ABSTRACT

Advances in image and analysis technology have been an immense benefit to the field of museum conservation. X-ray Fluorescence, 3-D imaging and industrial X-ray/CT scans all provide data through minimally destructive and non-invasive analysis.

Recent research at the Science Museum of Minnesota utilized equipment including the Bodelin ProScope HR, the Leica Stereo Explorer, the Next Engine Desktop 3-D Scanner and CT scans provided by North Star Imaging, Inc. This technology not only provides the conservator with needed analysis of composition and detailed images of surface structure, but equipment such as the Next Engine scanner can create three-dimensional images of an artifact that can be viewed from a variety of angles and measured without further handling of the artifact. This technology creates virtual duplicates that can be shared, measured, and studied by other institutions, thus providing larger data samples for researchers and information for conservators without subjecting artifacts to risks through repeated handling.

1. INTRODUCTION

Keeping up with and gaining access to technological tools for analysis is a perennial problem. Not only is cutting edge technology expensive, but a certain level of expertise is required in order to obtain and interpret the data. The Conservation Department of the Science Museum of Minnesota (SMM) and the students at the Arch/Bio labs of the University of Minnesota (UM) found that they needed increasing amounts of technology in the course of work and research. For staff members who have not kept up with technological advances, the escalating innovations in technology can be intimidating. Many distinctly remember a time when computers were not a part of everyday life.

Technology for conservation and analysis is increasingly becoming more a part of the conservator’s job. In recent years, a variety of techniques have been used to answer research questions as well as aid in collections conservation. Today more user friendly computer technology can be used to gather more data and share it.

In the course of the past few years, the Research and Collections Departments at SMM have utilized a number of techniques in order to improve care of collections and to answer research questions. However, the challenge is how to gain access to these technologies and still remain within a budget.

While the list is not exhaustive, the staff at SMM, with the help of partnerships, have been successful in utilizing several types of technology for research and collections management. Microscopic analysis included the Bodelin ProScope and digital microscopy. Three-dimensional imaging was used both in microscopic and macro formats. Research was also aided by X-ray and Computed Tomography (CT) scanning, and X-ray Fluorescence (XRF).

In the “old days” few conservation labs could afford the expense of such high tech equipment. Expenses included the initial purchase and maintenance of a specialized tool along with a technician to run it and to interpret the data. Most institutions were lucky if they had access to good quality cameras, specialty lighting (IR and UV), a computer, and maybe an x-ray. With the advent of more affordable computers, many conservators found themselves struggling to input raw data into computers running DOS and trying to retrieve usable information.
The technology was complicated and expensive. Budgets were (and are) constrained. Museum staff learned about technology out of necessity, often without formal training in the new resources. The more farsighted could see where the technology was going but it was not accessible yet – at least for the casual user. No wonder high tech analysis was used as a last resort.

Times have changed and specialist technical staff is no longer needed to run a computer or an SEM and interpret the data. While the equipment is still very expensive and might require some special training, there are ways to get around the problems of accessing the data and interpreting the analysis. Today, staff members are accustomed to working with computers. New user-friendly software makes the tools and analysis more intuitive and most proprietary software can be downloaded to programs we are familiar with, such as Excel.

2. THE RIGHT TOOL FOR THE RIGHT JOB

A single piece of technology, no matter how versatile, will not provide all the answers. Needed information about an object must be matched with the method. The first question should always be, “what do we need to know about this object?” The second will be how to decide which method works best for the desired output. Each technology has limitations. For example, some types of imaging equipment have limits on the size of object they can analyze, and some equipment requires training in order to understand the data. Using the equipment takes practice. In the case of the ProScope, it is very difficult to get a good image of an insect unless the operator has developed the skills in photographing three-dimensional objects with a limited depth of field. Museum staff will need to know enough about the technology to know if it will answer their questions. In addition, if it is necessary to work with an outside contractor or vendor for analysis, conservators will need to clearly explain their needs to that person. It is essential to be able to work with a technician who can provide the final data in a usable form. With the proper interpretation these technologies can provide insight into many aspects of an object.

3. ACCESSING THE TECHNOLOGY

The technologies being addressed in this paper include digital microscopy, CT scanning, 3-D imaging and 3-D printing. As always, there are numerous ways to gain access to these, depending on the cost and how integrated the technology is into the conservators’ daily routine. Equipment, such as a digital microscope, can be purchased if it is not too expensive and will be used frequently. If funding is not available through operating funds, then grant funding or donations can be sought. The SMM conservation lab used IMLS CPS grant funding to purchase the first digital microscope and a budget surplus to purchase a ProScope. The expense can be justified because it is relatively reasonable and is used constantly for examination and analysis of the collections.

