility for museums to display items from their storage, giving individuals access to non-visible parts of their history or culture that they feel are personally pertinent (Singh and Blake, 2012: 99). Similar to kindling a notion of collective past in tribal groups in the case of repatriation, the creation of 'universal collections' instills in digital cultural heritage the capacity to forge a common heritage (UNESCO, 2003a: Article 1). This common background is a platform upon which collaboration may be based and scientific questioning may be encouraged in younger generations.

DIGITAL REPATRIATION

Another realm of possibility lies in the notion of digital repatriation. This is the notion that technological techniques present modes of restoring indigenous material and cultural knowledge via digital images, recordings, 3D models and virtual environments. Digitization can serve as a means of solving a common problem that arises when a nation wishes to lay claim to objects, but does not have the means nor the facilities to house or maintain them. On the other hand, through digitization an institution that must repatriate an object may retain a digital copy or print a 3D replica.

Repatriation is a return of physical goods or cultural information to a nation defined either by political borders or tribal membership. In terms of political nations, more recently institutions and governments in the countries in which they are collecting have made formal long-term plans for the study, maintenance and eventual return of material. Return of material collected in the past can be bit more complicated. Digitization opens a dialogue on making specific relics accessible to the public in their area of origin (Bruno et al., 2010: 48).

While legislation, like the Native American Graves Protection and Repatriation Act of 1990 (Native American Graves Protection and Repatriation Act, Pub. L. No. 101–601, 104 Stat. 3048) has endeavored to sort exactly this issue for aboriginal groups, obstacles still remain in this area as well. Repatriation (Native American Graves Protection and Repatriation Act, Pub. L. No. 101–601, § 7, 104 Stat. 3054) covers items that fall under NAGPRA's definition (Native American Graves Protection and Repatriation Act, Pub. L. No. 101–601, § 2, 104 Stat. 3048) of "sacred objects," objects of "cultural patrimony," and "associated funerary objects." Most everyday items, which hold great value to contemporary societies, are excluded

(Lyons et al., 2011: 16). "Many cultural and historical artifacts of indigenous life are spread across the collections of museums and private holdings" (Resta et al., 2002: 1482). Although museums go to great lengths to make material connected with aboriginal groups accessible to their members, it is often inconvenient or financially infeasible for delegations to visit museums. When a nation does not have the means to care for material with which they are connected, cultural and scientific information essential to the development of the nation remains tied up in institutions and outside of their jurisdiction.

How can digitization serve as a form of repatriation?

Digitization has the capacity to play a big role in return of cultural heritage and revival of cultural identity without the issues of physical storage and preservation. The outcomes of repatriation have varied and depended greatly on the level of incorporation of the nation in the decision-making processes, which have historically not been high. On this matter, digitization presents a unique opportunity for a nation to take a more active role in the perpetuation and propagation of their cultural and natural history (Hennessy 2009, 2010; Singh and Blake, 2012).

In many cases, aspects of cultural heritage are dying away with its aging Elder stewards, as a result giving a nation the power to actively integrate a digital archive into their own spheres of cultural impartation and public education is an imperative way to safeguard cultural heritage. "Artefacts of historic or cultural significance have knowledge and information associated with them that complete the picture of their significance. Of themselves, they may be impoverished without the additional context of the knowledge of their production, use, history, ownership, etc." (Arnold, 2007: 19). These kinds of information can be considered intangible cultural heritage. The UNESCO (2003b: Article 2) Convention for the Safeguarding of the Intangible Heritage acknowledges intangible cultural heritage as:

> the practices, representations, expressions, knowledge, skills—as well as the instruments, objects, artifacts and cultural spaces associated therewith—that communities, groups and, in some cases, individuals recognize as part of their cultural heritage. This intangible cultural heritage, transmitted from generation to generation, is constantly recreated by communities and groups in response to their environment, their interaction with nature and their history, and provides them with a sense of identity and continuity, thus promoting respect for cultural diversity and human creativity.

Intangible heritage may be manifested in manners that do not yield physical products, but have been documented in ethnographies and images and may be digitized yet.

Digital repatriation can be construed in terms of the digitization of artifacts, objects and ethnographic material as a unification of tangible and intangible. This new digital heritage stands as documentation of the past as well as a bridge to the future. Digitization preserves language, oral history, cultural knowledge and material culture in an interactive form that can be viewed, explored, read, heard, studied and incorporated in linguistic programs and pedagogic virtual reality environments. Such access, control and ownership of digital heritage may act as an initiative to increase native involvement in archaeological, linguistic and other related research and education.

Basing her doctoral dissertation on five years of close fieldwork with a Doig River First Nation group aboriginal to northeastern British Columbia, ᑕᓀᖚ, or the Dane-z̲aa, Hennessey (2010: 3) argues "community participation in documentation and safeguarding is essential in developing digital strategies that are focused on keeping intangible heritage alive in social practice." With theoretical framework built around the notion that a nation's perspective should guide the process and govern what is accessible and to whom, her dissertation explores the issues of ownership and native involvement in curation of their own digitized cultural material.

Even within an indigenous culture, access to certain aspects of tangible and intangible heritage are traditionally restricted to specific audiences by factors such as gender, age, or status (Singh and Blake 2012: 95, 99). In digitizing heritage it is important to consider the constructs that govern access to sacred and taboo objects and knowledge. If nations are consulted accordingly and digital techniques are employed efficiently resolutions to the issues of ownership and controlled access may be met. Questioning the spiritual and social significance of broadcasting some of the work of their Dane-z̲aa ancestors, Hennessy notes, "People used cultural protocols associated with the traditional care and handling… to think through the ways in which… [representations] should be restricted or circulated in new media contexts" (Hennessy, 2009: 6, 2010: 12). The Dane-z̲aa gained intellectual and property rights on their tangible and intangible cultural heritage and governed what they would make accessible and to whom.

Digital repatriation can provide a platform for Native groups not only to house and maintain their own artifacts but also to exhibit them in the manner they see fit. In this way, digitization empowers a nation to define their identity on their own terms and in their own voice (Hennessy, 2010: 9; Singh and Blake, 2012: 95). 3D models and virtual environs can hold the educating presence of cultural artifacts in an accessible and easily maintainable manner. Here digitization has the ability to re-animate, invest new meaning and significance in, as well as make cultural legacy relevant to young generations.

What role can immersion play in breaking the 'fourth wall'?

Dawson et al. (2011: 388) cite French philosopher, Denis Diderot's 'fourth wall' theory as a "metaphor for framing the traditional relationship between indigenous peoples and archaeological discourse." In this case, the fourth wall is an invisible barrier between an indigenous group playing the role of passive observer and their ethnographic and material culture being studied, displayed or housed in a museum. They present two case studies to demonstrate how digital simulations can break the 'fourth wall' to bring the two closer and incite active involvement.

Central to digital repatriation are the notions of presence, immersion and embodiment previously discussed. In order for indigenous people to connect with their cultural heritage through digital media, these must elicit distinct memories, emotions and visions of the past. Dawson et al.'s (2011: 389) interviews with participating Elders confirmed that achieving connectedness to objects and environments does not necessarily require and can even transcend physical contact. Connectedness correlated directly with the sense of presence an immersive atmosphere provided. "These observations lend credence to the hypothesis that the meanings attached to objects in the real world are sometimes transferable to digital replicas in virtual spaces" (Dawson et al., 2011: 389).

Elements of a virtual reality system that lend themselves to presence and immersion are closely related to narrative and authenticity. Attention to fine details, such as nature of lighting, reflection and absorption values of materials, presence of smoke or objects included in the background, cultivate an aura of authenticity in an environment. The story an environment can tell without words is crucial in transporting a viewer to that time and place. These can help to stir up memories, put oral history in context and set the stage for future diffusion—particularly between the generations. When a viewer begins linking the different elements present in a virtual environment and reflecting on how these converge to embody their own personal experiences, they transform into an active participant in the environment. This was illustrated with the Siglit–Inuvialuit Igluryuaq sod house and Thule whalebone house recreated by the Glenbow Museum that Dawson et al. (2011) discuss. The latter has gone on to become an Internet exhibit (Glenbow Museum, 2008). This project used "focal metaphors of hearth, home and household to understand northern ecological narrative, cultural resilience, and the use of space" (Dawson et al., 2011: 393). Here the presence of smoke and artifacts common to home life (fig. 2.7), evoked sentiments and conversation in the nine Inuit Elders (fig. 2.8) who

> donned stereoscopic glasses to tour each virtual world, where they experienced the sensation of being inside these ancient dwellings. Within seconds, they were surrounded by virtual structures of hide supported by frameworks of whalebone ribs, jaws, skulls, driftwood, and sod. The Elders sat together in each virtual world, attempting to touch digital objects such as lamps and drums, as they gestured and whispered amongst themselves in their native Inuktitut. 'All the stories I used to hear when I was young are coming back to me,' said Mark Kalluak as he navigated around the Thule virtual dwelling. 'It really makes me think about what it would have been like to live in my ancestors' home.' Another Elder, Donald Uluadluak, explained in Inuktitut that he felt like a magician: 'No one has ever seen these buildings before. Now we are able to and it will help us understand who we are.' (Dawson et al., 2011: 395).

FIG. 2.7. THE GLENBOW MUSEUM'S THULE WHALEBONE HOUSE WEBSITE

The virtual representations of their heritage caused the Paatlirmiut Inuit Elders to remember the objects of their childhood and stories of their grandparents. In this way, the digital renderings established a connection between them and with their cultural heritage and made them eager to share their own recollections. All of the Elders involved all expressed optimism that digitization had the capacity to play a supporting role in the future of their cultural legacy. They felt that digital replicas of their cultural heritage could capture the attention of the younger generations who they struggled to interest in traditional ways and knowledge. (Dawson et al., 2011: 396, 398). Establishing a connection with youth is a problem common to indigenous groups as well as the museum community. Digital techniques of visualization and interaction serve as a way of enlivening the subject matter and establishing a platform for diffusion.

FIG. 2.8. PAATLIRMIUT INUIT ELDERS WEARING 3D GLASSES TO VISUALIZE THE THULE WHALEBONE HOUSE IN THE UNIVERSITY OF CALGARY'S CAVE® AUTOMATED VIRTUAL ENVIRONMENT (*published in Dawson et al., 2011: 396 as figure 3, ©2011 Dawson, Levy, and Lyons, for usage permission please see appendix I*)

VIRTUAL EXHIBITION

The topic of digitization in museum exhibition and education is growing exponentially. This section presents a brief discussion of the potential of digitization and visualization to engage visitors in a way cordoned off and remote specimens cannot. Virtual and augmented realities can simultaneously re-contextualize their specimens and allow museum visitors to interact with and experience them virtually *in-situ.* These systems illustrate not only the physical dimensions of a specimen, structure, or site, but also the spatial and cultural relationships it had to its surroundings (Campana and Remondino, 2007: 5; Flynn, 2007). Specimens can be experienced with many different senses beyond strictly vision with techniques like the application of haptic technology. This opens up the experience to a wider audience (Lepouras and Vassilakis, 2005: 97).

The introduction of new apps almost daily encourages people to visit museums as well as explore their exhibits and collections remotely. The incorporation of virtual and augmented realities in these apps really draws in users and enables them to interact with the exhibits and share their experiences over social media, which doubles as good marketing for museums. Initiatives that invite visitors to take part in digitization by taking pictures with their own cameras and uploading them online to generate 3D models are great ways to bring some attention to the issue of museum digitization and get visitors involved (Snavely et al., 2006, 2007). The end results of a digitization day could be the generation of midrange-quality 3D models covering much of a museum's exhibition halls, a buzz around the project and an increase in attendance.

Set within a museum, interactive virtual environments are effective didactic tools in that they offer users a self-paced way of focusing on what is of interest to them (Dellepiane et al., 2011: 40; Westin, 2011: 58). These present the opportunity for a museum to communicate directly to and capture the attention of young and old audiences in an educational and immersive manner without having to tone down the subject matter to make it easier to comprehend.

How can virtual exhibition be utilized to transmit intangible cultural knowledge?

Virtual reality has the power to break the 'fourth wall' and allow visitors to infiltrate prehistoric environments, foreign cultures or remote collection sites. The now familiar concepts of presence, embodiment and immersion are key in transporting a viewer from the context of the museum exhibit to the temporal and environmental setting of the model (Flynn, 2007: 88, Forte, 2010; Westin, 2011). In his 2006 doctoral dissertation Champion (2006: 77) writes, "while a virtual environment can have a sense of social presence, to have a dynamic sense of cultural presence, we need to have a sharable way of expressing socially understandable beliefs and behavior (active cultural presence).” One method of cultivating an active cultural presence is through narration. Narration can be passive (textual) or interactive (character based). In the latter, not only can visitors visit places, they can interact with the inhabitants from the day and age. These characters help to create an immersive atmosphere and impart knowledge related to daily life and intangible culture such as ritual tradition, oral history or handcrafts (Flynn, 2007: 88, 89).

This kind of storytelling or guided instruction is one way virtual reality tackles the difficult task of digitizing and conveying intangible culture. The process of mastering these aspects of culture is often arduous and since their true byproduct is an action, not an object, their legacy is easily lost. Despite this, intangible skills, processes and traditions remain an essential conduit of artistic expression and a cornerstone of cultural heritage (Carrozzino et al., 2011: 83). Carrozzino et al. (2011)’s virtual representation of the ‘Artistic Handicraft of Lucchesia’ for the Virtual Museum of Sculpture is an example of how virtual reality systems aim at transmitting intangible cultural knowledge. Their project digitally documented a contemporary artisan carrying out the traditional process of sculpting a statue of San Francesco from start to finish and represented it through different media represented in a virtual environment. A linear storyboard progression guides the viewer through the phases of production and an open environment allows the viewer to investigate peripheral aspects of the scene. Reception was positive, even for participants who preliminarily were critics of technology and viewers who proclaimed themselves disinterested in history (Carrozzino et al., 2011: 86). Here the immersive and interactive character of the environment prevailed to transport the audience to the scene and impart fading cultural craft knowledge.

Another example of a virtual environment meant to educate the public is WolfQuest, a simulation where the user participates as a member of a wolf pack (Westin, 2011: 53–55; Minnesota Zoo and Eduweb, 2012). With the perspective and capacities of a wolf, the user partakes in the group dynamics and ecological role of the pack. The simulator has been acclaimed for its realism and ability to engage audience and make them feel a part of the pack. This is the essence of what Westin (2011: 50) believes should be a virtual environment’s objective, to “activate the visitor in a way that makes her involved in the exhibition and makes her feel more like a contributor than a visitor and more like a creator than a user; thus promoting a creative reasoning that trains her inductive problem solving skills." When a virtual environment successfully achieves these aims, learning is inherent in the experience, no matter what the subject matter, no matter what the background of the user.

In this chapter, many applications of museum digitization have been discussed. The role digitization can have in managing collections, transforming specimens into tools of scientific research and disseminating information, makes it a worthy enterprise. The next chapter follows the process of digitization of one artifact and the realized and proposed applications of the consequent 3D model.

