western association
waac
for art conservation
Newsletter

September 2014

Volume 36 Number 3

President's Letter

Katherine Holbrow

Contents

Well, Members, my year as WAAC President has ended with the annual meeting, and Cat Coueignoux will be your voice on this page for the next year. Cat is already working hard on next year's meeting. In hindsight, now, I can see that pulling together the actual program is easy. Organizing this event taught me a lot of things, and one was that WAAC members have the remarkable ability to produce excellent presentations at the least warning. Maybe I am biased, but I thought all the talks were amazing: strong, scholarly, and entertaining. Not to mention concise (we all know that's the hardest part)!

There was also a fun San Francisco vibe at the meeting that made it really special. What better place for opening talks encompassing epistemology and decontextualization of mandalas (Jeff Durham), conservation strategies for social practice (Amanda Hunter Johnson), and psychedelic rock posters of the late 1960s (Victoria Binder)? That's a suitably mind-bending line-up for the City of Love, and I felt my inner flower child cheer when Jimi Hendrix blasted and colored lights flashed in the elegant former Reading Room of the old San Francisco Library (now the Asian Art Museum).

The meeting also showcased conservation's great range. What a breadth of experience and creativity I saw presented over the course of the week, in talks, workshops, and tours, and in just plain conversations too. It staggers me sometimes what diverse, interesting people go into conservation. Does the rest of the world realize how special we are? My WAAC fortune cookie said "curators value your opinion," so maybe.

But seriously, we know that one of the best things about the WAAC meeting is that you get to hear all the talks, regardless of specialty. This meeting had something for everyone. There was a great group of treatment talks, including those by Donna Williams and Nick Calderaro on objects, and Shiho Sasaki and Anne Zanikos on paintings. Some talks confronted larger issues in collections care, such as Donald Sale's struggles with the unique situation at the Royal Pavilion in Brighton, Ellen Carlee's and Kelly Bennett's collections move sagas, the Sherring-Moeller survey of 15,000 photographs, and Denise Migdail's explanation of evolving thangka care.

Others bravely tackled knotty scientific problems, such as Chris Stavroudis' battle against shrinking canvas, Vanessa Muros' unusual archaeological finds, and Donald Sale's plastics assessment. LACMA really came through this year, including presentations on new data on LED light sources (Charlotte Eng), the latest efforts to stabilize the Watts Towers (Christina Fisher), and protecting Michael Heiser's Levitated Mass (Mark Gilberg).

The tours, workshop, and the Angels project were resounding successes too. Chris Stavroudis' cleaning workshop was (literally) standing room only. A stellar team descended on the Chinese Historical Society of America and did their magic, while the tours showcased some unique conservation spaces and projects around San Francisco. The banquet was delicious, and some of us even got a ride on the 1906 LeRoy carousel. I thought everything went perfectly!

President's letter, continued

Interestingly in that regard, both our first and last speaker felt called upon to quote poet Burns, “the best-laid plans of mice and men, gang aft a-gley.” Maybe we need to roll out a new fortune cookie: “embrace the a-gley.” Or maybe my idea of perfect is another’s a-gley? But however you interpret that quotation, please don’t conclude there’s no point in planning. Plan to come back to California again next year for another great meeting (in a beautiful oceanside setting next time). And thanks for a great, supportive, WAAC-filled year.

Katie

Regional News

Catherine Coueignoux
column editor

Alaska

Recently, the Anchorage Museum conservation department hosted **Tommy Joseph**, who conserved and taught about totem pole conservation, while treating a pole carved by him and donated to the museum. He also helped assess and prepare to conserve another pole for display in the museum. **Sarah Owens** is attending Poles, Posts, and Canoes: The Preservation, Conservation, and Continuation of Native American Monumental Wood Carving, at the Hibulb Cultural Center and Natural History Preserve in Washington. **Monica Shah** has been working with artists and researching objects in the collections to increase access to them and to increase our knowledge about the objects themselves.

Helen Alten is settling into her position as the Director of the Sheldon Museum and Cultural Center. Her conservation treatments have revolved around repairing exhibited collections and materials broken by children in the discovery area. A pending NEH grant would pay for an environmental engineer to improve the museum’s climate control capabilities. In the meantime, an architect is drawing up plans to improve the facility with the idea of bringing in more outside shows and borrowing collections from large Eastern institutions. Materials analysis will be included in the winter exhibits upgrades.

And, finally, the Sheldon Museum and Cultural Center was accepted into the New Pathways Alaska program – one of ten Alaska arts organizations, only two of which are museums – which is designed to foster innovative community collaborations and preserve the culture of this region. It has, historically, been the rich source of Northwest Coast materials that are now housed in the largest museums of the world.

One project is a new cultural center at Klukwan whose shell is already constructed. The contents will include the famous, and rarely seen, Whale House poles and screen. The Sheldon Museum and Cultural Center currently holds material in trust for the Chilkat tribes. Upon completion of the Klukwan facility, it will no longer be caring for some of this material, and the Sheldon Museum will work to coordinate its collections to complement with the Chilkat ones. This is an exciting period for Northwest Coast tribal materials.

Ellen Carrlee and **Scott Carrlee** finished moving the Alaska State Museum collection into a new storage vault, utilizing dozens of museum professionals statewide in a real-life training workshop funded by IMLS and organized using the Incident Command System. Scott continues statewide field services while the museum is dark, and Ellen turns to the preparation of objects for the new exhibits. Pre-program intern **Lisa Imamura** begins her studies at Queen’s University this fall.

Regional Reporter:
Ellen Carrlee

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WAAC Newsletter

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Internet

Articles and most columns from past issues of WAAC Newsletter are available on-line at the WAAC website, a part of CoOL (Conservation OnLine) http://cool.conservation-us.org/waac/.

Deadline

Contributions for the January *Newsletter* should be received by the Editor before **August 15, 2014.**

Western Association for Art Conservation

The Western Association for Art Conservation (formerly, the Western Association of Art Conservators), also known as **WAAC**, was founded in 1974 to bring together conservators practicing in the western United States to exchange ideas, information, and regional news, and to discuss national and international matters of common interest.

Individual Membership in WAAC costs $40 per year ($45 Canada, $50 overseas) and entitles the member to receive the WAAC Newsletter and the annual Membership Directory, attend the Annual Meeting, vote in elections, and stand for office. Institutional Membership costs $45 per year ($50 Canada, $55 overseas) and entitles the institution to receive the WAAC Newsletter and Membership Directory. For membership or subscription, contact: Denise Migdail secretary@waac-us.org

Regional News, continued

Arizona

Linda Morris and staff recently treated over 60 lithographs from the United States Pacific Railroad Expedition and Survey from the1850s. Selected lithographs were chosen to create the exhibition *Trails to Rails: John Mix Stanley and the Pacific Railroad Survey of the 1850s*, on view at the Tucson Museum of Art through September 2014. Other ongoing projects are being completed with the assistance of long time interns **Alison Pinto** and **Rachel Shand**.

Brynn Bender and **Dana Senge** surveyed collections and provided preventive care guidance for the Holzwarth Historic Site, a 1920s dude ranch along the headwaters of the Colorado River inside Rocky Mountain National Park. Brynn traveled to Yellowstone National Park to identify treatment needs for the ethnographic collections recently removed from exhibit.

Dana has been busy treating items for exhibit at Aztec Ruins National Monument in New Mexico. **Maggie Hill-Kipling** and **Bailey Kinsky** are treating historic decorative metal lamps from Scotty's Castle at Death Valley National Park. Maggie also traveled to Big Bend National Park in Texas to work with collections in storage.