Another tried-and-true method is to develop partnerships with colleagues in other departments or institutions in order to share expertise and data. SMM’s Departments of Archaeology and Conservation developed a close relationship with the UM Archaeology Department. One UM archaeologist, John Soderberg, was adept at 3-D imaging (both acquiring it and at producing top quality images). The author, Gretchen Anderson, took on one of Soderberg’s students, Giovanna Fregni, and the imaging partnership began. During her internship, Fregni began researching early metalworking technology of the Minnesota Copper...
Complex. While studying the museum’s collection of spear points she realized that in order to examine use wear and accurately measure the collection, she would need equipment that would provide a better surface image as well as 3-D imaging that UM could provide. Arrangements were made to transport the artifacts to the university where 3-D images could be made and used for analysis (fig. 1).

Fig. 1. Copper spear point (53-46) from the Science Museum of Minnesota with 3-D microphoto of surface showing wear (Photographs by G. Fregni)

Other strategies must be used for other pieces of equipment that are cost prohibitive, or too large and too complicated for the layperson to use. SMM paleontologist Bruce Erickson connected with North Star Imaging, Inc., a private company that does industrial scanning on engine parts, amongst other things. North Star was interested in expanding their services to museums and SMM was interested in finding out what was in the interior of a Late Jurassic/Early Cretaceous crocodile skull of the species *Goniopholis*. North Star Imaging scanned the specimen in exchange for experience and publicity. They were thrilled to work on something different than the usual fare (fig. 2).

Once an object has been imaged it can also be reproduced in 3-D. Three-dimensional printing technology is not terribly expensive or hard to get. And there are companies available for hire to produce these casts. This may be worth the investment if the object is needed for display or research and is too fragile to be handled.

4. WHAT CAN TECHNOLOGY PROVIDE?

Collections data can now be far more detailed and stored in far less space than ever before. Databases can hold complete descriptions along with photographs and links to the raw data of analysis as well as the interpretation. In addition, the artifact can be compared to the data to track any changes, such as deterioration or fading. By building a file of micro- and macro-photographs and creating 3-D images, the data can also be shared on websites or sent directly to other institutions. Online databanks, such as Britain’s Archaeological Data Services provide an
easy way to share data between field archaeologists, museums and researchers. Three-dimensional images can allow museums to share virtual copies of artifacts without having to remove the original from collections. The result is that researchers do not have to travel to access data about artifacts, and there is reduced handling of fragile objects.

Fig. 2. CT image of *Goniopholis sp.* (Image courtesy North Star Imaging, Inc.)

5. MICROSCOPY

One of the most ubiquitous tools available to the conservator is the microscope. Members of conservation staff are comfortable working with dissecting microscopes adapted to be used with film and digital cameras. With the addition of a software program, they can be attached to monitors or projectors so that a group can see the images as well as being able to capture the images for the catalogue. The images are clear and help in the identification of materials, damage, and pests, and can also be shared amongst colleagues and used in teaching. However, microscopes do have their limitations, especially when the object is too large for the stand.

The SMM purchased and used two types of digital microscopes – both are affordable:

1. Intel QX3 / QX5: It is an educational toy, the modern version of the amateur microscope. It is light, portable and inexpensive, and costs under $100.00. The QX5 is compatible with both PC and Mac platforms. Magnification is at 10X, 60X and
200X, although the optics are not the best, particularly at the higher magnifications. However, they are adequate for pest identification and object examination. The unit is capable of both still and motion capture and can be hand-held or placed in its stand. It works with both transmitted light (for slides and transparent objects) and reflected light (for opaque objects, such as metals and minerals). The stand that was provided with the unit is clumsy to work with. However, a stand was easily built that provided better control for focusing. The Paleontology Department at SMM has used the QX3 extensively in the field to examine and document specimens and because the unit is so inexpensive there is no concern about it being damaged by dust or weather.

Fig. 3. ProScope and image of bronze artifact (A81:5:58) showing where carbonate corrosion has replaced metal (Photographs by G. Fregni)

2. The Bodelin ProScope HR CSI Science Level (fig. 3) is a handheld microscope that can be purchased for a relatively reasonable cost (under $600.00). The ProScope connects to a computer using a standard USB cable and can be used for both still shots and films. In addition, it can be mounted on a standard microscope and be used as a digital camera that downloads directly to the computer. The advantages are that it is portable, and is easy to use and share information. As mentioned above, the ProScope has a limited depth of field, however the range of lenses available (0-10X, 30X, 50X, 100X, 200X, 400X and 1000X) and its ease of use make it a valuable tool for detailed examination of artifact surfaces and pest identification.