CHAPTER 3.
THE ROMAN BOY (IN 821): DIGITAL ACQUISITION OF A CLASSICAL POLYCHROME PORTRAIT

OVERVIEW

Chapter three concentrates entirely on the development of a case study undertaken in order to best convey the impact digitization can have in a museum setting. The case study provides a glimpse into what creating a 3D model of a museum specimen entails, including geometric data capture, post-processing and projection of color information. It also demonstrates actual and potential uses of the model in scientific research and exhibition.

This chapter strives to navigate through a highly technical subject matter to speak to an audience that may differ in scientific background, but hold in common a concern with the continuance of cultural heritage. Background information is presented in order to place the specimen in temporal, cultural and scientific context. In an attempt to guide and encourage further development of digitization in the museum science as much information as is possible is offered on each stage of model creation (although sometimes in the form of appendices). The latter part of the chapter consists of specific applications of the model in contemporary research and an analytical discussion rooted in empirical thought.

INTRODUCTION TO THE CASE STUDY

In selecting a specific museum specimen to digitize few criteria were truly necessary to consider. The object needed be of archaeological interest as according to the discipline of study. That it dated to a precise time period, originated from a particular geographic location, or had been forged of a specific material matter naught. What was the most important, however, was that the object selected was of contemporary scientific value and interest.

With this premise in mind, an autumn afternoon meander through the Ny Carlsberg Glyptotek's sculpture galleries presented a grand prospect. A special workspace designated to sculptural polychromy research has been visible among the sculptures of the Glyptotek for years. Yet, it is with new vision that old forms take new shape. With walls of glass, this workspace offers visitors a peek into the inner workings of an ongoing project, a project of great scientific circumstance and a project that the museum wishes to share with the world. On this particular afternoon and by this particular visitor, the workspace was perceived as a window into a project that could benefit exponentially from digital documentation and visualization.

HISTORICAL BACKGROUND ON THE PORTRAIT

Polychromy studies have been the focus of research for the 'Ancient Sculptural Polychromy in the Ny Carlsberg Glyptotek' project since 2004 (Østergaard and Pingel, 2009; Østergaard and the Copenhagen Polychromy Network, 2009, 2010, 2012; Therkildsen, 2011, Østergaard, 2011; Ny Carlsberg Glyptotek, 2012a, 2012b). This interdisciplinary project comprises collaboration from academies of art history, chemistry, classical archaeology, conservation, and geology in a collaborative called The Copenhagen Polychromy Network.

The Glyptotek acquired the Roman portrait that serves as the subject of this case study, IN 821 (fig. 3.1) in the early 1900s. Considering the portrait dates to around AD 235, it is still in quite good condition save for a broken nose, scratches and encrustations on the face and chips to the ear. The portrait was sculpted from a fine-grained white marble and displays fine detail characteristic of a high level of craftsmanship. Subtle differences in texture give depth and dimension to the hair, eyebrows and expression of the youth.

This portrait is of particular interest to the Copenhagen Polychromy Network as a result of the highly polished skin surface, especially on the cheeks and chin. It is one of a few sculptures that are being examined to set a score.

> In the course of the second century A.D., sculptors began showing irises and pupils on marble sculpture by means of incision and carving. At the same time… on marble portraits of the highest quality, the skin surfaces are polished to a porcelain-like gleam. These developments have been interpreted as heralding a new monochrome aesthetic in sculpture, born of an increased appreciation of the materials themselves. However… color demonstrably continued to be used on sculpture, both in the round and in relief. (Østergaard, 2008: 56)

The Roman boy (IN 821) and a selection of other Late Severan Roman portraits with highly polished surfaces have been scrutinized in order to assess whether the onset of incised eye anatomy and a high degree of polish on the skin indicate that only statement features were painted. Investigative results confirm that they do not

(Skovmøller and Therkildsen, 2012). Examinations under raking light, microscopy, ultraviolet fluorescence and visible-induced luminescence were undertaken in order to detect traces of pigmentation. These investigations yielded traces of pigments on all features of the portrait. If not to showcase the quality of the material and artistry of the sculptor, the highly polished surfaces are believed to have leant to the achievement of a highly realistic aesthetic (Skovmøller and Therkildsen, 2012: 40). Priming was further enhanced by the application of thin layers of paint by skilled artisans using techniques of shading, highlighting and tonality to achieve a realistic representation of the subject. In this way, applying thin layers would allow the marble material to be drawn through the paint, which would contribute to special optical effects.

FIG. 3.1. THE ROMAN BOY (IN 821).
(*Images Taken by R.H. Therkildsen and Provided Courtesy of the Ny Carlsberg Glyptotek*)

POLYCHROMY BACKGROUND

Marble statuary has long been viewed as the height of sophistication. While admiring classical sculpture one is struck by how stark beauty lies in the small details: the meticulous finishes of texture, the subtle chisel marks brandished by the hand of the artist, the grain of the stone. The pristine white marble statues so common to contemporary museum galleries and sculpture gardens, however, emanate quite a different aesthetic than that which their sculptors originally intended. Clean classical sculpture was instead polychrome, painted in many colors. In antiquity, this stylistic technique pervaded both the spheres of sculpture and architecture and was regarded an important implement in conveying the essence of the subject (Østergaard, 2008: 40).

How do we know classical sculpture was polychrome?

Although it has long been established that the statuary and architecture of antiquity were painted in color, much debate has ensued and still exists as to the extent and stylistic trends (Richter, 1928). As the debate is rooted in an intersection of archaeology, aesthetics, philosophy, and ideology, views have historically been complicated and entangled (Brinkmann, 2004: 36–37; Østergaard, 2004). This is mainly because examples of well-preserved classical sculptural polychromy have very rarely been discovered. In the majority of cases, direct evidence of pigmentation has been preserved in small swatches. These remaining extant vestiges are often so minute that they elude the eye and are visible only under microscopy.

Remarkably, a few sculptures have been discovered with an impressive amount of intact color information, notably Sciarra Amazon (Østergaard, 2008: 48; Therkildsen, 2011: 31) and the Treu Head (Verri et al., 2010). While pigmentation has been discovered among the different features of a great number of sculptures, cases have been noted, especially in the area of Pompeii, where skin was left uncolored. In these instances, skin was instead toned with the application of wax in a process referred to as 'ganosis' in the ancient literary sources (Richter, 1928; Østergaard, 2008: 47, 49). Whether they are contemporaneous or indicative of different trends is unclear. Skin pigmentation has served as a particularly acrimonious issue within the field of polychromy studies. Scholars are of different schools of thought on the subject. One group believes that solely the expressive facial features were represented in color while skin was either highly polished or treated with wax. Another adheres to the conjecture that classical statuary was portrayed in full color (Verri et al., 2010: 42).

The aforementioned Treu Head stands as an archetype for the latter group. The Treu Head is a Roman bust dating to the mid-second century AD, which contained an unprecedented amount of original pigmentation when acquired for the British Museum in 1884 (Verri et al., 2010: 39). The Treu Head manifested a noteworthy amount of pigmentation especially on the face (for specifics on the thickness and composition of the Treu Head's pigment traces, please see Verri et al., 2010: 44). Displaying such direct evidence, the Treu Head has held a definitive role in the debate surrounding polychromy, especially in terms of the degree to which portraiture manifested skin pigmentation.

In terms of indirect evidence, bare swatches of marble, although devoid of any paint remnants may still provide clues (Brinkmann, 2008: 21; Ny Carlsberg Glyptotek, 2012b). Deviations in stone color, called 'color shadows' as well as erosion marks on the stone tell a story. These minute differences in the color and morphology of the present marble surface demonstrate that pigments stood with varying permanence and weathered away at different rates. Another clue previously hidden under paint, are faint incisions. These marks were made by sculptors to guide painters and indicate that color placement was carefully considered and carried out.

Lastly, evidence exists in the written and archaeological record to suggest that ancient sculpture was painted in color (Brinkmann 2004: 39). Surviving paintings depict polychrome statues and architectural elements. Some of the manifestations of polychromy suggest that coloring may have been with shades closer to pastel than primary colors (Østergaard, 2008: 45–46). Whether this is indicative of the polychromy or the painting style of the time can be debated.

From what were pigments made?

What is known about the components of pigments used in antiquity has been gleaned from the written record and more recent scientific discovery. Pigments were primarily composed of inorganic materials such as minerals (table 3.1). Occasionally organic materials were extracted from plants and animals and incorporated in pigments, perhaps as binding agents (Ny Carlsberg Glyptotek, 2012b; Beale and Earl, 2011). In these cases, small amounts of binding medium were mixed with minerals to yield pigments. Due to the slight original presence and poor preservation over time, binding mediums are difficult to detect.

TABLE 3.1
PROMINENT PIGMENT COMPONENTS

PIGMENT	**COMPONENTS**	**DESCRIPTION**
CINNABAR	mercuris sulphide	popular, expensive red mineral pigment
OCHRE & HAEMATITE	iron oxide	earth color found in hues from orange to reddish-brown
RED LEAD	lead tetroxide	red in color, also known as 'minium'
MADDER LAKE	organic pigment derived from root of madder plant	pinkish-red in color, also known as 'alizarin'
ORPIMENT & REALGAR	arsenic sulphide	used to produce yellow pigments
AZURITE	copper mineral	source of deep blue, weathers into malachite and turns green, expensive
MALACHITE	copper carbonate mineral	green in color, quite expensive
EGYPTIAN BLUE	silicium, natron, calcium	oldest known synthetic pigment, made from sand, sky blue, also used to create highlights
CARBON BLACK	carbon	used to create shadows
LEAD WHITE	lead carbonate	synthetically produced white pigment
(Verri et al., 2010; Ingemark, personal commun.; Ny Carlsberg Glyptotek, 2012b)		

What function did polychromy serve?

Polychromy has been interpreted as a stylistic trait common to constructs of antiquity including both private portraiture and public monuments. Providing social and religious context, color enabled people to understand the unspoken narrative of sculpture. In addition to the physical morphology and geometry of the surface, colors were used to add depth, enabling people to comprehend complex imagery related to mythology and history from afar. Although the occurrence of enduring pigments has been debated on the following, Ara Pacis Augustae and Trajan's Column are prime examples of monuments where color would enable vision and comprehension on the part of the viewer (Østergaard, 2008: 52). Examples of color layering and the use of color as a means to highlight, shadow, tone and contour substantiate this notion.

These techniques also indicate that polychromy was used as a means of refining the appearance of the statue and making it more true-to-life. The aim in replicating the likeness of a person or event was to reanimate it in a way that made it seem as realistic to the viewer as possible. Brinkmann (2008: 24) relays, "Not only do the ancient writers tell of paintings of grapes so convincing that birds hungrily darted at them, they also single out sculptures at particular shrines that struck pilgrims as fully alive. The goal of the artist was to give life to his work."

Here again the Sciarra Amazon (Therkildsen, 2011: 32) and Treu Head (Verri et al., 2010: 45, 50) are exemplars of the intricate use of color to create tonal effects. The Treu Head was painted with a palate of precious pigments paired to achieve precise color and tonal effects. Verri et al. (2010: 39)

> found that complex mixtures of pigments, and selected pigments for specific areas, were used to create subtle tonal variations. These included: calcite, red and yellow ochres, carbon black and Egyptian blue for the flesh tones; calcite to provide highlights on the flesh areas; lead white and Egyptian blue for the eyeballs; a red organic colourant in the nostrils, the lachrymal ducts and the inner parts of the mouth; and red and yellow ochre for the hair.

Through this layered carefully plotted evidence, it can be considered that painting was quite a thoughtful process, regarded nearly as painstakingly as sculpting.

How can polychromy be detected?

Color has degraded steadily since their application in antiquity. Thousands of years of exposure to the elements and more recent handling, cleaning and casting have worn off and catalyzed the chemical breakdown of the pigments, leaving them nearly undetectable today. Even colors seen with the eye just a half century ago are waning at alarming rates (Østergaard, 2008: 42). This factors in for the 'time is of the essence' outlook of polychromy research and documentation. Undertaking such an endeavor is vital in creating new knowledge on the topic of sculptural polychromy, understanding what processes are to blame for deterioration and developing a strategy for preventative treatment (Østergaard, 2011: 23–24).

Many tools (table 3.2) can be applied to the detection and study of sculptural polychromy starting with the naked eye and extending to more powerful techniques. These have proven essential in discovery and identification of isolated cases of pigment, as well as in more complex instances of pigment layering. Raking light has been useful in highlighting morphology on a macro scale. This enables photographs to uncover the barely discernable weathering traces, chisel marks and incisions that guided and inspired painters (Brinkmann, 2008: 22). "With the help of more advanced analytical techniques… it is possible to definitively ascertain the composition of a pigment layer" (Brinkmann, 2008: 22).

TABLE 3.2
TECHNIQUES USED TO DETECT SCULPTURAL POLYCHROMY

TECHNIQUE	**CAPACITY**
VISUAL EXAMINATIONS	detection of traces of pigmentation and subtle chisel markings under tungsten and raking light by the naked eye and under microscopy
TECHNICAL IMAGING	for reference and study, photographs are taken under different lighting conditions (UV, IR) with color correction
SAMPLING	enables wider range of invasive and destructive investigations (SEM-EDX, FT-IR, GC-MS)
SCANNING ELECTRON MICROSCOPY (SEM)	used with energy dispersive X-ray spectrometry (EDX) for detection of elemental chemical composition
FOURIER TRANSFORM-INFRARED SPECTROSCOPY (FT-IR)	determination of a compound as organic or inorganic
ULTRAVIOLET FLUORESCENCE (UV-FL)	differentiation of materials with similar optical properties but different chemical composition, detection of organic compounds
INFRARED REFLECTOGRAPHY (IRR)	detection of areas of pigmentation depending on the rate of absorption of wavelengths
VISIBLE INDUCED LUMINESCENCE (VIL)	detection of Egyptian blue synthetic pigment which absorbs visible radiation and re-emits infrared radiation between 800-1000 nm.
RAMAN SPECTROSCOPY	detection of areas of pigmentation depending on the state of excitement and scattering of photons
X-RAY FLUORESCENCE (XRF)	detection of chemical composition
RAMAN SPECTROSCOPY	detection of areas of pigmentation depending on the state of excitement and scattering of photons
GAS CHROMATOGRAPHY-MASS SPECTROMETRY (GC-MS)	detection of organic binding elements
	(Østergaard, J.S, and the Copenhagen Polychromy Network, 2009, 2010, 2012; Verri et al., 2010; Therkildsen, 2011)

Casting infrared and ultraviolet radiation on the surface of marble causes sections of it to fluoresce to varying degrees, depending on the chemical composition reflected. It is generally accepted that this is related to bioluminescence, which means that the differences in brightness result from organic material contained in different pigments still embedded in small pores in the surface of the stone (Brinkmann, 2004: 38, 2008: 23; Ny Carlsberg Glyptotek, 2012b). This makes it possible for researchers to "differentiate between materials with similar optical properties but different chemical composition" (Therkildsen, 2011: 31). Visible-induced luminescence (VIL) is a tactic that illustrates the presence of Egyptian blue, a pigment used in sculptural polychromy for the color blue, as well as to create depth and highlights. VIL can uncover pigmentation on a sub-microscopic scale, providing a glimpse past the capacities of the naked eye (Therkildsen, 2011: 32, 35).