Audrey Harrison created custom microclimate containers for an extensive collection of metals at Palo Alto Battlefield National Historical Park. Audrey also continues to treat ethnographic collections in Tucson. **Paige Hoskins** applied backing boards to the paintings collection of Little Bighorn Battlefield National Monument.

Marilen Pool continues working on the survey, organization, and rehousing of the Archaeological Perishables collection at ASM. She is also conserving objects for both the Amerind and Arizona Historical Society Museums.

Teresa Moreno has been working with ASM curators and representatives from the University of Arizona President's Office to coordinate the installation of a new exhibit of specially selected objects from ASM's Save America's Treasure's Southwestern Pottery and Basketry collections as well as their collection of Navajo textiles. The objects have been selected for a rotating exhibit that will be housed in the newly restored and renovated 'Old Main' building of the University of Arizona.

The territorial style building was constructed in 1887 to house the newly established university, and the first classes were held in the building in 1891. It was listed on the National Register of Historic Places in 1972. The exhibit will highlight the holdings of ASM and other university collections and museums including the Center for Creative Photography, the UA Libraries Special Collections and the UA Mineral Museum.

Regional Reporter:
Brynn Bender

Hawaii

Collections Manager Michael Juen of 'Iolani Palace will be leaving the position on July 30th and accepting the position of registrar at the Bullock Museum in Austin, TX.

Regional Reporter:
D. Thor Minnick

Los Angeles

In September 2014 **Elizabeth Shaeffer** started a 1 year Mellon fellowship in textile conservation at LACMA. She is a recent graduate of the Winterthur/University of Delaware Program in Art Conservation.

At the Autry National Center, **Özge Gençay-Üstün** is on summer leave to work at the excavation in Tell Atchana/Alalakh in Hatay, Turkey and will return by the end of August. **Jennifer Kim** is back from her maternity leave. **Lalena Vellanoweth** won the hearts and minds of the Autry staff while covering for Jennifer during her leave.

The basket collection survey, cleaning, and prep for move continues at a rapid pace thanks to the help of several volunteers: **Nicole Alvarado**, **Julia Kim-Lameman**, **Kim Owens,** and **Kate Reilly**. The collection move is on schedule to be completed by the end of this year.

Dawn Jaros became the conservator at the Academy of Motion Picture Arts and Sciences earlier this year. She moved here from Chicago, where she was working in the Prints and Drawings department at the Art Institute of Chicago. Dawn has been working with **Amanda Burr**, conservation technician, these past months reorganizing the paper lab and preparing several outgoing loans. Amanda Burr will be joining the class of 2016 at Buffalo State College later this year. The Academy is sad to see her go, but wish her the best of luck. **Madison Brockman** joined the conservation team as the conservation technician in May. Madison will be focusing on conserving and rehousing the library's collection.

The Antiquities Conservation department at the Getty Villa welcomes their 2014/15 intern: **Sara Levin**. Sara is a graduate of the Winterthur program and recently completed a Kress Fellowship at the University of Pennsylvania Museum of Archaeology and Anthropology. She comes to the Getty with experience and a deep interest in archeological artifacts.

Erik Risser travelled to Tunisia and Vienna to examine some of the ancient bronzes to be included in the exhibition *Hellenistic Bronzes* in preparation for their loan. **BJ Farrar** joined Erik in Vienna as they are designing and fabricating an adjustable lift cage for the deinstallation and transit of the Apoxyomenos from the Ephesus Museum. **Jeffrey Maish** will lead the preparations for this exhibition which is scheduled for July 28 through November 1 2015 at the Getty Center.

BJ Farrar and **Mac Lowry** both presented papers at the 4th International Mountmaker's Forum May 14th in Santa Fe, N.M.

Marie Svoboda traveled to Oxford in September to deliver a paper at the conference Understanding Egyptian Collections. She will be presenting her current project on the study Romano-Egyptian mummy portraits for the APPEAR project (ancient panel painting: examination, analysis, and research).

The entire staff: **Eduardo Sanchez**, **Susan Lansing-Maish**, **Jeffrey Maish**, Marie Svoboda, and Erik Risser, as well as the mount makers BJ Farrar, McKenzie Lowry, and **David Armendariz** are very busy preparing for two collaborative exhibitions opening this November 19th at the Getty Villa: *Ancient Luxury and the Roman Silver Treasure from Berthouville* (from the Bibliotheque National of France) and *Dangerous Perfection: Funerary Vases from Southern Italy* (from the Antikensammlung, Berlin).

These exhibitions will highlight the long-term collaborations, research, and technical studies that have developed from these amazing projects.

Tania Collas and **Elizabeth Drolet** are busily installing *Grandes Maestros del Arte Popular de Iberoamérica*, a traveling exhibition of contemporary folk art from Central and South America as well as Spain and Portugal that will be on display at the Natural History Museum starting November 9, 2014. They are also preparing for the deinstallation of the museum's California History Hall in early 2015.

Paper conservators at LACMA presented a poster at the IIC Conference An Unbroken History, Conserving East Asian Works of Art and Heritage, in Hong Kong, in Spetember. The poster ise entitled *The conservation of a large-scale eighteenth-century Korean Buddhist painting on silk*.

The project was undertaken by **Chi-sun Park**, professor of conservation at Yong-In University, Yong-In, Republic of Korea. A gallery at LACMA was converted into a mounting studio. Professor Park brought equipment and staff, and they worked for a year to repair and scroll mount this painting. In the painting, the Buddha Seokgamoni sits at the center of the composition on a lotus throne and preaches to a large assembly of enlightened beings, guardians, and disciples. The poster will emphasize the collaboration between LACMA's conservators and Professor Park's team and the public outreach afforded by working in the gallery.

Asti Sherring and **Laura Moeller,** current IMLS fellows in paper conservation at LACMA, gave a presentation at the annual WAAC conference in September on the museum's IMLS funded project to inventory the museum's photographic collections. The project is focused on correcting information in the TMS data base in preparation for the opening of a Photographic Study Center. The inventory involves systematic rehousing and organization of the collection to facilitate research and safe access and handling.

Laura Moeller will be attending a Mellon funded workshop and symposium on platinum and palladium photographs in Washington D.C. this October, with funds provided by FAIC and the NEH.

Naoko Takahatake, **Charlotte Eng**, **Diana Rambaldi**, **Linda Stiber Morenus,** and **Erin Jue** are currently writing papers on the examination and treatment of chiaroscuro prints. This work is part of a larger collaboration and upcoming exhibition organized by LACMA, and Philadelphia Museum of Art for 2016. The paper being written by Naoko, Charlotte, and Erin will focus on the in depth analysis and treatment of Antonio da Trento's *Martyrdom of Two Saints,* from circa 1527-1530.

Regional Reporter:

New Mexico

M. Susan Barger just participated in a session on Emergency Planning and Preparedness at the joint meeting of the Texas Association of Museums and the New Mexico Association of Museums in Lubbock, Texas.

Mark MacKenzie has been the chief conservator and director of conservation for the Museums of New Mexico since 2007. With four museums and eight historic sites to care for, as well as eight or more exhibitions per year, the conservation unit is very busy. The recent addition of a portable Raman spectrometer and microscope to the materials research/science unit allows the analysis of artifact materials, pigments, resins, and dyes. This analysis supports such large projects as New Mexico's Museum of International Folk Art's major exhibition *The Color Red*. This exhibition traces, through art and artifacts, the production, trade, and use of reds derived from the cochineal insect.