6. FROM X-RAYS TO CT SCANS

3-D imaging is also becoming increasingly cheaper - what was $20,000 equipment four years ago now costs $3,000-4,000, including bundled software. Stereo microscopes such as the Leica
Stereo Explorer can be used to create 3-D microphotographs of artifacts. The software layers the images and then builds a 3-D computer model that is then draped with a “skin” that is formed from multiple two-dimensional color images of the object. The measurements are also embedded in the image. The resulting image can be rotated and examined from different angles, allowing the researcher to more easily see minute surface variations and textures. This technology is currently being used at the UM Anthropology Labs to examine cut marks on bone in fine detail. The SMM is also using this technology to examine cord mark decoration and building techniques in Woodland ceramics. The imaging process also aided in the author’s (Fregni) research in Copper Complex metallurgy. By examining the surface she was better able to understand how copper spear points were manufactured and used.

X-ray and CT Scanning also are indicators as to how times have changed. Traditional X-rays “see through” the soft tissue and show the denser skeletal material. These images are very helpful diagnostic tools formed from static, single perspective views. However, CT uses X-rays but provides more data by taking 180-degree images of a body (or object) as it passes through the machine. The resulting images are printed as a series of slices. The technology was developed in the 1970s, with the first medical installation in the US at the Mayo Clinic in Minnesota. At that time all of the images were produced on film. Today the image is digital, making the data easier to reassemble and recreate as a three-dimensional image.

In 1980, archaeology curator Dr. Orrin Shane worked with a local hospital to run X-ray and CT scans on SMM’s Egyptian mummy. A donor had acquired the mummy in the late 1920s and, as it had no provenience, there were concerns about its authenticity. When the museum constructed a new building, the mummy was to be reinstalled in a new case. These events created an opportunity to answer the authenticity question. At that time, Minnesota was on the cutting edge of CT scanning – it was the new, exciting diagnostic tool for medical research. Since SMM was connected by skyway to St. Joseph’s Hospital, the mummy was placed on a gurney and wheeled across the skyway to the new X-ray and CT Center. The relationship was beneficial to both the hospital and to SMM. The hospital learned innovative uses for its new piece of equipment and gave SMM the X-ray along with a few diagnostic scans that proved that the mummy was authentic. The key image of SMM’s mummy CT scan is a slice through the skull. According to the ancient Egyptian methods of mummification, the brain was removed with a hook or spoon inserted through the nose. To do this, the septum (the bone supporting the nose) was broken, and in the image the septum is clearly broken. Fake mummies do not have this feature. The traditional X-ray of that area does not show this view of the septum, where the CT scan provides a positive identification for the mummy’s authenticity (figs. 4-5).

Today, CT scans have many more uses than medical diagnosis and authenticating mummies. Industry uses the technology to look for imperfections and defects in any kind of manufactured item – everything from widgets to engines and every material from plastics to steel.

There are two primary methods of scanning: linear and conical. With a linear scan, the x-ray slices the object into minute sections – like a loaf of bread. The object is placed on a platform as a machine passes over, taking images one slice at a time. Each slice is made of images rotating 180 degrees. The intervals from which the data is taken can be adjusted, much like changing the thickness of the slice on a bread slicing machine.
Fig. 4. X-ray scan of mummy (1-1514) showing septum (arrow)
(Image courtesy Research and Collections Division of the Science Museum of Minnesota)

Fig. 5. CT scan of mummy (1-1514) arrow indicating broken septum (X-ray by St. Joseph’s Hospital, St. Paul, MN; image courtesy Research and Collections Division of the Science Museum of Minnesota)
In the second method, data is gathered by subjecting the object to a cone of radiation. The object is set on a rotating platform. This method provides less data, but still yields a wealth of information. In both cases, all of the data is interpreted through the software and 3-D images are built up that can be rotated and viewed from every angle.

However, it is important to remember that CT scans will expose the object to radiation. The amount of radiation is determined by the strength and frequency of the sampling rate, as well as by the method. Medical CT scanners use less radiation and accumulate less data. They are set for the levels of radiation that can be “safely” tolerated by the human body. Industrial scanners do not have those limitations and can penetrate denser objects.

Done properly, different materials constituting the object can be identified. Objects can also be reassembled in three dimensions and the “skin” can be applied.