As pigments continue to fade, documentation of their presence and research into the causes of their degradation become more important. All of the aforementioned methods of studying polychromy have independently contributed much to the science. "The problem is that there is hardly any objective documentation in formats allowing comparative study" (Østergaard, 2008: 43). In the remainder of this chapter, the ability of digital methods of documentation and visualization to create a platform of convergence between these techniques will be presented, explored and analyzed.

METHODOLOGY ADOPTED

The digitization undertaken in this case study can be divided into two phases: digital capture and the processing of this data into a 3D model. In the first phase, a triangulation laser scanner was used to collect points of reference from the surface of the portrait. In the latter, these points were merged and connected to create geometry mirroring that of the portrait (for hardware and software used in these stages, please refer to appendices B and C).

On-site data acquisition

The Roman boy (IN 821) was digitally acquired using a scanning technique based on trigonometry. The scanner emits a laser beam from a known distance and angle from the scanner's lens, which allows it to obtain the precise x, y, and z coordinates of each point of the object's surface topography (Boehler and Marbs, 2004: 292; Kelly, 2011: 3). Scans convey these measured vertices in three dimensions through the creation of points clustered in a cloud, or point cloud. These points can then be connected to create geometry of the distinct morphology of the object.

Of interest in the acquisition campaign were the properties of dimension, surface geometry, and color information. The portrait was presented for scanning on a turntable in the middle of one of the sculpture galleries. Scans were taken from specific angles and heights as opposed to a head on approach in an attempt to acquire as many points as possible from the more geometrically complex areas, for example under the chin and the top of the head, around the ears, and below the brow bone.

The scanner acquisition campaign entailed capturing two sets of single scans circumnavigating 360° around the portrait. The turntable allowed the scanner to remain stationary at a distance of 17 inches. The first set of 16 scans was captured with the scanner tilted about 135° away from and situated nearly below the portrait, while the second set of 15 scans was captured with the scanner tilted about 45° toward and positioned nearly above the portrait. The turntable was rotated incrementally after each scan to allow overlap between scans for alignment purposes.

With the settings used to capture the geometry of this particular subject, the NextEngine 3D Scanner HD had a dimensional accuracy of 0.015 inch and a capture density of 22,500 points per inch squared. Daylight, delivered through a large window, served as backlighting and two diffuse lights were employed as side lighting on the campaign.

Post-processing

The acquisition yielded a project file containing the 32 single overlapping scans. These scans needed be cleaned and aligned to one another in order to create a cohesive model. The Align feature in the acquisition software presented pins to place in points of common geometry to both scans (fig. 3.2). One by one, each scan was manually aligned. Next, extraneous points were trimmed from the project. From this manually aligned and trimmed model a .ply (polygon file format) file was created for further refinement in MeshLab. MeshLab is free, open source software created in the visual computing lab of the Italian Institute of Information Sciences and Technologies, ISTI–CNR, for processing point clouds into 3D models. MeshLab has been designed specifically with cultural heritage applications in mind and has been used extensively in instances of the documentation and restoration of artifacts, cultural monuments and historic buildings (Cignoni et al., 2008). MeshLab is quite the protagonist of this case study and it is in this software that the model truly takes shape.

The aligned .ply file exported from the scanning software was found to contain 8,673,763 vertices and 17,081,988 faces (fig. 3.3a). Since extraneous points can cause inaccuracies, in order to create geometry with the highest fidelity to the morphology of the subject, it was necessary to make the model as clean and compact as possible. A pipeline of filters to tidy up the model and remove outlying points was run (for specific pipelines used in MeshLab, please refer to appendix D.) Operations to remove unreferenced and duplicated vertices and faces were carried out. In the end, these filters and processes did not lighten the model much, but did eliminate much of the noise.

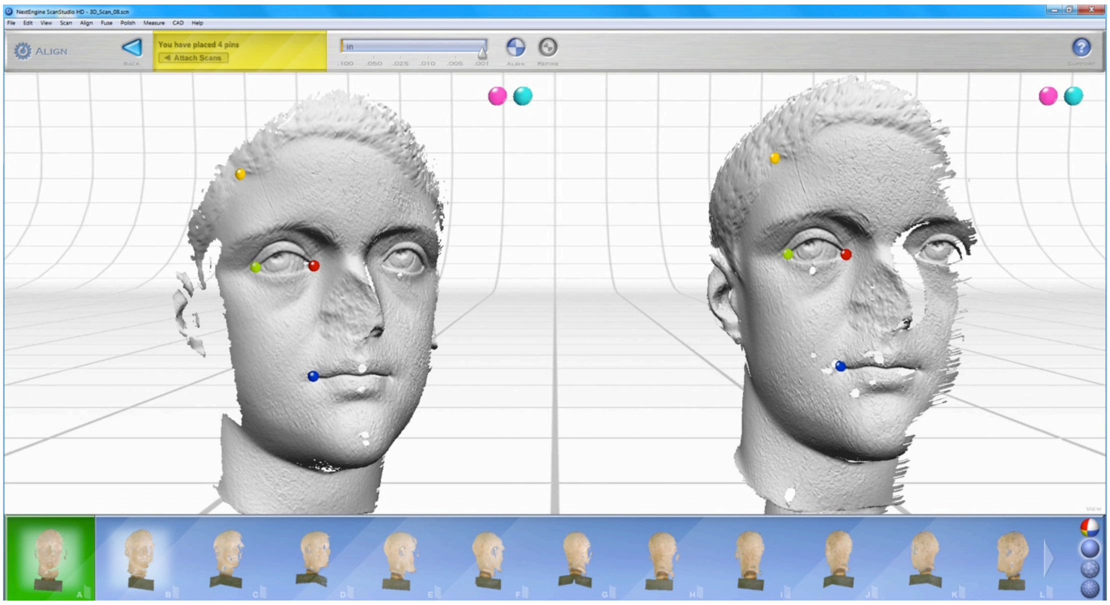


FIG. 3.2. ALIGNMENT PROCESS IN NEXTENGINE SCANSTUDIO HD

Thirty-two scans worth of points make for a geometrically precise, yet exceptionally heavy file. In order to lighten the file and make it practical for use, the number of points within the model had to be reduced. It was of the essence in this case study to strike a balance, creating a model light enough for scientific use without sacrificing the quality of the model. With a clean set of data, the model was next subsampled to display 6,000,000 vertices. This means that the vertices, faces and edges that comprise the geometry of the model are assessed and from these a new point cloud is created uniformly reflecting the arrangement of the samples. A final step in anticipation of recreating the geometry was to further subsample the point cloud according to the Poisson-disk distribution (fig. 3.3b).

From this simplified point cloud, a Poisson mesh was created, in effect redrawing the geometry of the model to create polygons of a cohesive model. Creation of the Poisson mesh also causes the model to lose its color information (fig. 3.3c). Smoothing pipelines were run in an attempt to reduce places on the model that appeared slightly noisier or rougher than the Roman boy (IN 821). These areas were some of the smoothest on the portrait and perhaps their reflectivity caused the laser to create some noise. These actions resulted in the final geometry (fig. 3.3d).

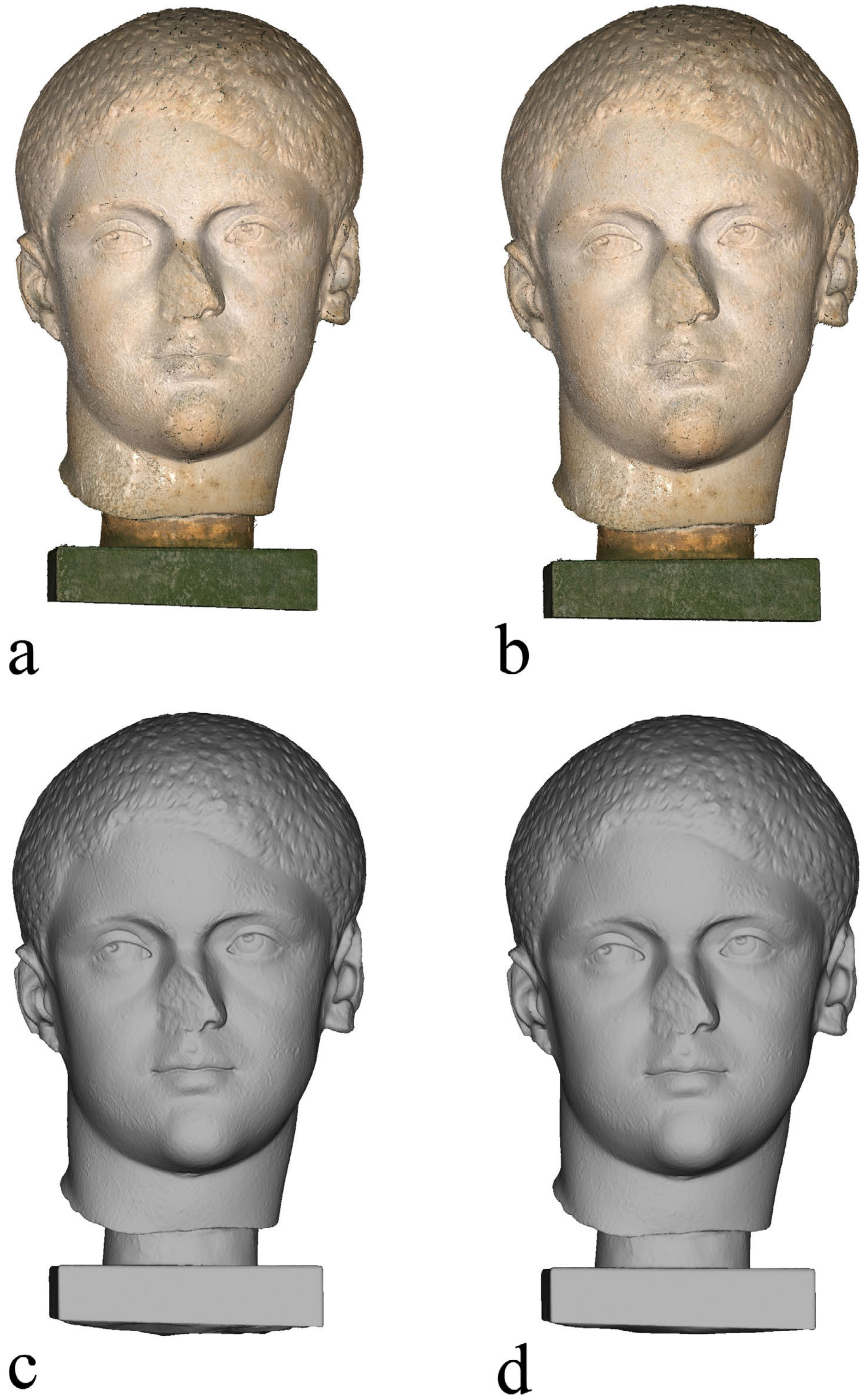


FIG. 3.3. STAGES OF MODEL CREATION IN MESHLAB

a. scans aligned into point cloud, b. subsampled point cloud, c. Poisson mesh, d. Laplacian smoothed mesh

There are a few different manners to project color information on the white Poisson mesh (Callieri et al., 2002; for specific pipelines used for color projection in MeshLab, please see appendix E). Within MeshLab, color information can be transferred from the original point cloud to the final Poisson mesh. This is a per vertex method of projecting color where each vertex is assigned red, green and blue (RGB) color values (Callieri et al., 2008). In many cases, the color information captured by the scanner is not of a very high quality and gets distorted in the process of alignment. The attribute transfer for the Roman boy (IN 821) is one of those cases. Color projection is also possible by texturing mapping color information captured in digital images. In MeshLab, images can be aligned to the geometry of the model by eye and/or optimized by the program (Corsini et al., 2009; Sottile et al., 2010; Dellepiane and Callieri, 2011). For each file aligned to the model, depth maps and different masks are created in order to yield texture mapping with the most fidelity. Masks assign a weight to each pixel,

> calculated by considering three main values: the angle between the normal of the vertex associated with the pixel and the direction of view, the distance between the point of view and the vertex (depth) and the distance of the pixel from a discontinuity in the 'depth map' (that is a map where each pixel has the value of the depth of the associated vertex). These values are combined to calculate a weight. The colour value of each vertex is a 'weighted sum' of the contributions of all images. (Dellepiane and Callieri, 2011)

Model realized

The final model contained 5,709,792 vertices and 11,419,568 faces. The color projected onto the model originated from four photographs (taken in 90° increments) provided by the Ny Carlsberg Glyptotek (fig. 3.1). The color obtained in these images was calibrated using Munsell Color X-rite standards. Images were originally taken in RAW format at a high resolution under tungsten light. Texture mapping these images onto the model proved a more effective manner of projecting color than performing a vertex attribute transfer of the scanner's color information (fig. 3.4). The four image standard used in initial research of the portraits posed a problem for projection. These four images did not provide 360° coverage of the portrait. Information for the areas around the ears, chin and on the top of the head was not captured (fig. 3.4b). Since imaging for a 3D model necessitates images be taken from more angles than generally pursued, the incorporation of a 3D model can expand the scope and structure of study.