Regional Reporter:
Silvia Marinas-Feliner

Pacific Northwest

J. Claire Dean has been spending most of the summer at the Hibulb Cultural Center working with UCLA/Getty program intern **Betsy Burr** during her summer internship at the Center. **Ellen Pearlstein** (UCLA/Getty Program associate professor) also spent 3 weeks at the Center working on feather objects.

At the end of July the Center hosted two important conservation events. The first was the Poles, Post and Canoes symposium that brought Native American and non-native museum professionals and carvers together to discuss the care of monumental, carved wooden objects. This was followed by a 3 day workshop, Caring for Totem Poles, presented by conservators **Mike Harrington** and **Andrew Todd** with support from Lummi artist **Felix Solomon**. Both events drew an international attendance and were very well received.

Corine Landrieu has been busy working on outdoor sculptures this summer, including *Skip to My Lou*, a monumental cedar artwork by Ursula Von Rydingsvard, and a replica of a Haida House for the city of Redmond. She was delighted to take part in the Poles, Post and Canoes symposium and the Caring for Totem Poles workshop held at Hibulb Cultural Center.

The RBCM conservators have been travelling. **Betty Walsh** attended the CCI Gellan Gum Workshop in Toronto in March. **George Field** went to New Mexico in May for the Mount Builders Forum. **Kasey Lee** presented a paper at the AIC meeting in San Francisco in June. And **Lisa Bengston** will be taking a poster to the IIC Congress in Hong Kong in September. **Kay Garland** also went to Vancouver for a workshop on collections storage. Many thanks to the CMA and the CAC for their financial support through bursaries and grants.

Several conservators also presented at or attended the annual Vancouver Pacific Conservation Group meeting at the Burnaby Art Gallery. Thanks to **Elisabeth Czerwinski** and **Tania Ainsworth** for organizing.

While not travelling, the staff has been busy with exhibition work, including *Our Living Languages*, an exhibit of intangible heritage. The artifact list was appropriately short. They're now working on a major travelling exhibition on a gold rush theme, involving multiple loans from as far away as South America and Australia. With hundreds of objects on the wish list and less than a year until the opening, this will be a challenge.

At the same time, they continue to plan for their site redevelopment which should begin next summer.

They were honoured to host a Queen's MAC intern this summer, **Kaslyne O'Connor** from the paper stream. She even presented at the PCG meeting. And we're looking forward to **Rachel Stark** joining us from the Fleming program in the fall.

Regional Reporter
Corine Landrieu

Rocky Mountain Region

Bianca Garcia, Winterthur Conservation Fellow, joined the conservators at the Western Center for the Conservation of Fine Art (WCCFA) to assist in the ongoing treatment of two rare murals by Olinka Hardy, considered Oklahoma's first modern artist, for the Oklahoma City University School of Law. Bianca also travelled to Salt Lake City with **Carmen Bria** for a week long project to treat an 11 ft x 16 ft painting by Utah artist David Dornan.

Conservation interns at the Buffalo Bill Center of the West this summer included **Anahit Campbell**, a second year masters student at West Dean College in England; **Blanca Guerra** and **Zulema Marin**, both graduates of Escu ela de Restauracion y Conservacion de Bienes Culturales in Spain; pre-program interns **Stephanie Cashman**, **Cristiana Ginatta**, and **Katrina Zacharias**; as well as high school student **Kevin Page**. In March, **Pam Skiles** joined the Denver Art Museum staff as associate paintings conservator. Her position is shared between the DAM and the neighboring Clyfford Still Museum. Since her arrival, Pam has skillfully readied a collection of 50 British paintings for travel and exhibition. At the CSM, Pam assisted **James Squires** with the stellar exhibition *The Art of Conservation*.

Gina Laurin, Courtney Murray, and **Sarah Melching** worked on the installation and maintenance of the exhibit *American Western Bronze*. In conjunction with the Alexander Phimster Proctor Foundation, several of the bronze sculptures by the artist were analyzed using handheld XRF to help determine working methods, manufacture, and composition.

Allison McCloskey and **Julie Benner** treated and readied numerous quilts from the collection for a new rotation of these varied and colorful textiles.

A new rotation of Oceanic objects opened in August– primarily tapa cloths and masks. The effort has involved the expertise of Gina, Allison, Julie, Courtney, Sarah, and contract conservator **Julie Parker**. Contractor **Jeff Yearick** has fabricated three-dimensional mounts and conservation assistant **Caitlin Whaley** has been covering and toning rare earth magnets.

Sarah and Caitlin worked together on two exhibitions: one featuring politically- and socially-inspired posters from the American Institute of Graphics Arts archive and the other, *At the Mirror*, a selection of 20th-century color woodcut prints.

Kate Moomaw has been taking advantage of the season to perform outdoor sculpture maintenance. **Lia Kramer** and **Samantha Hunt** have been working with Kate this summer as pre-program outdoor sculpture interns, learning the ropes of documenting, washing, waxing, etc.

Courtney Murray is nearing the end of her third year as a WUDPAC fellow. She has covered a lot of territory in the past 11 months, and the staff is delighted that she will be continuing at the DAM as a Kress Fellow in objects conservation. Courtney will carry on with work on several 18th-century polychrome Ecuadoran Magi figures.

Expert mountmaker **Steve Osborne** welcomes **Nick Donaldson** as his assistant. Both are skillfully working on a range of custom and intricate mounts for the upcoming Cartier exhibit.

Regional Reporter:
Paulette Reading

San Diego

No news reported.

Regional Reporter:
Frances Prichett

San Francisco Bay Area

The textile lab at the de Young has a new pre-grad intern, **Lindsay Ocal**. Lindsay has multiple degrees in Egyptology, art history, and Biblical languages. As she is interested in objects, she is working on appropriate multi-material "textile" objects including basketry hats, a ballet tutu, and shoes. She has also assisted **Yadin Larochette** of Larochette Textile Conservation in lining a tapestry.

Yadin has been at the deYoung for two weeks on contract to work many projects varying from three tapestries, magnet display, fiber identification, and even replacing the four filters in the old Nilfisk vacuum.

The paper conservation lab at the Fine Arts Museums is pleased to welcome its first Mellon Fellow. **Heather Brown** began a two-year fellowship in September.

The objects lab at the de Young has not paused since the successful opening of the *Salon Doré* at the Legion of Honor. **Lesley Bone** is working on a chapter for the catalogue on African sculpture for the upcoming show *Embodiments: Masterworks of African Figurative Sculpture.* With **Catherine Coueignoux**, a new member of the lab, she has been examining over one hundred and twenty sculptures.

Lesley has also been overseeing a reorganization of the de Young's sculpture garden, which has involved lots of heavy lifting, thankfully with the help of machinery. The lab is very much looking forward to the arrival of **Geneva Griswold**, the lab's new (and first) Mellon Fellow, in the fall.

The Conservation Center at the Asian Art Museum is seeking a new Head after the departure of **Katie Holbrow**. In the meanwhile, **Mark Fenn** is the Acting Head of Conservation.

Shiho Sasaki and **Jennifer Parson** (née Badger) are working full time preparing for a Japanese print exhibition scheduled for next spring. Jennifer will be moving to Germany to join her husband in October 2014 so the lab looking for a part-time paper conservator to replace her.

The entire conservation staff participated in the AIC 42nd Annual Conference in May, where **Denise Migdail** presented a paper "In Consideration of the Thangka." **Colleen O'Shea** joined the lab as a third year intern just in time to help out in hosting the 2014 WAAC Annual Meeting. **Courtney Helion** just celebrated her first year as conservation technician and is looking forward applying to conservation schools in the fall.

Rowan Geiger and **Tegan Broderick** of SF Art Conservation are currently treating a large Mark di Suvero sculpture recently exhibited by SFMOMA at Crissy Field. The company also recently supervised the conservation and repainting of two monumental painted steel sculptures by Alexander Calder. They are on display at Princeton University until September.