SMM has been working with an industrial imaging company, North Star Imaging, to examine a crocodile skull (Goniopholis sp.). The imaging equipment they used gathered data using a cone spread of radiation. The skull was set up on the platform at the foramen magnum (the area where the spine attaches to the skull), so that the snout was pointed straight up. The platform rotated and three sections were scanned – the snout, the middle area and the base. The data was manipulated and the three separate scans were stitched together into a single, seamless image. The detail was astounding. The senior paleontologist was able to see internal structures that had never been visible before (fig. 6).

This technology goes far beyond a simple x-ray. Its greatest advantage is that the inside of objects and specimens can be examined without opening or compromising their integrity. Moreover, this technology can provide much more information, including distinguishing different densities in materials – down to the level at which tree rings can be read. Applied uses can include identifying construction techniques, identifying different materials used in construction, identifying old repairs (both legitimate and non-legitimate) and authenticating artifacts. With Goniopholis sp. the difference between the actual fossil and matrix could be differentiated for the first time.

7. 3-D SURFACE SCANS

For surface analysis, 3-D scanners have a variety of uses. While some are large enough to handle dinosaurs, others are portable tabletop units. The smaller scanners, like the Next Engine Desktop 3-D Scanner can be used to create 3-D images that can be viewed individually or combined into films in which an object can be manipulated and seen from different angles (fig. 7). In this case, the author (Fregni) made scans of several copper spear points to take multiple measurements of angles to compare them, all being done with minimal handling of the artifacts. Once the 3-D image was made, the software was used to take multiple measurements and calculations that were then downloaded into a spreadsheet. The digital images allowed far more accurate measurements to be taken and allowed direct comparisons to be made, both visually and numerically. By making these images available to others, the images can be added to databases in order to create a larger sampling base. Other researchers will be able to use the same 3-D images to answer their own questions without having to travel to the institution.
Fig. 5. 3-D image of copper spear point (53-46) from Science Museum of Minnesota collection made using tabletop scanner (Image by G. Fregni at the University of Minnesota Arch/Bio Lab)

Fig. 6. *Goniopholis sp.* (Image courtesy North Star Imaging, Inc.)
8. MAKING 3-D IMAGES THREE-DIMENSIONAL

Any object that can be imaged in 3-D can also be replicated in a 3-D printer. By using computer assisted design (CAD) technology, an exact 3-D duplicate can be made of the original in a variety of materials. Three-dimensional prints are made in several different ways, either by building up layers of plastic to re-produce the object or by triangulating a laser into a substance that fuses the material in order to form the image.

Fig. 6. Rapetosaurus krausei skull (Photograph by Rebecca Newberry, Science Museum of Minnesota)

These scanners can be used to replicate missing parts, or replicate objects too fragile for more traditional methods of casting. They can also be used to resize objects enabling more refined research. Kristi Curry Rogers, one of SMM’s paleontology curators at the time, was working on a particularly fragile specimen, the skull of a juvenile Rapetosaurus (Rogers and Foster 2004) (fig. 8). It was a key specimen in her research and an important specimen for display. The skull was too fragile to handle, much less to be mounted for exhibition. In addition, there were missing parts. The skull was carefully packed and sent to Research Casting International in Trenton, Ontario for scanning and casting. Detailed scans were made using CAD, drawings were completed and a model was printed in 3-D (fig. 9). Since there were many losses, as is common with paleontological specimens, the missing pieces were filled in by a combination of sculpting missing parts and scanning other specimens. These parts were then scaled to match the size of the original specimen. If the right bone was missing, but the identical left one was present, a mirror image could be reproduced (fig. 10). Rogers requested that some of the minute structures from inside the skull be enlarged so that she could easily see how they fit together. In this way the specimen was better understood, and more accurately assembled. The original material is still too fragile to handle or mount, however the 3-D model is now on display at the Field Museum.
Fig. 9. 3-D print of *Rapetosaurus krausei* skull created by Research Casting International
(Photograph by Research Casting International)

Fig. 10. CAD drawing of *Rapetosaurus* skull showing how parts were used from adult and juvenile skulls to create a completed model (Image by Research Casting International)
9. CHEMICAL ANALYSIS

X-ray Fluorescence (XRF) analysis is another tool that is becoming more affordable. The portable machine is easy to use and the data downloads into Excel (fig. 11). XRF gives a detailed list of the elemental characteristics of an artifact. This not only helps in research and analysis, but has also been used in conservation to identify toxins and other materials. The XRF bombards a minute area of the surface of the artifact with x-rays, penetrating less than a millimeter below the surface. The electrons absorb the radiation, causing a disruption in which the electron moves up to the next orbit. As the energy dissipates, the electron moves back to its original orbit. This rate of energy exchange is unique to every element and is used by the XRF to identify the individual elements within an object. Readings can be taken quickly and work can be done either in the lab or in the field. While XRF is an excellent tool for analyzing heavier elements, lighter elements can be difficult to determine with some models. It also is difficult to distinguish between metals and oxides. However, this can be compensated by complementing XRF with visual analysis or with a more complete understanding of the raw data (Ketcham and Carlson 2001).