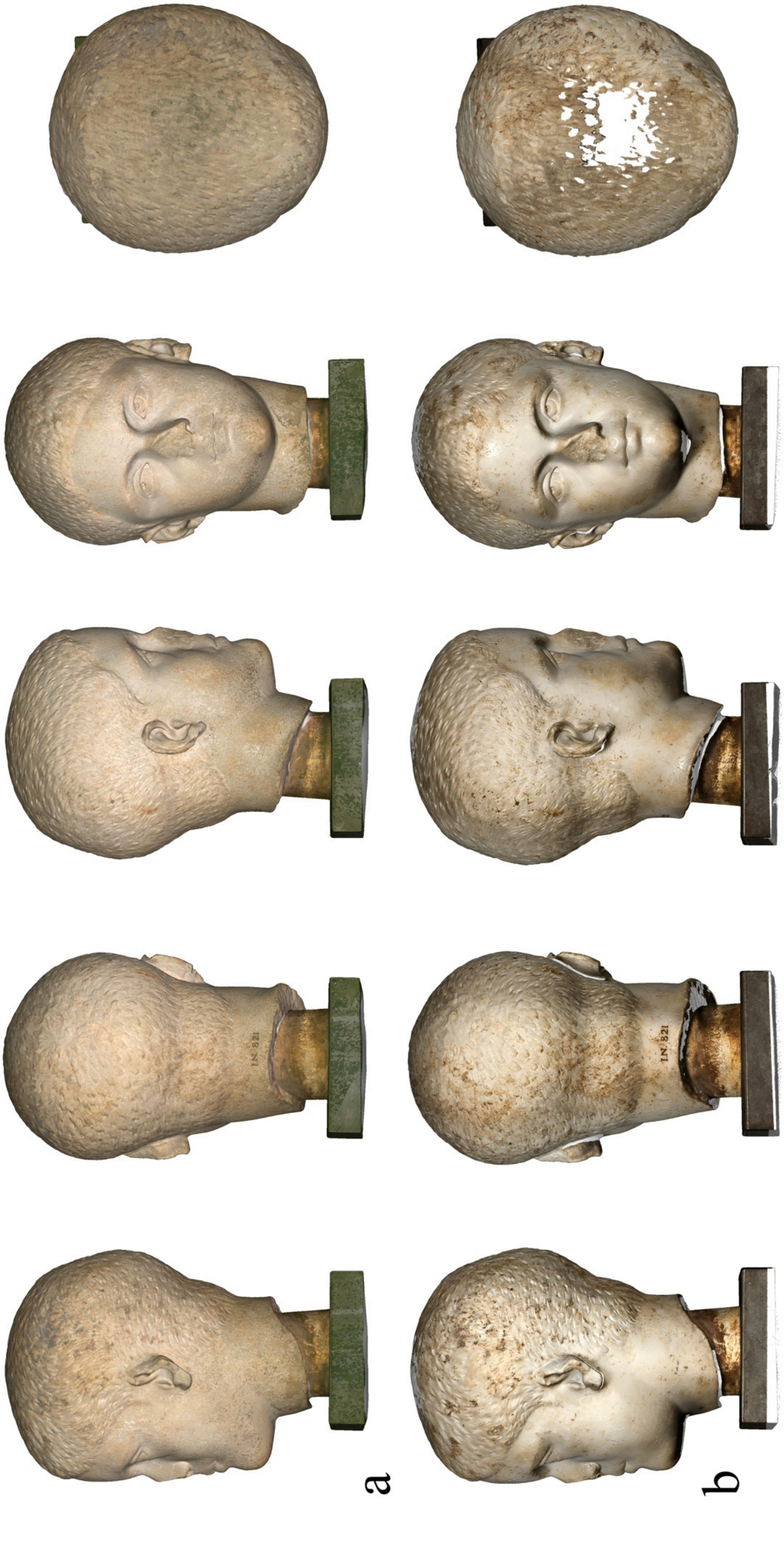


FIG. 3.4. COLOR PROJECTION STRATEGIES
a. vertex attribute transfer in MeshLab, b. texture mapping in MeshLab

Although the current color information is important for general aesthetics and in demonstrating the process of pigment fading and erosion, viewing the model without color information is a method of visualizing geometry that is easily obscured by color texture (Wachowiak and Kara, 2009: 155). In the case of the Roman boy (IN 821), texture is understood as having been intimately connected with the painting. Surface geometry of portraiture was carefully planned out and precisely constructed. The juxtapositions of smooth and textured surfaces played an important role both in setting the stage for paint layers and creating special optical effects. In order to best visualize the detailed topography of the model's surface, geometry-accentuating shaders were applied in MeshLab. (fig. 3.5, appendix F). These shaders enhance perspective of subtle details, like the fine chisel strokes that created the eyebrows and hair (to interact with an in-pdf Universal 3D visualization, please see appendix G).

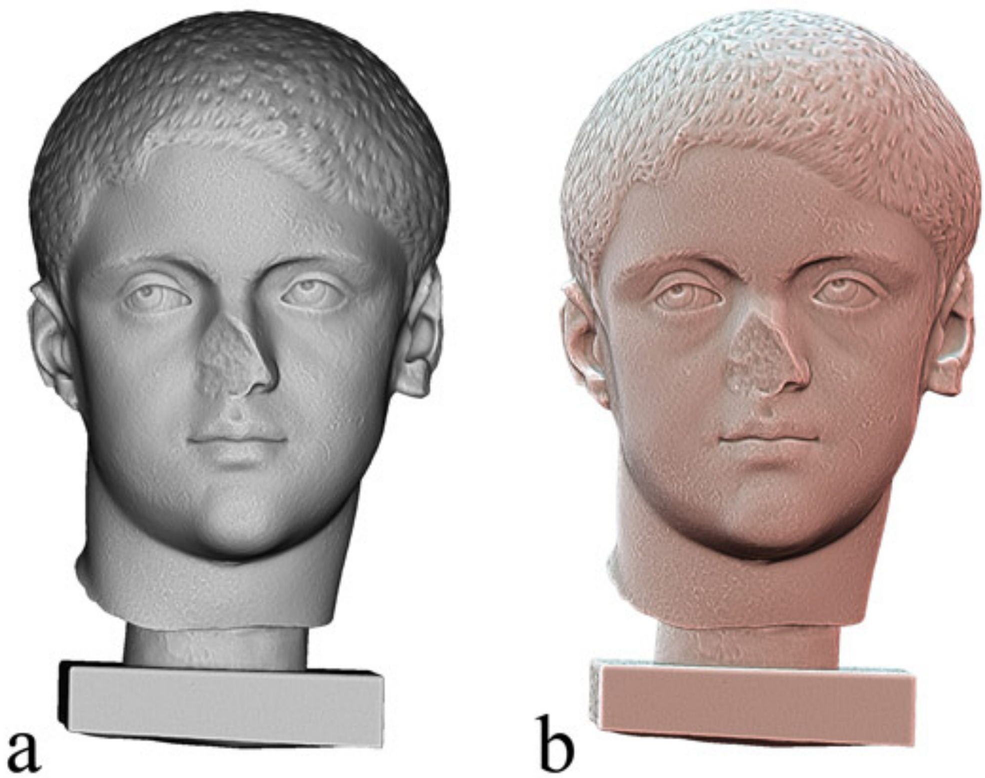


FIG. 3.5. VISUALIZING GEOMETRY IN MESHLAB WITH SHADERS
a. Lambertian radiance scaling b. lit sphere radiance scaling

Equally important to the optical aesthetics of the portrait is the materiality of marble. To access this, the model was next decimated and imported into Blender, free, open source software. This program is used for generation and elaboration of 3D models and computer animation, especially for creating renderings with realistic light qualities. The model needed to be decimated, or reduced in size and quality, in order to be a manageable size for Blender. In this instance the focus is more on color texture and less on geometry, so a slight degradation of the surface geometry is undetectable. Within Blender, the model of the portrait, with its contemporary color information (fig. 3.4b), was assigned properties to match the actual white marble material of IN 821. Ascribing a marble material to the 3D model gave it these qualities subsurface scattering (fig. 3.6). Light is absorbed by, scattered within, and reflected from objects differently depending on specific properties of their material of construction (Jensen and Butler, 2002). Allocating the correct properties to the model enables the model to react to light simulations in the same manners the subject reacts to light and yields a more realistic rendering which can be used in research, but especially in exhibition.

FIG. 3.6. MODEL AS VISUALIZED IN BLENDER

SPECIFIC APPLICATIONS

The main objective of this case study was to create a model that could be used as a speculative and interpretive apparatus for archaeological research. Digital acquisition and the creation of 3D models ring in a new mode of studying statuary. They are not only means of gaining precise documentation, but also create a three-dimensional backdrop upon which to experiment, theorize and visualize data related to polychromy studies. Here many different kinds of data can be amassed and visualized in relation to one another. Allowing for the projection and visualization of imagery in one place, models enable interplay of data three-dimensionally and create a new analytical arena for interpretation. The interactive nature of 3D models provides a manner of visually connecting and relating with the portrait, sculptor and painter to a degree that has yet been unprecedented. Models stand as three-dimensional canvases upon which researchers can both explore and communicate their data within research communities and to the public. Outside of research, creation of 3D models of classical polychrome statuary also has many implications for conservation, dissemination and exhibition.

Projection of technical imagery

Among the uses of 3D models, giving dimension to data is one of the most important. Advanced technical images derived from methods such as VIL, ultraviolet fluorescence (UV-FL) and infrared reflectography (IRR) can be projected on the model to convey detection of organic compounds or pigmentation and to present the unique opportunity to explore data in three dimensions. Information obscured by the light of day, while on exhibit in a museum gallery, can be unlocked through special modes of photography. Projecting this information on a model enables researchers to experience it in a more realistic way than through two-dimensional photography.

Equipped with VIL and UV-FL images provided by the Ny Carlsberg Glyptotek (fig. 3.7), the model was texture mapped to exhibit these images (fig. 3.8). The white flecks observable in VIL images (fig. 3.7a and 3.8a) convey the presence of Egyptian blue. Note the flecks of Egyptian blue among the tufts of hair, under encrustations, as well as on the smooth skin surfaces. The UV-FL images (fig. 3.7b, 3.8b and 3.9) showcase the presence of organic compounds on the surface and within the pores of the marble’s surface. These traces are demonstrated through fluorescence.

FIG. 3.7. TECHNICAL IMAGERY OF IN 821 *(Images taken by R.H. Therkildsen and Provided Courtesy of the Ny Carlsberg Gylyptotek) a. visible-induced luminescence, b. ultraviolet fluorescence*

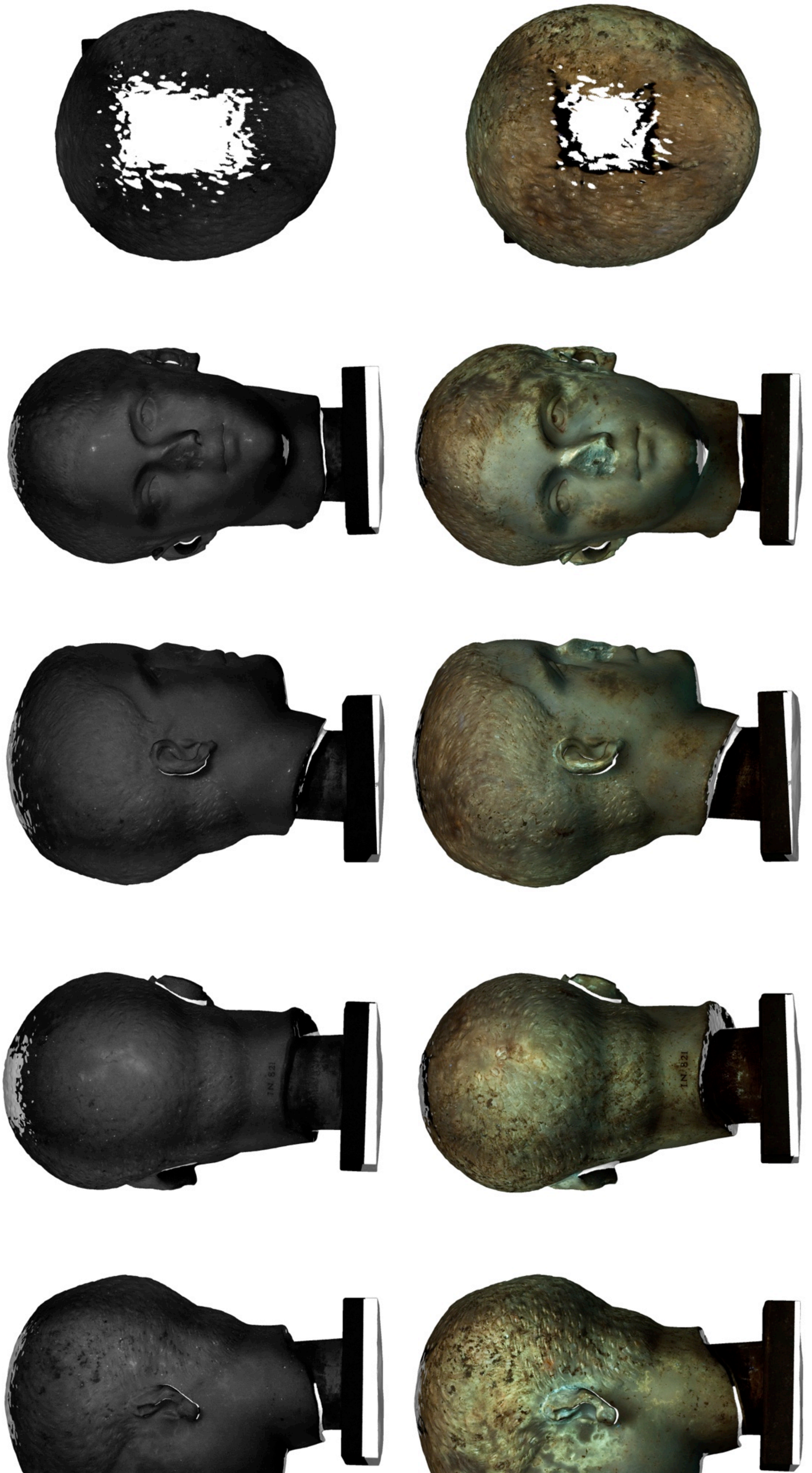


FIG. 3.8. TECHNICAL IMAGERY TEXTURE MAPPED ON THE MODEL WITH MESHLAB
a. visible-induced luminescence, b. ultraviolet fluorescence

The same issue of coverage as was experienced with the Tungsten images (fig. 3.4b) was encountered. Despite the blank areas, the detail of the projections is quite exceptional, evinced in a side-by-side comparison of the eyes of the portrait as imaged (fig. 3.9a) and as modeled (fig. 3.9b). Both representations of the UV-FL information provide great detail as to the presence of organic compounds around the tear ducts. The projections can be opened together and visualized in layers for comparison.

a

b

FIG. 3.9. COMPARISON OF AN AREA OF DETAIL
a. UV-FL image taken by R.H. Therkildsen and provided courtesy of the Ny Carlsberg Glyptotek, b. 3D model with UV-FL data texture mapped

Mapping of pigment traces

Along with technical imagery, visual examinations of portraits help conservators to paint a more complete picture of how pigments constituted the polychromy of antiquity. Models can serve as 3D maps for pinpointing sources of color information detected with the aid of microscopy. These points of pigment are designated distinct x, y, and z coordinates on the 3D model, making easier the reference, discussion and comparison of pigment traces. This leads to more accurate studies of the positions and interactions of pigments and chisel marks.

The subject of this case study has been examined for traces of pigmentation quite extensively. The areas of greatest interest to the Copenhagen Polychromy Network on this portrait are the skin surfaces that exhibit a high gloss finish. On these surfaces, despite subsequent cleanings and handlings, evidence of pigmentation was found. The Ny Carlsberg Glyptotek provided their data related to source locations of pigmentation on IN 821 in the form of two-dimensional images circumnavigating the portrait in 90° increments, taken at 0°, 90°, 180°, and 270° (fig. 3.10).

FIG. 3.10. PIGMENT TRACES ON IN 821 MAPPED IN 2D
(*Images prepared by R.H. Therkildsen and Provided Courtesy of the Ny Carlsberg Glyptotek*)

Numbers were assigned, grouped by feature and pigment color, to the 368 points detected on the sculpture. These points were then plotted on the 3D model using the PickPoints tool in MeshLab. To avoid distortion or possible loss of information through texture mapping the images from figure 3.10, the points were plotted by eye with the previously prepared labeled images for reference. Descriptions of the locations of pigment traces on the portrait and of points plotted on the 3D model were compiled (table 3.3 located in appendix H). This table could be input into or serve as the basis for a sort of relational pigment trace database with statistics on color, feature, coordinates and related data obtained through technical imaging.