Regional Reporter:
Alisa Eagleston-Cieslewicz
Assistant Conservator
SFO Museum
San Francisco, CA
alisa.eagleston@flysfo.com

Texas

Heather Hamilton reports that **Rémy Dreyfuss,** the current conservation intern in the paper lab at the Harry Ransom Center, University of Texas at Austin, presented his conservation internship projects to Harry Ransom Center staff July 29th. Rémy is in his fourth year of the five-year conservation graduate program at the Institut National du Patrimoine in Paris.

During this six month internship, Rémy undertook numerous complex projects to conserve Ransom Center collection materials. He has recently completed a large project to conserve a collection of Masonic scenic backdrop models. The 115 models depict stage backdrops used in Masonic ceremonies. The models were designed by the celebrated theatrical supplier Sosman and Landis Scene Painting Studio of Chicago around 1900.

The models were housed in a travel trunk, which would have been used by a salesman to transport them for marketing to temples. A second trunk contains a model stage. The backdrops could be

Regional News, continued

displayed on this miniature stage to give a buyer an idea of the full-sized backdrops, also manufactured by Sosman and Landis. Rémy developed a solution to safely reattach the hand-painted scene boards that had come loose from their wooden supports and performed repairs on damaged boards. Rémy and photograph conservator **Diana Diaz** also photographed each group of backdrops, installed on the miniature stage, for future reference by researchers.

Regional Reporter:
Ken Grant

Membership

Chris Stavroudis
membership secretary

WAAC welcomes the following new members and (very) late renewals.

Kelly Bennett; Victoria Binder; Caitlin Breare; Tish Brewer; Heather Brown; Kathryn Carey; Jacklyn Chi; Céline Chrétien; Jennifer Correia; Megan Crouch; Elise Effmann; Charlotte Eng; Debra Evans; Christina Fisher; Debra Fox; Rowan Geiger; Tina Gessler; Cristiana Ginatta; Nicole Grabow; Emily Hamilton; Courtney Helion; Joyce Hulbert; Sarah Kleiner; Laura Kubick; Breana Latty; Allison Lewis; Laura Moeller; Johana Moreno; Suzanne Morris; Vanessa Muros; Jennifer Myers; Patricia O'Regan; Colleen O'Shea; Kathleen Orlenko; Marta Pinto-Llorca; Allison Rabent; Shiho Sasaki; Melody Scarborough; Asti Sherring; Kristen St.John; Beth Szuhay; Debra Vigna; Annie Wilker; and Jane Williams.

By now, all members should have received their 2014 e-WAAC Membership Directory via the correspondence email address you provided to WAAC. If you have had trouble with the pdf file or did not receive your 2014 Membership Directory, please let us know by emailing WAAC at membership@waac-us.org.

Jobs

Cantor Arts Center, Stanford University

OUTDOOR SCULPTURE COORDINATOR / CONSERVATOR

With Cantor staff, develop and manage program for siting, installation and maintenance of Outdoor Sculpture Collection. Maintain works in good condition; develop budget, work plan and goals; train, hire and work alongside Stanford and occasionally non-Stanford students hired for the Outdoor Sculpture Maintenance Crew; plan, schedule, coordinate and monitor special projects such as annual survey, installations, de-installations, conservation treatments and repainting.

Develop and maintain campus contacts, with vendors/consultants/contractors and other relevant departments. Schedule and work closely with specialist contract conservators and other service providers; write reports and perform record keeping of paper, photographic documentation and data files; contribute to Conservation blog with posts on activities and help maintain blog-site; work with Education Department and Public Relations department in creating signage as needed for special projects, and communications with university, public and staff.

Collaborate closely with supervisor, director, curators, events staff, collections manager and finance manager on all aspects of program. Act as consulting Lab Conservator and advisor to staff in absence of A+S Lab Director.

Perform object conservation treatment on an occasional basis in the lab.

Requires a masters degree in art history and conservation. A minimum of 5 years progressively responsible experience managing outdoor sculpture or in conservation. Supervisory experience required. Must have clean driving record and ability to drive electric vehicle on campus. Must be able to lift and carry heavy materials short distances.

The expected schedule for this position is Monday – Friday, 8:30-3:30, 30 hours per week, though the position requires flexibility to work some evening or weekend hours as required by projects.75% FTE Two-year fixed term.

Contact: Susan Roberts-Manganelli, Director, Art+Science Learning Lab

WAAC Publications

Handling Guide for Anthropology Collections

Straightforward text is paired with humorous illustrations in 41 pages of "do's and don'ts" of collection handling. A Guide to Handling Anthropological Museum Collections was written by Arizona State Museum conservator Nancy Odegaard and illustrated by conservation technician Grace Katterman. This manual was designed to be used by researchers, docents, volunteers, visitors, students, staff or others who have not received formal training in the handling of museum artifacts. Paperbound and printed on acid-free stock.

Price: $8.85

($6.60 copy for orders >10 copies)

Back Issues of WAAC Newsletter

Back numbers of the *Newsletter* are available. Issues Vol.1 - Vol.14, #3 (Sept. 1992) are $5/copy. Issues Vol.15 - Vol.29, #3 (Sept. 1997) are $10/copy. Issues Vol.30 (Jan. 2008) and after are $15/copy. A 20% discount will be given to libraries seeking to obtain back issues to complete a "run" and for purchases of ten copies or more of an issue.

Prices include shipping and handling. Make checks payable to WAAC drawn in US dollars on a US bank.

For information please contact the WAAC Secretary:

Claire Gerhard

Send prepaid orders to:

Donna Williams
WAAC Fulfillments

3D Printing in Conservation

No matter how meta or theoretical conservation may become at times, ultimately we work on and with things. We care about how they are made, what they are meant to be, how they change, how to fix them if they are damaged. When a new way to make things is developed, it is both relevant and interesting to our profession.

3D printing was born just over thirty years ago. In a progression that echos that of the computer, lab to industry to geeks to early adopters to the consumer market, it is becoming part of our lives and our work.

I started thinking about a 3D printing issue five years ago, knowing that there would be curious minds in the conservation community who would be playing with it and, moreover, that we would soon be having these objects handed to us for display, storage, and treatment.

The articles in this issue describe the analysis of museum objects, the materials of 3D printing, the making of missing parts and replicas, the creation of complex models, and the design and 3D printing of a tool for a specific application. Bookending these are the timeline below and a short glossary of 3D terms. (The tantalizing issues of authenticity and intellectual property rights will have to wait for another time.) The contributions come from Italy, Germany, Britain, Switzerland, Los Angeles, Minneapolis, and Chicago. Some of the information is worth keeping as reference material, and as is the case with all technology, some will soon be out of date. Consider it a snapshot of this moment in our profession.

The History of 3D Printing (an annotated timeline)

1982 - 1986 Charles “Chuck” Hull invents the first form of 3D printing – Stereolithography, a printing process that enables a tangible 3D object to be created from digital data. The technology is used to create a 3D model from a picture and allows users to test a design before investing in a larger manufacturing program. He invents the first working 3D printer. He patents Stereolithography and founds 3D Systems.

1987 Drs. Carl Deckard and Joe Beaman invent Selective Laser Sintering (SLS).

1988 - 1992 Scott and Lisa Crump invent Fused Deposition Modeling (FDM). They patent FDM and found Stratasys.

1995 Researchers at MIT develop ZPrinting.

The concept of 3D printed self-replicating machines is introduced by Klaus Lackner and Christopher Wednt.