While XRF is described as being non-destructive and non-invasive, there are materials that can be damaged through prolonged exposure (Mantler and Klikovits 2004; Garside and O’Connor 2007). Fibers and wood are especially susceptible to desiccation or burning caused by the radiation. This is a consideration when XRF is used to analyze the chemical make-up of pigments used in paintings, on paper, or on fibers.

However, as with any form of technology, care must be taken to understand the results. Interpretation requires an understanding of the limitations of the technology as well as knowing how to work with the raw data. Chemical readings from XRF will sometimes overlap and create a false peak. By learning the different ways in which data can be viewed, the conservator will be able to use a powerful tool that can not only provide information about the make-up of inorganic artifacts, but will also be able to immediate identify toxins on the surface of the object.
10. THE BOTTOM LINE

But all of this does cost money. The question remains: how to get access to expensive technology?

First, it is important to determine what technological medium would be advantageous to own. A priority list should be made with the main criteria for equipment that will be frequently and easily used (i.e. software that makes data gathering and analysis reasonable). Just as computers have now replaced typewriters, film cameras and microscopes have improved and are able to expand capabilities that combine with current digital equipment.

The next step is to create strategies for purchasing by building the priority into the department or lab budget. Larger institutions can look into a partnership with other departments and share expenses. Other familiar avenues include writing grant proposals or looking for donors. Finally, purchasing used equipment or older models is always a viable option. However, it is important to ensure that the model will provide the necessary information and will interface with the existing technology.

However, owning a piece of equipment might not be an option. This could be due to budget constraints or lack of physical space. This is where community partnerships are useful. Cooperation between UM and SMM has been beneficial, as has SMM’s relationship with North Star Imaging. In partnering with North Star Imaging, SMM was able to have highly specialized work done, and North Star Imaging was able to demonstrate new applications for their technology.

SMM’s experience with the mummy showed that some of these companies want to use their expertise on something more interesting than engine parts, or try out new equipment. It is advantageous to partner with an organization that has the equipment already and a staff that knows how to use it. In the earlier example of SMM’s partnership with North Star Imaging, the museum found that North Star wanted to expand their market and needed examples to sell their product. By agreeing to allow North Star Imaging to use the images, SMM was able to have the scanning done for free.

Sales representatives can also be a resource. They can assess whether or not a piece of equipment will be appropriate. If the equipment is portable, they might bring it to you, or as in the case with North Star Imaging, the artifact was brought to the company. Businesses will frequently loan equipment to an institution in order to understand if it is the right technology for the institution’s needs.

11. CONCLUSION

Conservators are accustomed to adapting tools originally designed for other purposes, such as examination and treatment. The creative use of high-tech equipment is simply another form of this action. The good news is that the technology is becoming more user-friendly and more affordable! It is the conservator’s job to know what is available that can be used effectively in examining and understanding the objects being cared for.

The personal computer was introduced over 20 years ago. Many conservators struggled with the primitive programming in attempts to wrench out useful reports and databases. Today there is hardly a lab without a computer. The technology has become easy to use and affordable. The same phenomenon is happening in other types of technology. Digital cameras have become ubiquitous. Digital microscopes such as the ProScope and the QX5 are now affordable and easy
to use (the QX5 is now marketed as a child’s toy). 3-D digital imaging can be done easily and for
the cost of what a high-quality film camera used to cost. There are companies who can provide
their services with medical and industrial CT scanning for in-depth analysis of materials and
structures. Other companies can use this data to produce casts of artifacts or specimens without
putting the object through the strain of mold making. Equipment such as the portable XRF is
becoming easier to use and interpret chemical analysis. Industrial scanning is also a great
resource; it can measure density and see inside the object. Each tool has its own niche and can
answer specific questions. The important point is to know the questions that need to be assessed
and how available technology can answer those questions.
In short there are many high tech tools that can be used to enhance the conservators work.
He or she must be an informed consumer.

1. Determine the right tool for the job. Understand what research question is needed, and
what it will take to get the answer. Decide if the cost of the technology is worth the
financial and time commitment.
2. Seek partnerships with other organizations or with vendors to use the equipment.

The 21st century is upon us. Embrace it.

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NOTE

1. Anatomy of the QX3 microscope
   http://micro.magnet.fsu.edu/optics/intelplay/intelanatomy.html
REFERENCES


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