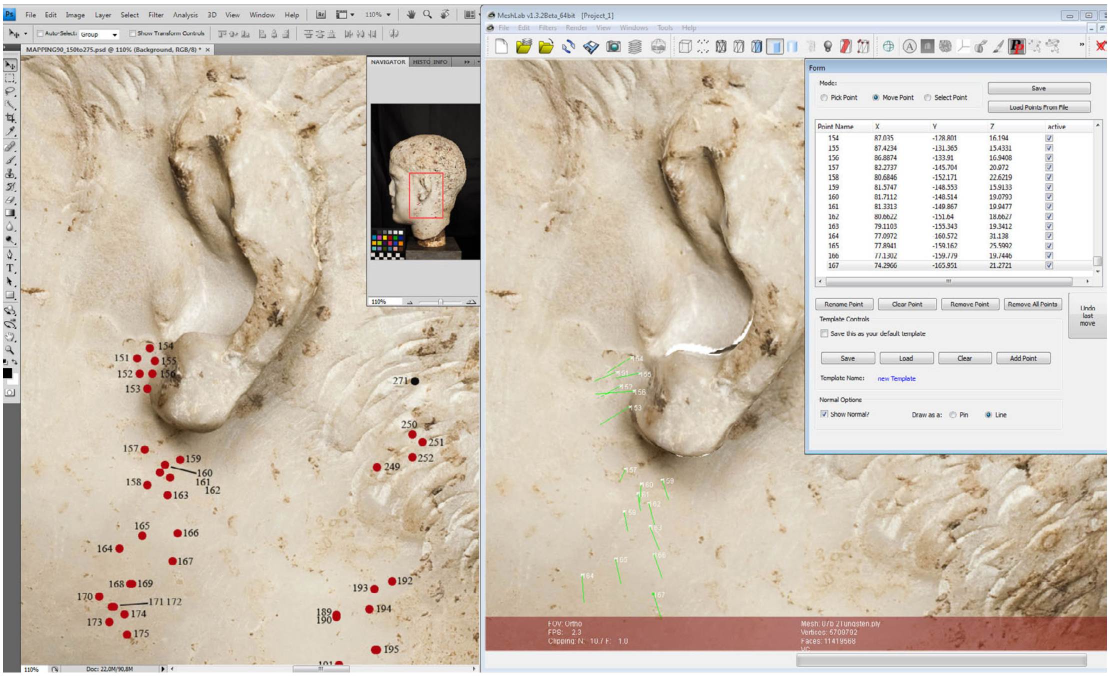


FIG. 3.11. MAPPING PIGMENT TRACES THREE-DIMENSIONALLY IN MESHLAB
screenshot: l. labeled image of IN 821 taken at 90° (portrait's left side) in Adobe Photoshop, r. points plotted on the model with MeshLab tool PickPoints

Within MeshLab, the PickPoints tool allows a cluster of points to be saved independently of the project and uploaded onto different 3D models. This is applicable to the case of IN 821 in that the points can be visualized on the tungsten, UV-FL or VIL 3D models to show correspondences between the presence and color of pigments detected visually and the advent of luminescence or fluorescence captured in imagery (fig. 3.12). Relation to surface geometry can also be visualized and explored. This is especially relevant for evaluating areas of detail (fig. 3.13).

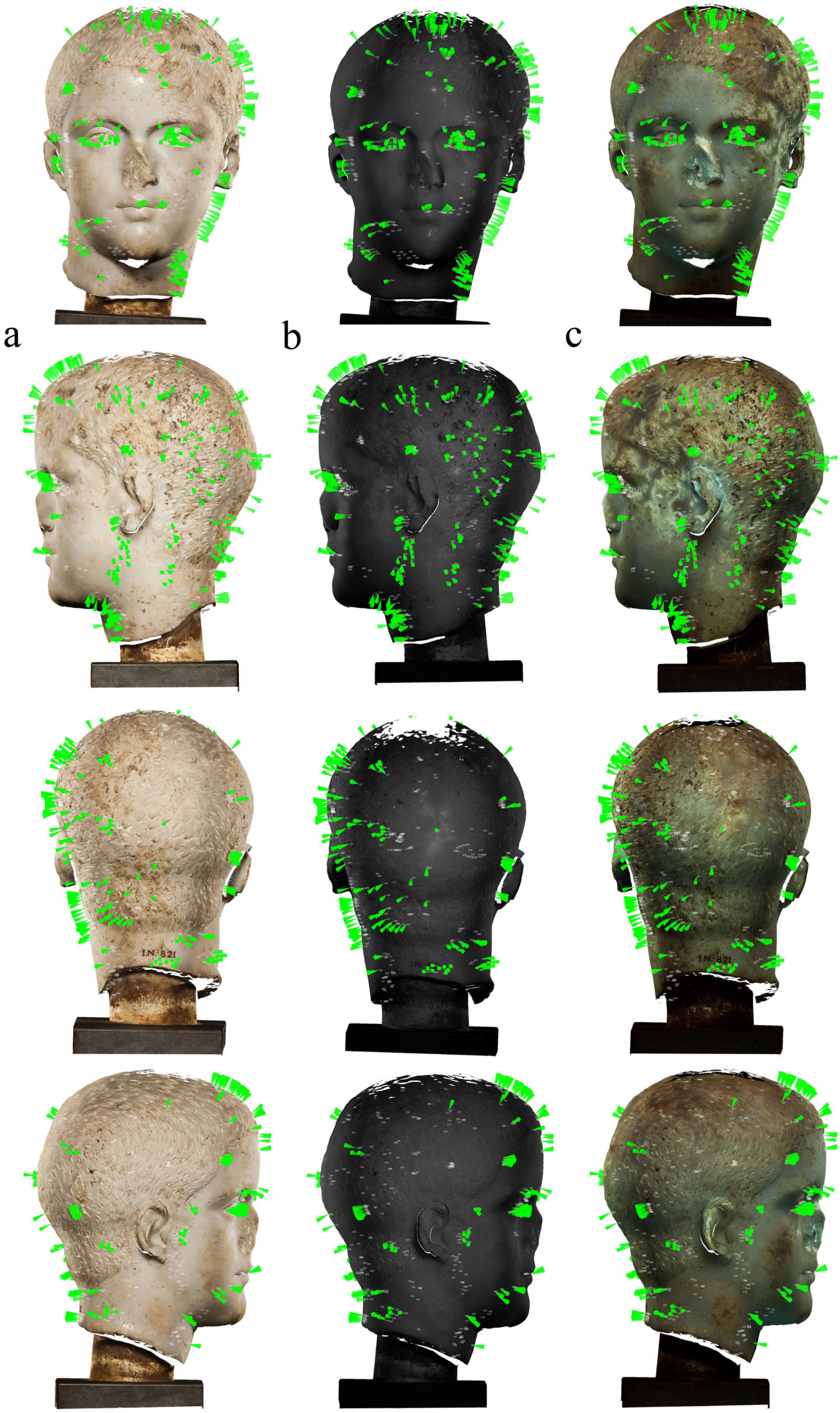


FIG. 3.12 PIGMENT TRACES ON IN 821 MAPPED IN 3D IN MESHLAB
a. tungsten, b. visible-induced luminescence, c. ultraviolet fluorescence models

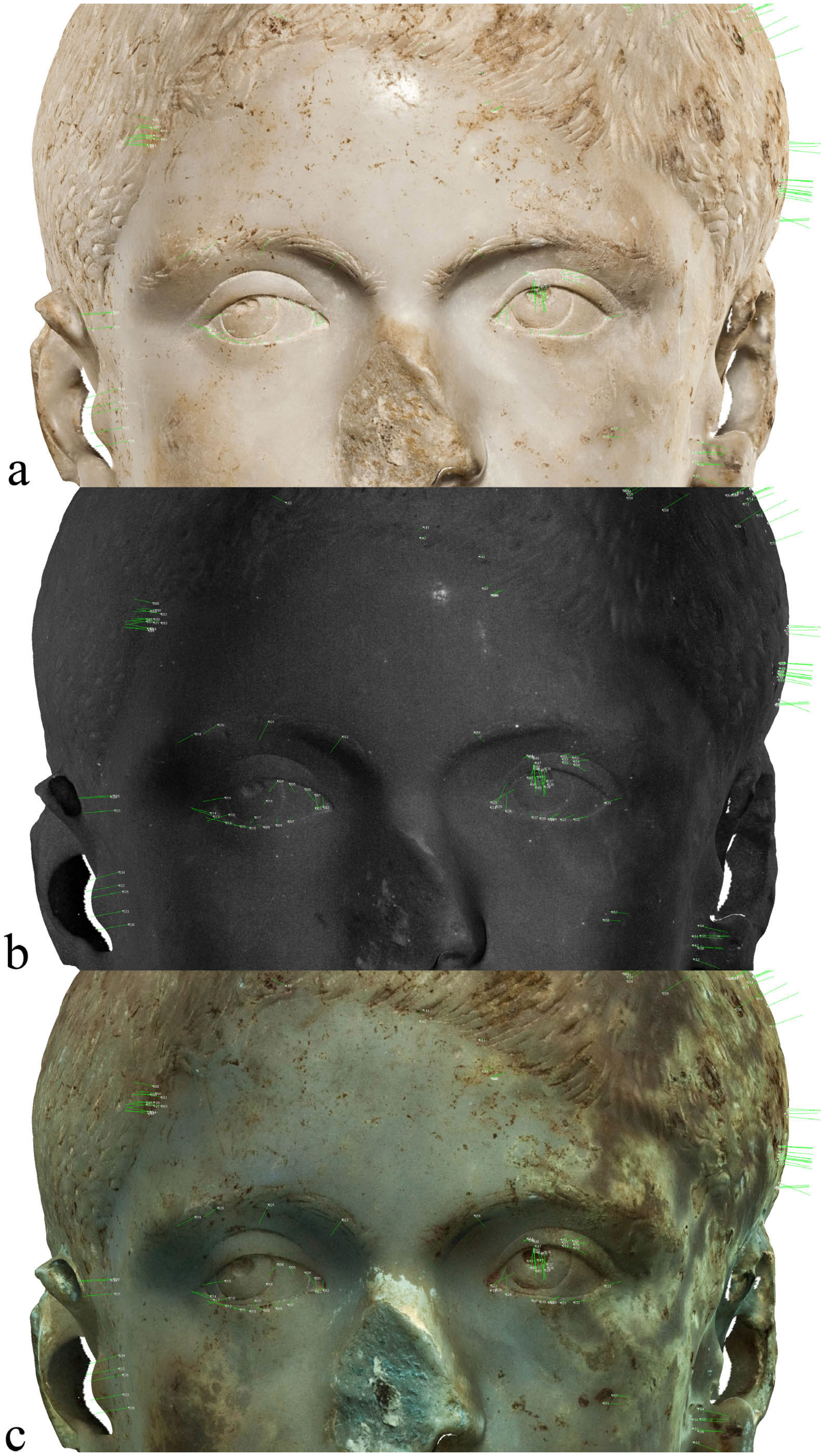


FIG. 3.13. CORRESPONDENCE OF PLOTTED POINTS TO TECHNICAL IMAGERY
a. tungsten, b. visible-induced luminescence, c. ultraviolet fluorescence

These 3D maps can be used for reference, analysis and comparison. The advantage of this type of mapping is the spatial component, which enables researchers to interact with and experience the data in a different way. Generally pigment traces are sought out by eye and microscope and mapped two-dimensionally. Three-dimensional mapping allows the pigment points from regions in close proximity from separate images to be visualized together and under different radiation. The correspondence of the data to surface geometry is also of great importance. On any model color information can be turned off and on to explore the relationship between surface geometry, pigment pinpoints, and luminous phenomena. Points of interest can in turn be compared to micrographs or imaged accordingly.

Optimally, the process of mapping pigment traces in three dimensions would occur at the same time as visual examinations, instead of transferred from two-dimensional photographs. The x, y, and z values for points would also be incorporated into object databases and saved along with models, images and other media. This case study serves as an example of a possible outcome of using a 3D model in mapping in the context of polychromy studies. It is, however, important to consider that the margin of error experienced would be lower and the results even more precise if this technique were used as a primary documentation method. Beyond the scope of this case study, 3D mapping has quite broad applications in digital cultural heritage.

Experimentation with the interplay and layering of pigments

Mapping of pigment information on 3D models opens the door for the visualization of color information in many forms with implications far beyond general exhibition. Directly on a 3D model, researchers can apply thin layers of colors corresponding to the pigments from antiquity to different degrees of translucency in an attempt to visualize the effects implemented by classical painters. Painting digitally makes it possible to add and subtract layers and explore the manner in which the interplay of pigments and textures created the ethereal effects that were so central to polychromy's basic tenet of creating a convincing vision of the subject.

In the case of IN 821, through fine detail texturing of the portrait's surface, a sculptor crafted a specific canvas for a painter to work on and those differences in texture when combined with paint created very special optical effects that could be drawn through the translucent layers of paint or accentuated by paint shading and gilding. Another factor in the appearance of the Roman boy (IN 821) is binding medium, which had a distinct impact on the color, concentration and transparency of paint layers. Although no traces of binding medium were found on IN 821, it can be assumed from contemporaneous subjects that egg tempera was among the media that served this purpose. When using egg tempera, paint layers appeared more shiny and opaque (Kakoulli, 2002: 58). Other binding media were likely also used on the portrait to give certain areas a more matte finish. Kakoulli (2002: 65) explains this in terms of subsurface scattering, "Aside from colour, pigments also influence the appearance of a paint layer, since the diffusion or scattering of the light is directly linked to the nature and particle size of the pigment. In general, the finer the pigment particles the greater the diffusion and hence the opacity of the paint layer."

As previously discussed, binding medium and the subtle color nuances created by sculptor and painter are difficult to trace back from a statue's current condition. Even more difficult is recreation without comprehensive knowledge of the sculpting and painting techniques of antiquity as well as how they translate digitally. As a result all color reconstructions, while rooted in thorough research, are highly hypothetical and often hotly debated. Creating digital color reconstructions is a newer field that presents viable alternatives to physical reconstructions (Pintilie, 2011). It is a subject worthy of quite in-depth research and experimentation, especially in classical polychromy. Based upon the research of the Copenhagen Polychromy Network and the Ny Carlsberg Glyptotek, color information was interpreted and a version of the Roman boy (IN 821) was digitally painted in polychrome.

The skilled surface manipulations of IN 821 set it apart from many other sculptures that have previously been the subjects of physical color reconstructions. These surface treatments were painstakingly created with small chisels, picks and smoothing techniques to create a life-like appearance. Viewed in plain white, the understated textures do not appear to have great depth. With the aid of color shading and highlighting, however, they would have gained realistic dimension; in this instance color reconstructions need be as dependent on surface geometry as the mapped traces of pigment. The sculptor and painter of IN 821 collaborated to create an accurate vision of the Roman boy without exaggerated geometry and presumably without excessive color. It was created in a time when colors were used more adeptly and intricately than they had in the past (Claridge, 2011).