2005 Open source collaboration begins. Dr. Adrian Bowyer at University of Bath founds RepRap, an open-source initiative to build a 3D printer that can print most of its own components. The vision of this project is to democratize manufacturing by cheaply distributing RepRap units to individuals everywhere, enabling them to create everyday products on their own.

The early machines were very large, very expensive, and not accessible to the general public / aritsts. Bowyer’s open sourcing for the RepRap (short for replicating rapid prototyper) made the 3D process available for development, at this point for early adopters capable of building their own devices. While some artists may have had access to these early machines, this should be considered an early date for 3D printed art.

2006 The first SLS (selective laser sintering) machine becomes viable. This type of machine uses a laser to fuse materials into 3D products. This breakthrough opens the door to mass customization and on-demand manufacturing of industrial parts.

That same year Objet creates a machine capable of printing in multiple materials, including elastomers and polymers, which allows a single part to be made with a variety of densities and material properties.

2008 RepRap releases the Darwin model, which can print over 50% of the parts needed to build another printer, allowing users who already have one to make more printers for their friends.

by Carolyn Tallent

Access increases. Interest begins to extend beyond the DIY / maker / hacker communities.

DIY co-creation service launches. Shapeways launches a private beta for a new co-creation service and community allowing artists, architects, and designers to make their 3D designs as physical objects inexpensively.

2009 MakerBot Industries, based in Brooklyn, an open-source hardware company for 3D printers founded by Adam Mayer, Zach Smith, and Bre Pettis, starts selling DIY kits that allow buyers to make their own 3D printers and products.

Thingiverse, a repository of primarily open-source hardware designs for the 3D design community, is founded as a companion website to MakerBot.

Awareness and access increase in US.

2010 NASA begins evaluating Couter Crafting 3D for 3D printing in space.

2011 No more assembly required. Makerbot decides to offer the ability to buy a ready to use 3D printer out of the box.

Users no longer have to build their devices. Printers begin to reach a larger market and prices begin to go down.

Printing Service, i.materialise, starts offering 14K gold and sterling silver as a printable material.

Researchers in UK present the world's first 3D chocolate printer.

Researchers at Cornell University began to build 3D food printer.

2013 First 3D printed gun, 3D prosthetic arm, 3D printed car.

Stratasys releases a printer capable of printing one object in multiple materials and colors, including polymers and elastomers.

Prices continue to go down; the *New York Times* estimates that a machine costing $20,000 in 2011 now costs $1,000.

2014 Expiration of key 3D printing patents.

According to Wikipedia, the 400,000th 'Thing' was uploaded to Thingiverse.

Hasbro toys and 3D systems announced a collaboration to make play printers for children to print Hasbro toys.

And closer to home, as it were ....

Dutch company FormArt develops process for 3D printing of works of art. Color and relief are recorded in one scan, depth of relief is currently limited to 1 cm. "FormArts can hardly be told apart from the original. Data can also be stored. In case of restoration, the specific features of the painting can be restored easier, faster, and cheaper." (FormArt website)

Van Gogh facsimilies created and sold. Fujifilm Europe and the Van Gogh Museum collaborate. "Each canvas is painstakingly examined and compared to the original work by the museum's curators before being admitted as an authentic Van Gogh Museum Edition." (Tribune International website)

Artist grows Van Gogh's ear with DNA and a 3D printer. "Artist Diemut Strebe and a team of scientists have grown a living replica of Vincent Van Gogh's ear out of tissue-engineered cartilage sourced from the great-great-grandson of his brother, Theo. Using a 3D-printer and computer imaging technology, the cells were molded to be identical in shape to Van Gogh's ear, which he self-severed during a psychotic episode in 1888. The ear is being kept alive inside a case of nutrient solution.

Layer by Layer: 3D Printed Art Objects in LACMA's Collections

3D printing has been quite a hot topic[1] in the news of late. Not surprisingly, objects constructed by this process have entered institutional collections. At the Los Angeles County Museum of Art (LACMA), we have identified two works of art as 3D printed. Results of the technical examination of these objects are presented.

3D Printing Technology

What is 3D printing? The technique grew from the manufacturing industry where it is referred to as rapid prototyping.[2] A manufacturing plant will not make just one of a particular widget because it is not cost effective. However, 3D printing allowed product designers, during their early design phases, to make just one scale model or part at a time as opposed to hundreds or thousands per "run." All that would be needed is a 3D computer-aided design (CAD) file that could be sent to the software associated with the 3D printer.

3D printing is defined as a process based on stacking many layers on top of one another to generate a physical object. There are many ways 3D printers can deposit these layers (See Table 1). The table illustrates the diversity of the printing methods and printable materials. The most common methods used are fused deposition modelling, stereolithography, and selective laser sintering.

Fused deposition modeling involves a plastic (or metal) filament that passes through a hot extrusion nozzle (Figure 1). At the nozzle, the plastic is heated above the glass transition temperature; upon deposition as a thin layer, it solidifies rapidly.

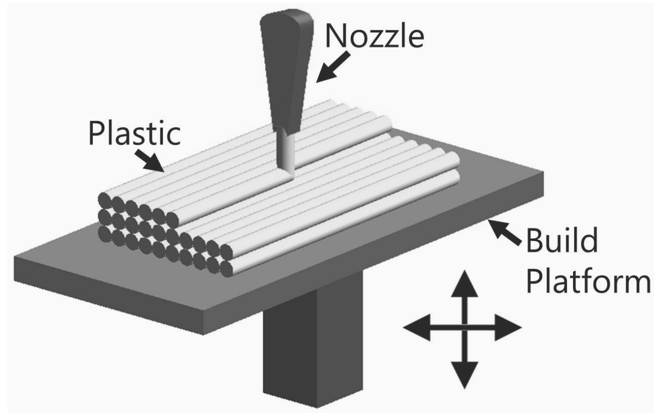


Figure 1: Schematic of Fused Deposition Modeling system [http://upload.wikimedia.org/wikipedia/commons/4/42/FDM_by_Zureks.png accessed August 29, 2014].

Stereolithography (SLA) uses a laser and photosensitive liquid polymer (Figure 2). As the laser is rastered across the liquid surface, a thin solidified layer is formed. The platform on which the layer is deposited is lowered step by step and the deposition repeated until the object is complete. Selective Laser Sintering (SLS) works in a similar manner. However, in the SLS process, the laser is rastered across powder, and the heat from the laser fuses or clumps together the powder particles. Again, the platform lowers, and the next layer is ready to be formed.

An excellent collection of videos of these technologies in action can be found at www.youtube.com/playlist?list=PL6ReneqBS2JDFuygm6Yta1iNBMaUds5fq.

Table 1: Major 3D Technologies

Technology	Material	How it works
Laminated Object Manufacturing	Paper, metals, thermoplastic	sheets of material are bonded to form an object
Stereolithography	UV curable resins, waxes, ceramics	liquid photopolymer in a vat cured by light
3D Inkjet Printing	Composites, polymers, ceramics, metals	liquid bonding agent is selectively deposited
Multi-Jet Modeling	UV curable resins, waxes	droplets of material are selectively deposited
Fused deposition	Thermoplastics, waxes	material is dispensed through a nozzle or orifice
Selective Laser Sintering	Thermoplastics, binder coated metals	thermal energy fuses regions of a powder bed
Selective Laser Melting	Metals	focused thermal energy fuses materials by melting as the material is being deposited
Direct Metal Laser Sintering	Metals	thermal energy fuses regions of a metal powder bed

by Charlotte Eng

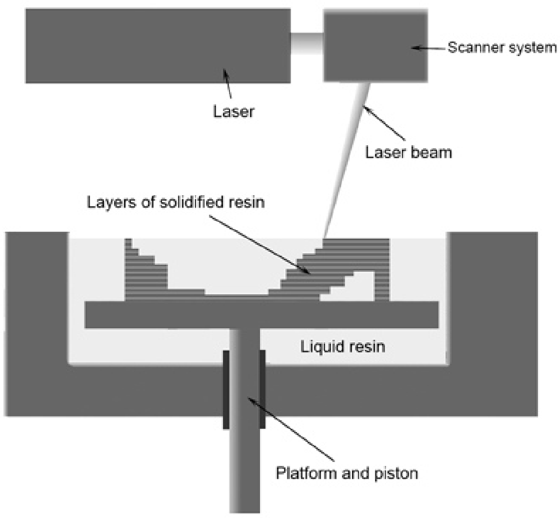


Figure 2: Schematic of a Stereolithography Apparatus [http://upload.wikimedia.org/wikipedia/commons/1/1e/Stereolithography_apparatus.jpg accessed August 29, 2014].

Case Study 1: Flatware Project for Alessi by Greg Lynn

In 2005, Greg Lynn was asked by Alessi, the Italian design factory, to create a prototype of a flatware set (Figure 3).

The prototype was acquired by the Decorative Arts and Design Department of LACMA in 2012. Soon after, there was a loan request for some pieces of the flatware. As the objects conservator Lily Doan was preparing them for the loan, she noticed that the metallic surface of the flatware pieces was atypical; it was very matte and grainy in appearance. The surface color of the different pieces varied considerably, some were more golden while others were grayish in color.

In the museum collection database, the flatware was described as steel and brass alloy, two materials that are already each alloys and are not traditionally mixed. To better understand what the material actually was, selected pieces from the set were examined microscopically[3] and analyzed using X-Ray Fluorescence (XRF) spectroscopy.[4]

Under the microscope, the surface of the metal appeared rough and granular. Interestingly, along the edges of the flatware, evidence of a layered structure, or steps, was observed. This is consistent with a 3D printing process (Figure 4). Under very high magnification, separate grey and gold colored areas can be seen, suggesting two types of metal have been intermingled.

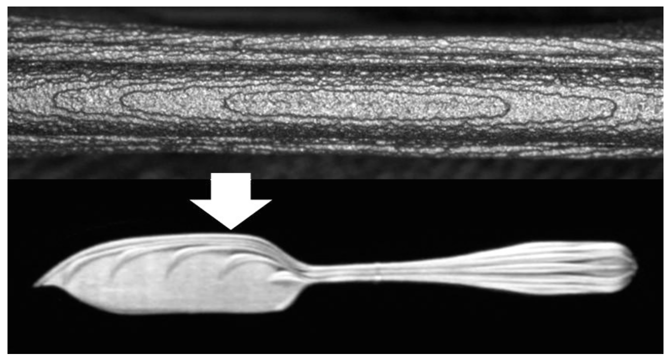
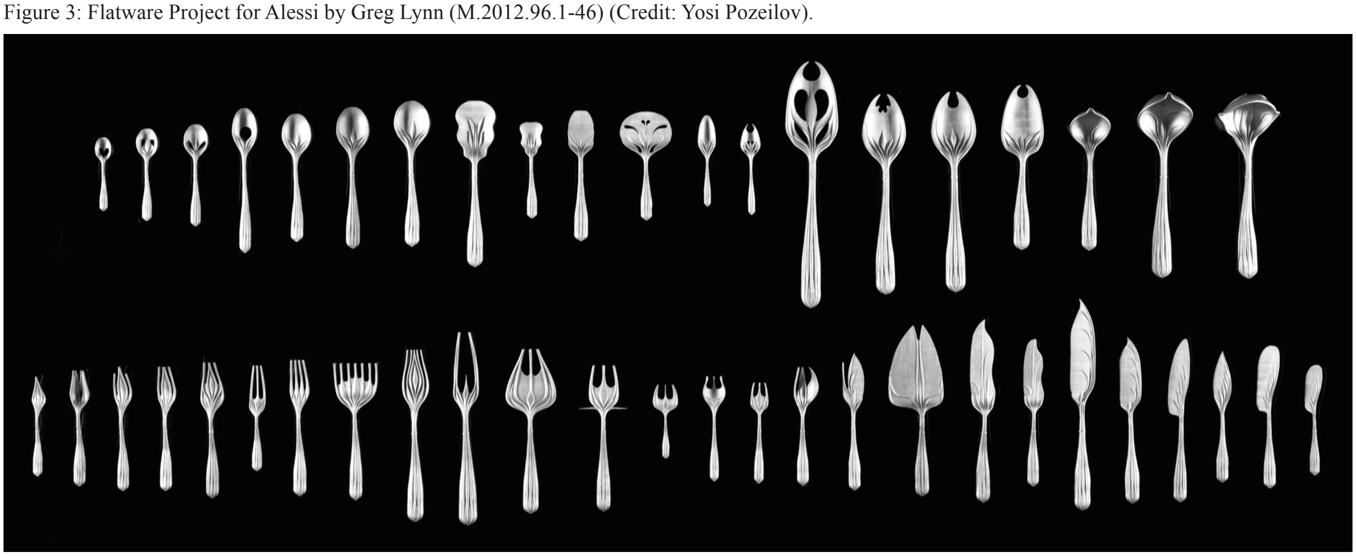


Figure 4: Steps seen on the edge of one of the pieces of flatware.

To identify the metals, we used a portable XRF spectrometer, which provides elemental information. The XRF analysis indicated that the objects were actually made of tool steel, an alloy that contains iron,tungsten, and bronze, which is a copper and tin alloy (not brass as described in the collection database).

Figure 3: Flatware Project for Alessi by Greg Lynn (M.2012.96.1-46) (Credit: Yosi Pozeilov).



In addition, the analyses of different pieces indicated that the ratio of the steel and bronze was highly variable (Figure 5). Some pieces had consistent amounts of steel and bronze throughout, while others contained more bronze at one end compared to the other. Still others had very small amounts of bronze.

This variability in the amounts of steel and bronze can be explained by the printing technique that was used to print these objects.

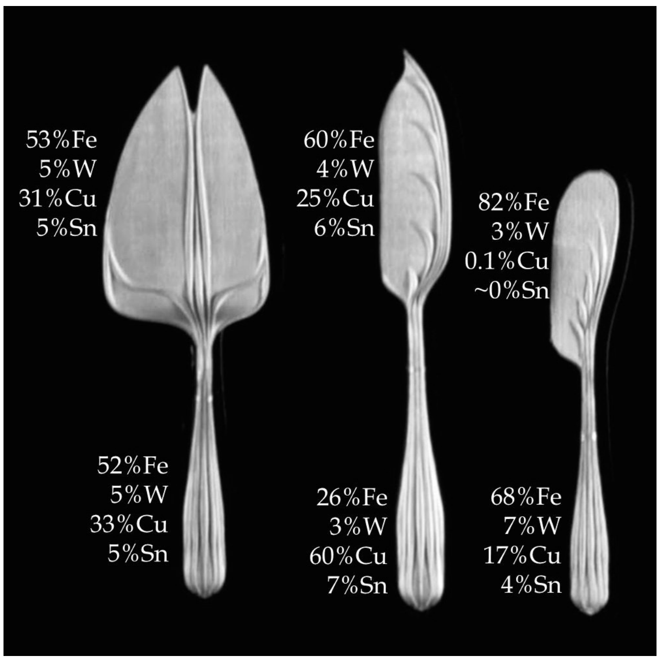


Figure 5: XRF Analysis of selected flatware pieces.