This type of portrait necessitates a different approach than has been taken to create other color reconstructions, one that takes surface texture into consideration with as much or perhaps more weight than pigment mapping. A digital color reconstruction was created in Blender (fig. 3.14) based on general advice from experts at the Ny Carlsberg Glyptotek and with inspiration drawn from the Treu Head (RGB values for remnant skin pigments), Sciarra Amazon (eye lashes). The contemporary surface—both geometry and color texture served as the basis for thin layers of paint. To bring the process of creating a color digital reconstruction closer to the techniques used in antiquity, a tablet and stylus were used to mimic the brush strokes of the painting process and imitate pigment concentration produced by pressure exerted. Painting was done directly on the 3D model through texture painting, this instead of painting on 2D images which could have been texture mapped onto the model. Subsurface scattering and specular maps were employed to create the hypothetical reflective properties of marble, paint with different binding media and gilding. This part of the case study aims simply to experiment and thus create a far from definitive digital color reconstruction to generate discourse on the subject of digital color reconstruction. Painters have long been the invisible face of classical sculpture. While they were no doubt exceptionally adroit artists, their identity has worn away with their pigments, so it is interesting to think of re-establishing their presence.

Exhibition and dissemination

3D visualizations make it possible to create and disseminate research information as well as projections of what statuary looked like in color. 3D models allow for different levels of experimentation. They can be duplicated and made to represent many different interpretations along the lines of color placement, concentration, and vividness. These are also more easily changed and manipulated than physical reconstructions with a much wider potential audience.

Color reconstructions, while slightly divisive in the archaeological community give a new face to classical sculpture. They have the potential to market scientific research to possible sponsors, thereby gaining polychromy projects more funding, or target a wider audience, thus bringing in more visitors to a museum. Many exhibition techniques are conceivable. It has been proposed that the color from 3D models can be projected on an original sculpture via video projector to create an interesting exhibition effect (Dellepiane et al., 2011: 54). In this way, the evolution of polychromy research can be represented with traditional and opposing views on old and new hypotheses alternated every few minutes.

FIG. 3.14. DIGITAL COLOR RECONSTRUCTION OF THE ROMAN BOY (IN 821)
created and rendered in Blender

Incorporation of 3D models in museum exhibition can provide the public with more than just a vision of a sculpture in color, but also a depiction of the research that led to those conclusions. Visualizations have the potential to contribute a clearer understanding of how polychromy from antiquity is studied and how it relates to the geometry and finish of the white marble sculptures that line the halls of museums today.

Inclusion of 3D models of polychromy subjects in 'universal collections' can further bring the subjects of polychromy studies to the attention of the remote public. Models can also be manipulated, for feature in virtual reality systems, from marble museum artifacts to animated living storytellers and legacy bearers. Within museums, featuring virtual reality systems alongside collections in special exhibits has great potential. A virtual environment of the workshop of a sculptor would be another effective way of transporting a user into the culture of classical sculpture and acquainting them with the atmosphere, artisans, raw materials, stages of production, and tools of the trade. A precedent in the aim of conveying artistic handicraft through virtual environments has been set by the Virtual Museum of Sculpture (Carrozzino et al., 2011). It is a great mode of diffusion for the intangible aspects of sculpture—artistic techniques, workshop dynamics and the division of labor behind the creation of Roman portraits. Such a virtual environment could be based on archaeological excavation and analysis. Contemporary sculptor, Peter Rockwell's (1991) interpretations of the working processes of artisans at Aphrodisias, based on their unfinished statuary, give one such example. Along these lines, the presence and processes of painters could be hypothesized as well.

Interaction through virtual reality systems and apps can help draw an audience and bring recognition to the subject matter, the institution and its research. For the public, 3D models and virtualizations have the ability to influence perceptions, change preconceived notions and encourage the formation of new interpretations of classical sculpture. Without a doubt, this interest can only have positive effects in the realm of funding that perpetuates new research.

The inclusion of 3D models and data, as the ones herein presented, into a relational or digital database is another step that could be taken to encourage scientific discussion and research. Making models available within an online collections database could give easy access to scholars and institutions for use in inclusion in their collections, research and virtual or physical exhibition.

With high quality surface geometry plotted in three dimensions, 3D printing has become a reality. With a 'click of the mouse,' via email or online collections database, models could be delivered and printed anywhere in the world. Scaled models of both the negative of the model as a mold and the positive of the model as a cast are possible to print (for a recent example of a large-scale 3D printing project at the Smithsonian Institution, please see Pfeifle, 2012). This provides a non-contact method of creating copies of the original portrait, which is leaps and bounds from the damaging methods that have been used to document and replicate previously (Dellepiane et al., 2011: 49–50). Copies could be used for exhibition (on site or as part of a traveling exhibition), research or in the context of repatriation. In terms of repatriation, hypothetically, a Roman museum with a claim to IN 821 could request a digital copy. They could certainly use the 3D model for research and exhibition, however they could also make a 3D print of the model or commission a replica cut from marble based on the geometry of the model. In the event that a museum would have to repatriate a portrait, they could have replicas made for the purposes of exhibition and research and then send the portrait arranged in custom packaging created from the 3D negative to those with the claim.

These are just some of the many possibilities generated from digital acquisition and 3D model creation of a museum specimen. All of the aforementioned applications of digitization promote artifacts and serve to safeguard the important places they hold in both our general cultural understanding and the development of polychromy studies.

ANALYTICAL DISCUSSION

Polychromy studies are an important facet of classical archaeological research as they endeavor to document, interpret and preserve quickly eroding archaeological information. These studies foster a better understanding of classical sculptural polychromy that brings archaeologists closer to their subjects: the painter, the sculptor, and even the customer who commissioned the colorful work. While interest of classical archaeologists dedicated to the study of polychromy is unwavering, this is not always the case as far as the public is concerned.

> Since the mid-nineteenth century, champions of sculptural polychromy have attempted to give scholars and the public some idea

> of what ancient statues looked like by producing colored plaster casts, but for all their efforts they have failed to make a lasting impression. (Brinkmann, 2008: 23)

3D models and virtualizations have the potential to reanimate classical statuary for the public and generate a compelling presence for sculptural polychromy within the broader research community. The heuristic value of 3D models, especially in this context, is without measure. They are active agents of study upon which data from many interdisciplinary studies may be projected and with which researchers and the public can interact in a variety of new ways. The inherent accessibility of 3D models cultivates a collaborative environment. To this end, 3D models can serve the polychromy research community, which seeks to create a forum for interdisciplinary and international research collaboration and hopes to achieve this through making scholarship on the subject accessible (Østergaard, 2011). This project, for example, has spurred mutually beneficial cooperation between Lunds universitet and the Ny Carlsberg Glyptotek. Here, sound scientific research and digital know-how meet to give ancient sculptural polychromy a virtual presence. The result is a progressive collaboration that continues to develop.

Although 3D visualizations can serve as powerful tools for investigation, they are often regarded as merely for exhibition purposes (Flynn, 2007: 86; Dellepiane et al., 2011: 38). It is through research that specimens may contribute to our worldly understanding. It is through research that specimens may be appreciated for their true value. And it is through research that specimens may gain the attention necessary to fund their preservation. Accordingly, the specific applications of the model created in this case study focus on scientific research. They seek not to simply reiterate previous documentation in a different form, but to present documentation in new manners and associations, that stimulate the drawing of new interpretations and parallels between data. In this case, projection of data on the 3D model highlights the manner in which virtual study can extend research methods and forge new relationships between researcher and subject.

It is an aim of this case study, and more generally, of this thesis to illustrate the manners in which an adoption of digital methods of documentation and research can help create new knowledge and perspectives. The capacity for 3D models to engage users, incite critical thought and create feedback make them imperative in the trajectory of polychromy studies as an archaeological science.

The blank spots visible on the models in figure 3.4b and 3.8 demonstrate how 3D models can provide a new scope through which to view data. The white spots highlight a deficiency of two-dimensional documentation and underscore the strength of a 3D model as a tool of scientific research. 3D models present the opportunity for researchers to visualize data in an all-encompassing manner and experience data in spatially state of the art ways. Documentation strategies simply need be adapted to suit 3D models in the future; more extensive photography of the portrait, for example, would have the ability to provide a complete texture mapping devoid of any blank spots or areas of reflection from tungsten lights. This is an example of how the introduction of 3D models can create cybernetic feedback and incite changes in research approach. Along the same lines, 3D mapping executed at the time of investigation would both save time and yield results with the most fidelity.

Technology though, as any man or machine, does have limits. Brinkmann (2008: 23) asks, “How would one reproduce the refinement of the brocade or the lustrous gilding from a few fragments of color in out-of-the-way spots, not to mention the subtleties of the flesh tone?” Even if a deluge of information were preserved, neither man nor machine would be able to reproduce the exact artful nuances created by the skilled painters of antiquity. The complexities of color use on classical statuary make research and representation a tricky field with or without digital involvement. Most often, only microscopic traces of pigment are remnant. These small clues do not provide much to evince the styles and traits of the classical sculptural painters. Still, digital techniques provide researchers with the best methods of studying, documenting, and understanding their data in conjunction. Digital methods also enable researchers to virtually experiment with hypothetical painting techniques. As a result, researchers may also make as many digital interpretive representations as they need. The tools and possibilities digital methods of documentation and research bring to the table are immeasurable.

CHAPTER 4.
CONCLUSION

ON THE ROLE OF DIGITIZATION IN MUSEOLOGY

> We've spent lifetimes and fortunes, both public and private, amassing these collections. They're utilized in small areas, but the questions they can answer are universal. The only way to get at that is to get access to the data. The fruits are far beyond anything we can even conceive. (Michael Mares, director of the Sam Noble Oklahoma Museum of Natural History quoted in Baker, 2011: 658)

The evolution of technology always presents new and different means of cultural diffusion. In 1945, Vannevar Bush published an article in Atlantic Magazine with his views on and predictions of the role of technology in science. Here Bush (1945: 108) introduced a hypothetical device called a memex (from memory extender) for use by an individual as "an enlarged intimate supplement to his memory." He proposed the memex as a piece of furniture similar to a desk in which articles, books, correspondences and data would be stored, accessed easily and visualized on "slanting translucent screens". Forty-five years later, Stefano Bruschini discussed the idea of a digital version of the memex (Frischer 2009). His vision extended the capacity of the memex as a mechanism to visualize different kinds of data, drive new research and create new knowledge. Beyond a data bank, Bruschini considered this a 'knowledge multiplier' with serious applications in the social and natural sciences. It is the adoption of this kind of innovative, positive attitude toward the digital movement that has enabled us to create and apply new technology to cultural heritage. Since Bruschini's appraisal in 1990, the rate of technological development has increased exponentially and similarly the potential for technological advancement in this field, digital cultural heritage, is without measure. Far beyond documentation, digital methods provide opportunities to stimulate new thinking and generate new knowledge.

What roles can 3D models play in the field of museology?

The by-products of digitization are instruments of new discovery that extend reach, enhance meaning and enrich context for cultural heritage. 3D models specifically can be used to expand the public's access to museum specimens, alleviate and monitor the stresses placed on specimens through handling, traveling or exhibition, freeze deteriorating specimens in a specific moment, encourage collaboration between different disciplines and facilitate research. Crosscurrents of influence exist between all of these areas of digital utilization and the application of 3D models, as one serves to perpetuate and uphold the others. The creation of 3D models from museum specimens is a form of digital culture construction, which can be applied in a variety of social and scientific contexts.

3D models can be featured in larger networks, for example digital databases or in virtual reality environments. In the latter, these pieces of digital culture can foster a sense of presence, embodiment or connectedness to create, strengthen, or maintain cultural identity through knowledge repatriation (Dawson et al., 2011: 387). Public interest can also be spurred by 3D and virtual reality representations of museum artifacts. Digital acquisition and creation of 3D models of museum artifacts have begun to play a definitive role in revolutionizing the relationship people have with natural history and how they experience the past.

How are archaeological collections and archives evolving with the adoption of digital technologies?

While digital technologies are transforming the relationships people have with artifacts, fossils and other specimens, they are also altering the presence these collections hold within a museum. Collections management practices are evolving to adapt to the new technologies and forms of information yielded by digitization. In archaeological collections, for example, physical artifacts themselves are not changing, but the manners in which they are housed, archived, accessed and reproduced are. Digital methods have yielded better storage structures and supports for fragile artifacts. Digital databases have begun to make illegible catalogs and precariously placed boxes of archived fieldnotes accessible to anyone over a network. These relational databases connect data about artifacts to their unique point of origin, collector, and time period, as well as to other artifacts. This has made collections information more accessible, connections between artifacts more tangible and collections more pertinent and valuable. Collections are being contextualized and bolstered by the accompaniment of digital documentation, representation and organization.

What questions does museum digitization raise?

Although it can be agreed that digitization has many positive effects, many questions and concerns surround the creation of digital culture and dissemination, which must be carefully considered by any institution contemplating undertaking a digital venture. Perhaps the deciding factor for many museums is cost. Is digitization affordable and cost-effective? In an attempt to address this issue, this thesis presents a case study in digitization using a highly affordable laser scanner and free open source software as well as transparent pipelines.

Major issues concern copyright, ownership, intellectual property, how to control and maintain correct credits and citations, permissions (Weech and Gaus, 2009: 541, 545). Who owns knowledge? This issue is especially relevant in the case of specimens related to aboriginals, ethnographers, or ancestors (Hennessy, 2009: 5, 2010: 75; Singh and Blake 2012: 95). Does digitization infringe on the spiritual privacy, religion or intellectual freedom of the artifact's creators and users? Can digitization devalue an object?

In their recent study, Singh and Blake (2012) interviewed people from museum and diasporic communities to decipher the consensus on digitization of cultural objects from the Pacific. In an account that "encapsulates both his support for digitization and concern" that sacred symbols may be wrongfully reused, a man from Papua New Guinea relayed,

> I see benefits of it… but the thing that I feel uncomfortable about online is that nowadays things are copied and then… replicas of the thing are made and copied. I think that sort of degrades what it is or removes any sacredness of what it is… It's my experience in Papua New Guinea that… China has copied certain images, like a Tubuan image. In fact, my father commented to me once when he saw an image on a lap-lap [sarong], where they separated the [body from] the headdress… He said to me, ''You know, they have ruined our culture by doing that.''

Singh and Blake (2012:100) make the point that not all people were in agreement with the gentleman from Papua New Guinea. Some shared the thought that the facet of a cultural object that is most secret and sacred lies in knowledge related to its creation and use, not in the physical object itself. They believed that if this form of intangible heritage is not the subject of digitization, the sanctity of the object is not compromised and the culture it represents is not 'ruined'.