It is likely that indirect selective laser sintering[5] was used to make the flatware. Tool steel powder coated with a polymer binder is used for the powder bed. As the laser rasters across the powder surface, it melts the polymer binder, fusing the coated metal powder particles together.

At this "green" stage of manufacture, the flatware pieces are very fragile because they are held together only by bits of the binder and contain countless voids. To strengthen the flatware objects, these voids are filled with bronze.

This is achieved by gently placing these porous steel objects in an oven. At high temperature (in excess of 900 ℃), the binder coating is burned off and liquid bronze is wicked through the porous steel structure via capillary action.

If the conditions are not optimal during this stage, the bronze infiltration is not complete. This could account for the variability in color and elemental composition of the individual flatware pieces.

Case Study 2: *Fashionista Golden Girl* by Ted Noten

LACMA also has a Ted Noten necklace made of plastic (Figure 6) in the Decorative Arts and Design Collection.

Ted Noten is a Dutch jewelry designer and artist. As part of his "Haunted by 36 Women" project, he created a number of Fashionista necklaces.[6] LACMA acquired the purple *Fashionista Golden Girl* necklace in 2013.

Figure 6: *Fashionista Golden Girl* by Ted Noten (M.2013.221.24) (Credit: Los Angeles County Museum of Art).

To verify the description in the museum database (i.e. glass-filled nylon, gold), it was submitted for technical examination.

At first glance, it did not appear that the object was 3D printed, but upon closer observation of the areas of high curvature, we were able to find concentric ellipses, again indicating the object was made layer by layer using a 3D printing process (Figure 7). These circles are the remains of the steps that were polished down during the post processing stage.

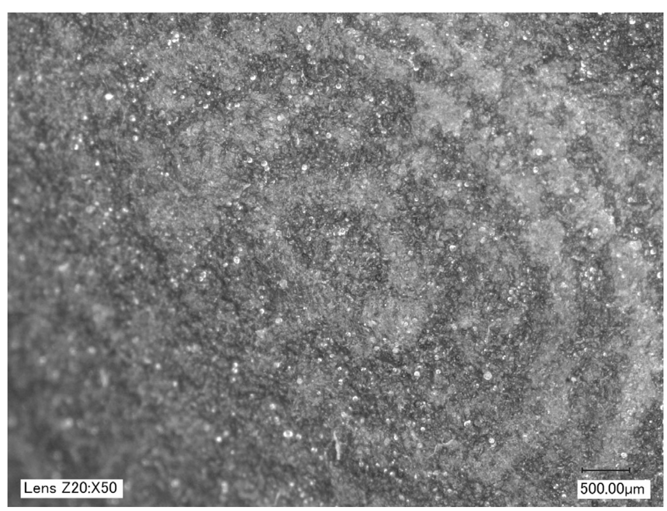


Figure 7: Detail of one of the shoes in *Fashionista Golden Girl.*

At really high magnification, we were even able to see plastic grains as well as shiny clear beads agglomerated together (Figure 8).

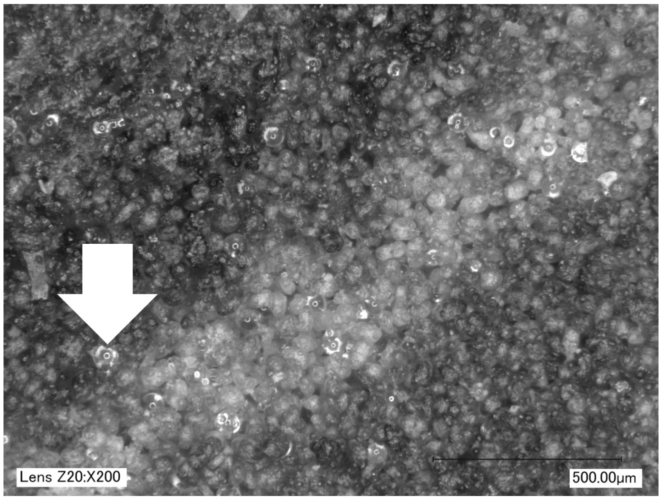


Figure 8: Micrograph showing glass beads (arrow) and granulated nylon.

Fourier Transform Infrared (FTIR)[7] and XRF analysis indicate that the plastic was nylon while the shiny beads were made of glass. The grainy surface indicates that the necklace was made using selective laser sintering, which was confirmed by the artist.[8]

Storage and Display Recommendations

Bronze infiltrated steel objects printed using the SLS method pose a long term stability problem if they are stored improperly. The facts that the steel and bronze are so intimately associated and especially that voids are present, make these objects susceptible to galvanic corrosion, a process in which one metal is protected preferentially at the expense of the other, which corrodes away.

In the case of steel and bronze, the steel will be the alloy that corrodes. Therefore, we recommended that for storage and display, these pieces should be kept in a low humidity environment, preferably below 35%RH. And as an extra precaution, scavengers that remove acids and other air pollutants should also be present.

Over time, 3D printed plastics like all plastics, will develop deterioration problems such as yellowing, crazing, embrittlement, delamination, and distortion. In addition, it should be noted that if the plastic is colored – as in the Ted Noten necklace – the colorants used may also fade or shift in hue over time. To slow down the inevitable deterioration, these objects must be appropriately stored and displayed.

For storage, lowering the temperature would decrease the rate of the chemical reactions leading to deterioration. Some of the chemical processes require oxygen and or water, so containers could be made with impermeable materials and contain oxygen scavengers and water absorbers. Light induced damage, particularly for objects made of the photopolymer resins used in stereolithography, could be mitigated by storage in the dark and display at low light levels with UV-blocking filters.

Conclusions

To determine whether an object was made by 3D printing, its surface should be examined for steps indicative of the process. However after objects are printed, they could be polished to create a final surface without noticeable steps. Therefore, communication with the artist is important, particularly if the object had been post- processed such that identifying attributes are not so clear.

Because 3D printed objects are made using techniques that grew out of the prototyping field, longevity was never a concern. Thus, for long term preservation, environmental conditions should be carefully controlled to slow down deterioration of these objects. As the 3D printing industry matures, it is hoped that there will be a stronger emphasis on use of more stable materials and combinations.

Acknowledgements

Sincere thanks to Lily Doan, objects conservator and Bobbye Tigerman, associate curator of LACMA's Decorative Arts and Design for their contributions to the investigations of these objects. I would also like to acknowledge Frank D. Preusser, LACMA's senior research scientist for his suggestions and support. Helpful comments and corrections of this article were provided by Terry Schaeffer, LACMA's scientist emeritus.

1 There are over 6000 hits in Google News if "3D printing art" is searched [https://www.google.com/?gws_rd=ssl#q=3D+printing+art&tbm=nws last accessed August 29, 2014]

2 Rapid Prototyping / History / Prototyping Technologies [http://www.mechanicalengineeringblog.com/tag/history-of-rapid-prototyping/ last accessed August 28, 2014]

3 Micrographs were captured using a VHX-2000 microscope with a 20-200x lens [Keyence Corporation of America, Itasca, IL]

4 XRF analysis was performed using a handheld Delta XRF Analyzer [Olympus NDT, Waltham MA]

5 http://repositories.lib.utexas.edu/bitstream/handle/2152/ETD-UT-2011-05-3301/VALLABHAJOSYULA-DISSERTATION.pdf

6 http://en.wikipedia.org/wiki/Ted_Noten

7 FTIR analysis was performed using an IlluminatIR FTIR microscope [now Smiths Detection, Inc, Edgewood MD]

8 www.tednoten.com/work/portfolio/haunted-by-36-women

Tea. Earl Grey. Hot. - About Materials in 3D Printing

Since the late 1980s 3D printing has been used to transform digital data into physical models and prototypes.[1] In recent years, 3D printing technologies are no longer exclusively used for the fabrication of models and prototypes, but also for the production of small object batch series or single unit projects by the industry and maker scene. Some people call it the 3rd industrial revolution, others can hardly wait to order "tea, Earl Grey, hot" from a 3D printer like Captain Picard did from the Star Trek replicator.