Other issues center on fidelity and authenticity. Do digital techniques present enough detail for use in research? Are intangible cultural meanings transferrable to digital replicas (Dawson et al., 2011: 397)? Can digital copies convey enough of the cultural context behind an object to worthily embody it? If digital techniques match the detail of the original, does digitization open the door to the creation of forgeries and illegal trafficking of fakes?

Finally, the pace of technological development is called into question (Frischer, 2008, 2009; Rosenthal, 2009). Is it worth it to invest in the hardware necessary when technology is so rapidly changing? Will the evolution of technology soon yield obsolete the digital file codes created? Can digital replicas be viewed with permanence beyond fad (Dawson et al., 2011: 397)? In the present, digital scholars should work on instilling the attitude that digital methods of documentation and research are here to stay. Another point of focus should be dedicated to ensuring the longevity of digital documentation (Rosenthal, 2009).

What does the future hold for museum digitization?

With each successful application, digital methods are gaining more recognition for their ability to effectively organize and visually communicate information about museum collections. While to differing degrees digital documentation currently plays a role in museum research, conservation and exhibition, advancements in precision, speed and capacity of data acquisition and processing will render that role more essential. In the past, the main catalyst for digital visualization was for presenting existing knowledge to the public, however, more recently, this has changed as new techniques for discovery and knowledge creation have been created (Flynn, 2007: 86). Not only can forms of digital documentation be applied to the management, research and dissemination of museum collections, in the future new technology can be evolved to meet the specific needs of this field.

Most importantly in the realms of research, new methods of investigation and visual combination of data will yield the creation of new knowledge. Since value lies in the connection between data more than in one document alone, the development of these techniques in the future is quite important. Digitization will continue to help decipher the story behind museum specimens, unlocking their scientific and cultural value. Research and dissemination will give a face to museum collections and draw public interest. This is one key of truly ensuring the advancement of digitization.

Although it can be considered that the role of a digital document as a tool of scientific research is most important, for digitization to have success it must also have a public presence. Only through a public presence can digitization gain funding and thrive.

This public presence can be garnered through the presentation of new media inciting public interactivity (virtual reality systems, augmented reality apps, Internet exhibits and computer games). Interactivity makes the scope of new scientific discovery and theory not only accessible to the public, but also relevant (Dawson et al., 2011: 388). The potential to spread an understanding of cultural and natural history collections and the way that their specimens contribute to advancements in science that effect everyday life is one of digitization's strongest applications in public outreach (Baker, 2011: 662).

In the future, more networks of scientific research will form, share knowledge and become connected. Hopefully they can become standardized and organized through one organization (Frischer, 2006: 6). This kind of uniformity would encourage digital publication, easier access to information and sharing across disciplines and data types. Official digital publication in 3D and the incorporation of 3D models embedded in databases are further steps that would render third party websites superfluous.

Much thought must also go into assessing the future of digitization methods and determining the longevity of the documents they yield (Rosenthal, 2009). The culture of documentation has changed quite a lot from copies being regarded as back-ups, to the digital copies serving as the document format most frequently used. We are still some generations from completely conceding that our world has become, for the most part, digital and not physical. Still, the size of digital information and the rapidly changing digital climate pose challenges for digital storage and function. A jump to open source as a norm could be another cost effective choice for the majority of cultural heritage and scientific digitization. Open source software has a history of strong community cooperation. As Rosenthal (2009) puts it, "Open source is extremely well preserved, the source code is in ASCII so it is immune from format obsolescence." Hopefully these software alternatives will become commonplace in the creation, study and manipulation of digital cultural heritage.

Digitization is so essential because it offers a means to supplement museum collections without supplanting them. The research opportunities that digital documents unlock are state of the art and lead to important scientific discoveries. The level of accessibility that digitization provides is unprecedented and makes museum collections relevant to the public. The conservation and collections management advancements that digitization compels serve to ensure the safety and continuance of museum collections for the future. Each of these inter-connected effects of digitization pay homage to museum collections, the cultures or scientific movements they represent and the potential they have to play an important role in future scientific discovery.

APPENDICES

APPENDIX A: SIMULATING DUST ACCUMULATION IN MESHLAB (V.1.3.2BETA)

Filters > Sampling > Dust Accumulation
Filters > Sampling > Hausdorff Distance
Quality Mapper

APPENDIX B: ACQUISITION EQUIPMENT

Triangulation laser scanner (NextEngine 3D Scanner HD)
Scanner software (NextEngine ScanStudio HD Pro)
Laptop Computer (running 64-bit Windows and with 16MB working memory)
Diffuse lighting (two lamps)

APPENDIX C: MODEL CREATION SOFTWARE

NextEngine ScanStudio HD Pro
MeshLab V1.3.0a (http://meshlab.sourceforge.net/)
MeshLab V.1.3.2Beta
Blender 2.61 (http://www.blender.org/)

APPENDIX D: MESHLAB MODEL REFINEMENT PIPELINES

Cleaning
Filters > Cleaning and Repair > Remove Unreferenced Vertex
Filters > Cleaning and Repair > Remove Duplicated Vertex
Filters > Cleaning and Repair > Remove Duplicated Faces
Subsampling
Filters > Sampling > Mesh Element Subsampling
Filters > Sampling > Poisson-disk Sampling
Remeshing
Filters > Remeshing, Simplification and reconstruction > Surfaces Reconstruction: Poisson
Smoothing
Filters > Smoothing, Fairing and Deformation > Laplacian Smooth

APPENDIX E: MESHLAB COLOR PROJECTION PIPELINES

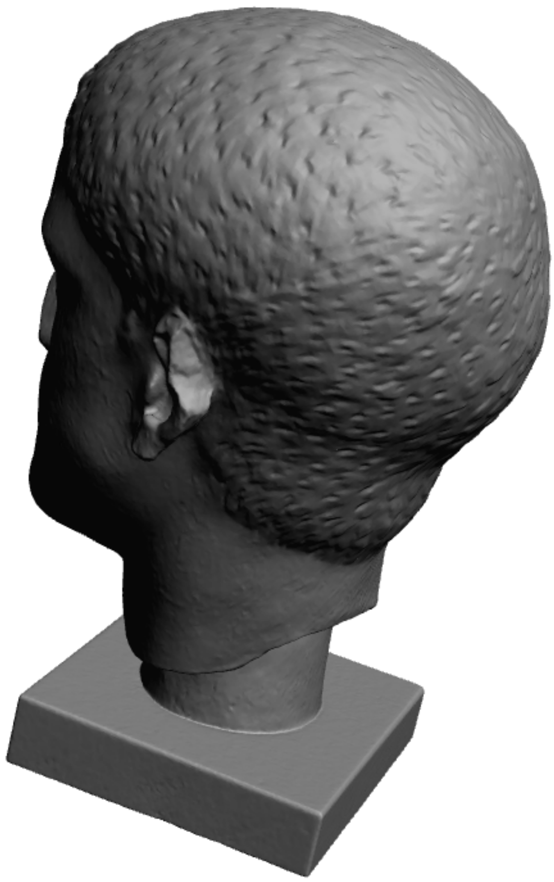
Vertex Attribute Transfer
Filters > Sampling > Vertex Attribute transfer
Texture Mapping (MeshLab V.1.3.2Beta)
File > Import Raster, Filters > Camera > Image Registration: Mutual Information and/or Filters > Camera > Set Raster Camera, Filters > Camera > Project Active Rasters Color to Current Mesh

APPENDIX F: MESHLAB SHADERS

Render > Shader > Radiance Scaling
Render > Shader > normalmap.gdp

APPENDIX G: INTERACTIVE UNIVERSAL 3D VISUALIZATION

click below to interact with model



APPENDIX H: TABLE 3.3. PIGMENT TRACES PLOTTED IN 3D

TABLE 3.3
PIGMENT TRACES PLOTTED IN 3D

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
0° (head on)					
001	-0.369660	-84.600600	60.386200	right tear duct	pink
002	1.406310	-87.544500	60.232000	right tear duct	pink
003	-0.368036	-87.627100	60.763800	right tear duct	pink
004	-8.863530	-80.664000	62.224500	right sclera	red
005	-6.172360	-81.468700	61.973400	right sclera	red
006	-2.617780	-83.069300	61.005000	right sclera	red
007	-6.699990	-89.940000	63.557100	right sclera	red
008	-9.430960	-90.602000	64.029600	right sclera	red
009	-12.281200	-91.041500	63.708900	right sclera	red
010	-15.464000	-91.414700	62.720400	right sclera	red
011	-17.731800	-91.321700	61.391300	right sclera	red
012	-20.993200	-90.948300	58.941100	right sclera	red
013	-23.686900	-90.121500	56.009200	right sclera	red
014	-24.348600	-89.533000	55.091600	right sclera	red
015	-20.991400	-85.251100	58.255500	right sclera	red
016	-11.493000	-85.067000	62.979900	right sclera	red
017	-14.227800	-88.945400	62.583200	right sclera	red
018	-20.179100	-89.006200	59.215400	right sclera	red
019	-27.482500	-69.509900	60.255700	right eyebrow	red
020	-22.253400	-66.814300	62.883600	right eyebrow	red
021	-10.679700	-65.274700	67.457300	right eyebrow	red
022	6.044750	-67.855300	73.099600	right eyebrow	red
023	39.798800	-86.620900	63.619500	left lower lash	black
024	39.632000	-87.576600	64.433100	left lower lash	black
025	40.907200	-87.512400	63.985600	left lower lash	black
026	43.113600	-88.485800	64.742400	left lower lash	black
027	49.036900	-87.794700	65.987700	left lower lash	black
028	52.791900	-90.329400	66.031100	left lower lash	black
029	53.300500	-90.337200	65.874500	left lower lash	black
030	50.886600	-90.055700	66.140200	left sclera	red
031	55.570000	-90.709000	65.271700	left sclera	red
032	58.659300	-90.995900	63.975200	left sclera	red
033	65.948300	-88.794400	58.059300	left sclera	red
034	50.680100	-78.871100	64.811100	left iris	black
035	51.470300	-79.287200	64.226700	left iris	black
036	52.296800	-78.696900	64.806600	left iris	black
037	52.667800	-81.660000	64.801100	left iris	black
038	52.846100	-82.316500	65.333000	left iris	black

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
0° (head on)					
039	52.050200	-82.765900	65.470400	left iris	black
040	50.034700	-82.930400	65.430700	left iris	black
041	48.980000	-82.327100	64.911800	left iris	black
042	48.216000	-80.978100	63.891200	left iris	black
043	50.546800	-80.749300	64.029500	left iris	black
044	48.265100	-75.358700	65.496800	left upper lash	black
045	48.647700	-75.601200	65.618900	left upper lash	black
046	49.609400	-75.894600	65.855300	left upper lash	black
047	50.103100	-76.977000	66.038800	left upper lash	black
048	49.816100	-77.893500	65.704500	left upper lash	black
049	49.723200	-78.520700	65.205400	left upper lash	black
050	56.076900	-75.742300	65.530000	left upper lash	black
051	56.386400	-76.377500	65.646700	left upper lash	black
052	56.375800	-77.061900	65.815200	left upper lash	black
053	58.735100	-76.326200	64.829400	left upper lash	black
054	58.852300	-77.071000	65.032300	left upper lash	black
055	58.902000	-77.836800	65.130000	left upper lash	black
056	36.284800	-67.261800	74.731400	left eyebrow	red
057	66.844000	-113.305000	63.180500	left cheek	red
058	64.864300	-114.808000	64.590800	left cheek	red
059	21.098500	-140.439000	88.286300	lips	pink
060	22.901500	-140.189000	88.130100	lips	pink
061	24.079200	-139.928000	87.770400	lips	pink
062	34.590800	-142.106000	82.805500	lips	pink
063	35.943000	-142.651000	91.985600	lips	pink
064	37.119000	-143.017000	81.127800	lips	pink
065	-26.492000	-158.919000	61.469900	right lower cheek	red
066	-22.939000	-155.982000	66.023500	right lower cheek	red
067	-11.238300	-152.411000	75.210200	right lower cheek	red
068	-8.535510	-152.504000	76.944800	right lower cheek	red
069	-8.348280	-154.629000	77.180700	right lower cheek	red
070	-20.294300	-163.405000	66.799400	right lower cheek	red
071	-26.763700	-186.087000	42.912600	neck	red
072	-23.741200	-187.420000	45.641400	neck	red
073	-22.209500	-188.898000	46.794200	neck	red
074	-10.131700	-210.862000	54.433200	neck	red
075	43.113100	-203.258000	44.727500	neck	red
076	43.806900	-203.258000	44.251000	neck	red
077	44.456700	-202.506000	43.826200	neck	red
078	49.849500	-204.851000	39.973000	neck	red
079	50.554600	-209.300000	37.927200	neck	red
080	51.425400	-209.967000	36.899700	neck	red

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
0° (head on)					
081	50.079900	-219.181000	37.583700	neck	red
082	46.951800	-229.488000	40.491000	neck	red
083	47.347100	-229.544000	40.096100	neck	red
084	43.470700	-227.179000	43.464800	neck	red
085	43.177700	-214.185000	44.390000	neck	red
086	46.013000	-211.555000	42.145300	neck	red
087	38.914700	-35.029000	67.991200	forehead	red
088	40.876600	-36.694600	68.050900	forehead	red
089	41.235200	-36.713800	67.930300	forehead	red
090	-36.131100	-43.735800	38.949500	hair	orange
091	-35.620800	-45.198300	39.763500	hair	orange
092	-34.406700	-45.844700	41.087000	hair	orange
093	-34.424300	-47.692800	41.994900	hair	orange
094	-36.937400	-49.544200	39.993800	hair	orange
095	-37.415800	-50.017500	39.636000	hair	orange
096	-37.555200	-49.579500	39.341300	hair	orange
097	-37.732200	-48.054500	38.923800	hair	orange
098	-37.779100	47.524800	38.800300	hair	orange
099	-36.802200	-45.662600	30.039600	hair	orange
100	-36.090600	-47.287300	39.982000	hair	orange
101	-36.182500	-48.029400	40.138400	hair	orange
102	-22.016800	-14.879400	36.938300	hair	red
103	-5.537920	-16.476800	56.539800	hair	red
104	9.309860	5.184810	33.425300	hair	red
105	13.621500	9.984290	15.100600	hair	red
106	23.632800	6.773140	33.980800	hair	red
107	25.901000	8.237770	26.131800	hair	red
108	37.394200	4.033150	35.912500	hair	red
109	37.165400	3.778460	36.910400	hair	red
110	36.466700	3.559450	38.038500	hair	red
111	35.485700	3.422460	39.152700	hair	red
112	35.208800	2.802990	40.820900	hair	red
113	40.914300	-8.766660	55.068200	hair	red
114	40.749100	-9.547520	55.837700	hair	red
115	40.201700	-10.082000	56.517800	hair	red
116	39.656500	-10.488200	56.914700	hair	red
117	39.666700	-11.137700	57.735400	hair	red
118	38.994600	-10.962400	57.456200	hair	red
119	37.982400	-10.774500	56.953100	hair	red
120	45.334400	7.001560	13.688300	hair	red
121	50.915500	4.114420	21.420500	hair	red
122	5.106660	6.956620	21.258300	hair	black

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
0° (head on)					
123	14.767900	6.331620	32.037500	hair	black
124	12.801200	1.994200	43.536400	hair	black
125	12.643300	1.725440	44.116600	hair	black
126	24.595300	8.811600	23.437700	hair	black
127	24.352500	8.440110	25.877700	hair	black
128	22.682200	7.823500	29.691800	hair	black
129	28.685300	8.712370	19.720100	hair	black
130	26.436300	8.804610	21.849900	hair	black
131	26.390100	8.373350	24.804700	hair	black
132	25.509500	7.397980	30.945900	hair	black
133	26.023600	7.122240	32.110800	hair	black
134	26.293500	6.845920	33.254200	hair	black
135	26.853900	5.275100	37.200800	hair	black
136	28.637600	4.354820	38.648000	hair	black
137	27.944900	3.318860	40.913700	hair	black
138	28.545900	3.353890	40.609500	hair	black
139	25.313700	-5.252630	54.757000	hair	black
140	25.922100	-5.217140	54.698900	hair	black
141	25.771300	-21.134500	64.632300	hair	black
142	24.916600	-23.582100	64.625000	hair	black
143	38.366900	-28.324900	64.802900	hair	black
144	33.087300	3.747150	39.323800	hair	black
145	35.521100	6.202500	30.756400	hair	black
146	42.291100	6.878750	17.040600	hair	black
147	42.496900	6.909050	16.799800	hair	black
148	42.446700	6.839450	17.361500	hair	black
149	43.998200	5.036040	24.670500	hair	black
150	51.362200	4.687410	17.540700	hair	black
90° (portrait's left side)					
151	85.654900	-130.614000	18.877400	face	red
152	85.666200	-132.789000	18.791400	face	red
153	85.791800	-136.203000	18.130900	face	red
154	87.035000	-128.801000	16.194000	face	red
155	87.423400	-133.365000	15.433100	face	red
156	86.887400	-133.910000	16.940800	face	red
157	82.273700	-145.704000	20.972000	face	red
158	80.684600	-152.171000	22.621900	face	red
159	81.574700	-148.553000	15.913300	face	red
160	81.711200	-148.514000	19.079300	face	red
161	81.331300	-149.867000	19.947700	face	red
162	80.662200	-151.640000	18.662700	face	red

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
90° (portrait's left side)					
163	79.110300	-155.343000	19.341200	face	red
164	77.097200	-160.572000	31.138000	face	red
165	77.894100	-159.162000	25.599200	face	red
166	77.130200	-159.779000	19.744600	face	red
167	74.296600	-165.951000	21.272100	face	red
168	73.465100	-167.746000	30.201300	face	red
169	73.533300	-167.734000	29.388700	face	red
170	72.206200	-168.786000	36.840500	face	red
171	71.544400	-170.474000	33.909400	face	red
172	71.551100	-170.607000	33.297200	face	red
173	69.619000	-173.246000	34.796300	face	red
174	69.668300	-173.697000	31.877500	face	red
175	67.376700	-176.975000	32.579900	face	red
176	51.111200	-184.000000	60.141100	chin	red
177	48.677300	-186.212000	56.839600	chin	red
178	53.286400	-184.514000	55.532100	chin	red
179	46.270400	-190.317000	55.272400	chin	red
180	51.646400	-189.803000	47.050000	chin	red
181	46.472500	-196.742000	43.087700	neck	red
182	46.544000	-210.884000	41.738800	neck	red
183	46.999800	-212.321000	41.280100	neck	red
184	44.068000	-215.920000	43.606300	neck	red
185	49.068500	-207.982000	39.577700	neck	red
186	49.557100	-208.661000	39.090200	neck	red
187	51.403200	-213.074000	36.687500	neck	red
188	49.354700	-220.248000	38.388200	neck	red
189	69.580700	-181.650000	-4.155940	neck	red
190	69.465300	-182.137000	-4.114830	neck	red
191	66.976800	-191.695000	-3.326670	neck	red
192	68.196400	-178.208000	-14.514400	neck	red
193	68.790300	-178.527000	-11.775200	neck	red
194	67.996000	-182.510000	-9.983750	neck	red
195	65.963700	-190.178000	-8.658130	neck	red
196	107.270000	-74.333100	-6.520680	hair	orange
197	107.175000	-75.004000	-6.254560	hair	orange
198	107.087000	-76.364300	-8.502660	hair	orange
199	106.700000	-75.949400	-4.887920	hair	orange
200	107.064000	-75.775500	-6.611920	hair	orange
201	107.123000	-75793600	-6.612710	hair	orange
202	106.987000	-77.250900	-7.352480	hair	orange
203	107.221000	-72.966900	-5.822140	hair	yellow
204	107.364000	-73.038900	-6.587960	hair	yellow

POINT	**COORDINATES IN 3D**			**FEATURE DESCRIPTION**	**COLOR**
	X	**Y**	**Z**		
90° (portrait's left side)					
205	107.406000	-73.257000	-7.386390	hair	yellow
206	106.980000	-74.712300	-5.337150	hair	yellow
207	106.893000	-75.144900	-5.183530	hair	yellow
208	72.805200	-22.230000	37.243000	hair	red
209	81.002200	-27.405700	28.958500	hair	red
210	70.860300	-3.954290	1.176720	hair	red
211	94.429700	-27.106400	-11.357900	hair	red
212	99.896100	-36.116300	-9.510810	hair	red
213	97.374400	-30.579200	-20.979900	hair	red
214	100.977000	-37.045600	-18.104200	hair	red
215	103.046000	-40.835700	-17.493100	hair	red
216	106.064000	-47.875400	-19.144700	hair	red
217	105.583000	-45.616600	-28.863600	hair	red
218	79.626400	-20.609200	-63.994100	hair	red
219	98.560900	-39.409200	-54.936900	hair	red
220	102.576000	-42.401500	-44.103100	hair	red
221	102.668000	-42.663000	-44.053300	hair	red
222	102.577000	-42.469900	-44.927500	hair	red
223	102.032000	-41.967800	-47.807500	hair	red
224	101.913000	-42.618200	-49.630600	hair	red
225	96.490300	-53.367400	-72.711500	hair	red
226	88.925100	-45.951300	-79.759500	hair	red
227	90.417400	-48.355500	-78.864500	hair	red
228	92.418500	-49.956300	-77.107100	hair	red
229	93.412000	-50.009700	-75.891800	hair	red
230	109.843000	-71.876400	-36.905300	hair	red
231	109.581000	-72.742100	-38.537200	hair	red
232	109.119000	-73.983900	-40.836300	hair	red
233	190.483000	-74.046100	-38.163600	hair	red
234	106.437000	-90.087300	-35.073000	hair	red
235	106.118000	-87.957900	-47.158500	hair	red
236	106.299000	-80.712000	-53.305800	hair	red
237	105.068000	-78.454400	-60.520400	hair	red
238	103.106000	-80.361800	-64.677000	hair	red
239	102.871000	-87.097800	-61.295300	hair	red
240	97.586300	-76.806100	-77.388300	hair	red
241	90.343700	-95.226700	-80.32700	hair	red
242	87.830500	-103.762000	-78.370000	hair	red
243	77.561000	-101.979000	-90.578000	hair	red
244	73.132800	-99.603800	-95.038400	hair	red
245	92.392300	-120.282000	-50.113600	hair	red
246	90.395200	-116.255000	-64.749800	hair	red

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
90° (portrait's left side)					
247	84.466400	-116.506000	-73.543500	hair	red
248	86.453900	-125.315000	-60.092100	hair	red
249	76.927200	-159.045000	-16.949300	hair	red
250	78.392300	-154.459000	-23.797600	hair	red
251	77.674600	-156.020000	-25.219200	hair	red
252	77.389200	-157.688000	-23.170100	hair	red
253	71.980400	-20.615500	36.823300	hair	black
254	72.433400	-20.858000	36.389100	hair	black
255	72.889400	-21.529800	36.395100	hair	black
256	97.840900	-37.619200	4.9261800	hair	black
257	97.418200	-33.116000	-6.310600	hair	black
258	97.459100	-33.095000	-6.731590	hair	black
259	98.694100	-33.852600	-11.242100	hair	black
260	93.955900	-27.030500	-38.682200	hair	black
261	107.265000	-88.306600	-32.867800	hair	black
262	106.645000	-90.049200	-36.867800	hair	black
263	106.731000	-90.225600	-36.538000	hair	black
264	96.725300	-49.043900	-70.240900	hair	black
265	105.973000	-66.362900	-56.133200	hair	black
266	104.943000	-68.351100	-58.134700	hair	black
267	91.136700	-79.355900	-86.156100	hair	black
268	99.071900	-107.175000	-51.327400	hair	black
269	98.516300	-105.531000	-57.838800	hair	black
270	85.749400	-129.376000	-53.186500	hair	black
271	82.285100	-145.527000	-25.454600	hair	black
272	67.944200	-150.779000	-57.013200	hair	black
273	67.866400	-150.938000	-57.013200	hair	black
274	102.544000	-91.531200	-56.502900	hair	blue
275	102.495000	-91.437900	-56.993600	hair	blue
180° (back of head)					
276	-9.357750	-188.513000	-46.934900	neck	red
277	-9.308470	-188.627000	-46.876100	neck	red
278	-6.187680	-192.765000	-46.256100	neck	red
279	-16.154000	-187.936000	-43.537100	neck	red
280	-18.308600	-188.308000	-41.844100	neck	red
281	-11.572500	-193.039000	-43.927300	neck	red
282	-15.879500	-195.030000	-41.070400	neck	red
283	9.167010	-216.641000	-42.408200	neck	red
284	6.692430	-214.810000	-42.908000	neck	red
285	3.557450	-211.479000	-43.481700	neck	red
286	1.999480	-216.915000	-42.800000	neck	red

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
180° (back of head)					
287	-1.362740	-213.775000	-42.805300	neck	red
288	-4.843720	-211.585000	-42.634500	neck	red
289	-10.560800	-210.770000	-41.293000	neck	red
290	-6.894280	-214.540000	-41.792600	neck	red
291	-5.738110	-217.062000	-41.745300	neck	red
292	47.095700	-204.271000	-31.051000	neck	black
293	51.172700	-214.930000	-20.609500	neck	blue
294	61.327600	-56.192000	-103.604000	hair	orange
295	65.202200	-56.286100	-101.868000	hair	red
296	60.268400	-52.310800	-103.026000	hair	red
297	57.079200	-59.055000	-105.745000	hair	red
298	62.350200	-101.844000	-100.695000	hair	red
299	52.005300	-106.262000	-103.902000	hair	red
300	53.842800	-111.103000	-101.848000	hair	red
301	8.339050	-105.366000	-110.289000	hair	red
302	54.110000	-172.108000	-52.260000	hair	red
303	47.362700	-167.618000	-59.893900	hair	red
304	47.005900	-167.507000	-60.157600	hair	red
305	49.587900	-171.670000	-55.642200	hair	red
306	52.783000	-177.042000	-48.180800	hair	red
307	46.829000	-176.000000	-54.571000	hair	red
308	40.596000	-177.573000	-56.663200	hair	red
309	38.399100	-179.771000	-55.904900	hair	red
310	37.824200	-179.665000	-56.315000	hair	red
311	33.338900	-180.452000	-57.932000	hair	red
312	28.714900	-179.905000	-59.456900	hair	red
313	-41.405000	-69.182500	-86.026900	hair	black
314	-47.223300	-73.910500	-81.484800	hair	black
315	-50.350900	-71.753500	-76.112500	hair	black
316	57.615700	-110.698000	-100.204000	hair	black
317	51.115700	-108.760000	-103.717000	hair	black
318	51.191700	-113.463000	-102.051000	hair	black
319	58.950100	-150.071000	-64.998600	hair	black
320	51.318900	-148.051000	-71.795600	hair	black
321	26.697400	-144.062000	-87.379000	hair	black
322	15.039200	-135.573000	-95.107300	hair	black
323	13.543500	-135.682000	-94.859300	hair	black
324	48.602200	-157.080000	-65.515700	hair	black
325	32.579700	-158.182000	-70.791000	hair	black
326	13.756800	-160.747000	-71.529000	hair	black
327	80.312400	-67.542200	-95.230900	hair	blue
328	45.047400	-180.341000	-51.552600	hair	blue

POINT	COORDINATES IN 3D			FEATURE DESCRIPTION	COLOR
	X	Y	Z		
270° (portrait's right side)					
329	-46.757400	-92.492300	25.667900	face	red
330	-46.090400	-91.612300	28.160700	face	red
331	-45.927200	-94.918700	28.870100	face	red
332	-45.315800	-144.394000	21.792600	face	red
333	-44.504400	-120.122000	23.233600	face	red
334	-45.274400	-110.323000	25.393100	face	red
335	-44.528200	-114.849000	25.834900	face	red
336	-43.365700	-122.083000	28.006800	face	red
337	-28.068800	-184.607000	-33.577300	neck	red
338	-28.526600	-184.289000	-33.051100	neck	red
339	-30.754400	-183.103000	-30.119600	neck	red
340	-30.490900	-184.459000	-30.022400	neck	red
341	-31.963200	-206.680000	-26.961100	neck	red
342	-32.642200	-206.876000	-26.247700	neck	red
343	-35.781100	-207.579000	-22.550500	neck	red
344	-37.833800	-204.060000	-17.638100	neck	red
345	-37.981800	-200.856000	-15.799600	neck	red
346	-40.190500	-196.790000	-8.683360	neck	red
347	-37.056700	-196.029000	-16.635500	neck	red
348	-47.585100	-115.137000	-67.952700	hair	orange
349	-47.810100	-115.852000	-67.187700	hair	orange
350	-49.425200	-114.628000	-65.719000	hair	orange
351	-48.764800	-115.447000	-66.146100	hair	orange
352	-48.409900	-116.344000	-65.873700	hair	orange
353	-47.520100	-117.397000	-66.209000	hair	orange
354	-46.977600	-118.616000	-65.792400	hair	orange
355	-47.728100	-118.285000	-64.868600	hair	orange
356	-47.333900	-119.761000	-63.796800	hair	orange
357	-47.668400	-119.662000	-63.268200	hair	orange
358	-46.635600	-121.028000	-63.750700	hair	orange
359	-46.848000	-121.406000	-62.956400	hair	orange
360	-47.359200	-121.047000	-62.076900	hair	orange
361	-37.249600	-16.696400	-17.319600	hair	red
362	-13.309400	-1.897920	22.982000	hair	red
363	-6.479520	1.789420	25.832900	hair	red
364	-43.311200	-140.036000	-38.016600	hair	red
365	-43.043900	-142.051000	-36.609000	hair	red
366	-43.454200	-143.717000	-33.162200	hair	red
367	-43.867900	-140.207000	-34.500000	hair	red
368	-43.568200	-143.752000	-30.410600	hair	red

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