Today, designers and artists are using these technologies in myriad ways, and consequenctly, 3D printed art and design objects, as well as architectural models, have become part of museum and private collections. Conservators are now challenged by a variety of questions about the technology and ageing stability of these objects.

This article is partly based on my MA thesis from 2011, which deals with the applications, technologies, and ageing properties of objects in contemporary art, architecture, and design made by rapid technology.[2] It summarizes the results of the light and dark ageing tests of 3D printed samples performed in 2011 and goes on to describe current trends of material development in 3D printing.

3D printing methods and materials

In order to understand material formulations and their ageing behaviour it is necessary to understand the various 3D printing technologies and their requirements. Today, stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling (FDM), and inkjet powder printing (3DP) are the most popular methods used for rapid technology. In addition to these, layer laminate manufacturing (LLM), material jetting (Polyjet), and paste extrusion are used for large volume objects, material combinations, large-scale machines, printing pens, and foodstuff printers.

A wide range of materials can be used in 3D printing (Gebhardt 2007: 1). Synthetic polymers are often found in the fabrication of industrial prototypes and functional models in design and architecture, metals are commonly applied in the aerospace and tooling sector, and ceramics are widely used for medical applications (Gebhardt 2007: 264 ff.; 305 ff.). But these distincions are lost in the fast growing maker scene, artists and designers who undertake experiments with industrial techniques and materials in order to break them down for home printer solutions.

Table 1 summarizes the techniques mentioned above and gives examples of materials. (Horsch 2014: 27, 73; FormFormForm ltd 2014; Gebhardt 2007: 202f.; i.materialise 2014; Koenig 2014; RepRapWiki 2014; Warnier et al. 2014: 10-15, 47, 49, 56, 124, 142, 146, 150, 170). One must keep in mind that this table only gives an overview and that the materials used in 3D printing are not limited to those mentioned.

The material formulations developed for the different 3D printing processes can be rather complex, e.g. for stereolithographic applications with its high requirements in photosensitivity.[3] Furthermore, some techniques/materials are difficult to identify because they require postproduction treatments. For example 3DP models have need of stabilization by using wax, resins, or UV coatings, whereas 3DP ceramics have to be consolidated by kilning before they can be glazed (Horsch 2014: 31f.; Warnier et al. 2014: 12).

Colour stability of 3D printing materials

When I began the task of investigating the ageing behaviour of 3D printing materials, I became aware that most studies dealing with the ageing stability of 3D printed objects were performed in regard to industrial applications. They mainly focused on testing the materials' hydrolytic and thermal ageing or the influence of ageing on the 3D prints' mechanical stability.[4]

Prior to 2011, little was known about the long-term ageing behaviour of 3D printed objects if stored or exhibited in museum conditions. A variety of conservators and technologists then began to observe that some polymer based 3D printing materials tend to yellow within a short period of time.

Based on these observations I started light and dark ageing experiments to examine the colour stability of synthetic polymers typically used for 3D printing in industrial and/or home user systems. These experiments were carried out on 3D printed samples, including material formulations based on epoxy resin (EP) for SLA, polyamide powder (PA) for SLS, and acrylonitrile butadiene styrene (ABS) for FDM.[5]

For each of the tested 3D printing materials, pieces were stored in the dark in climate-controlled storage rooms (85 days, 23 +/- 3° Celsius; 50 +/- 5 % RH). An equal number underwent the simulated light ageing procedure (91 days, glass-filtered daylight fluorescent lamps). Before and after, the colour and brightness of all samples were monitored by colorimetric measurements.

Under these conditions, I observed that a variety of the tested materials underwent changes in colour in dark storage as well as in daylight exposure.

The most notable changes were in all tested epoxy resin based samples after 91 days of light ageing as those significantly turned from white to yellow-brown. It is remarkable that most of the epoxy resin samples also showed significant colour changes after 85 days with exclusion of light.

by Denise Madsack

Table 1

Overview of 3D printing techniques, materials, and appearance

SLA sterolithography	liquid (often permeable to light) acrylics epoxy resins (EP) polyvinyl ethers	photo polymerisation	highly accurate
SLS selective laser sintering	powder polyamide (PA) alumide® (PA with aluminum) polystyrene (PS) polyethylene (PE) polypropylene (PP) thermoplastic polyurethane (TPU) silica sand	fusing	inaccurate
FDM fused deposition modelling	solid (pre-extruded) acrylonitrile butadiene styrene (ABS) polyethylene (HDPE) polyphenylsulfone (PPSF) polylactide (PLA) polycaprolactone (PCL) polyvinyl alcohol (PVA) polyamide (nylon) polycarbonate (PC) silicone (sugru®) thermoplastic elastomers (TPE) thermoplastic binder with wood, metal or ceramics as a filler	fusing and applying	accurate (rounded corners)
3DP inkjet powder printing	powder (substrate) and liquid (binder) gypsum starch clay ceramics glass metals wood paper salt cement	binding	accurate
LLM layer laminate manufacturing	sheets, adhesives sheets: paper coated with polyethylene polyester foils fibre reinforced composites adhesive films polystyrene and unplasticized polyvinylchloride sheets adhesives: EP, PE, acrylics, methacrylics	cutting and glueing	accurate
paste extrusion	solids cement concrete clay foodstuff bio materials	solids	extrusion
material jetting (Polyjet)	liquids see SLA (an object can be made out of different materials/colours)	photo polymerisation	highly accurate

All ABS samples, as well as the polyamide pieces, similarly underwent colour changes after accelerated daylight ageing. The corresponding colorimetric data revealed a shift into yellowing.

Reasons for the photo-oxidative ageing of 3D printing materials

One possible reason for the observed colour change is the presence of oxidation-sensible components in the material. Such components are aromatic molecules like biphenyl A in the epoxy resin based 3D prints or the typically oxidation-sensitive butadiene content in ABS (Gaechter and Mueller 1983: 48; Krebs 1999: 81). It is also important to note that the printing process itself can initiate a pre-oxidation of 3D printing materials. It is well known that such a pre-oxidation can accelerate the future oxidative ageing of plastics (Zweifel 2011: 3).

Pre-oxidation can be initiated during the heat impact caused by the extrusion process during FDM (e.g. of ABS) or Laser Sintering (e.g. PA), but also by the radiation energy used for hardening stereolithographic resins (e.g. EP resins). Moreover, with stereolithographic printing, residues of catalysts or monomers can remain in the material with the potential to speed up oxidative ageing.

Development of 3D printing materials by contemoorary artists and designers

3D printing has experienced an extraordinary degree of development within the last three years, not least due to the expiring of the first 3D printing patents from the 1990s. Therefore, my tests performed in 2011 could already appear slightly out of date.

Nevertheless, the objective here is not giving precise statements about the long-term stability of single materials, but to provide some background on the nature and technical environment of those materials. I also would like to provide some examples of 3D printing experiments made by artists and designers since that time.

Besides conventional 3D printing techniques some tendencies can be observed: use and imitation of natural materials, recycling printed plastics, and combinations of different synthetic polymers.

Various artists and designers have imitated and dealt with natural materials that already hold their own cultural significance.

For example the project *L'Artisan Électronique* by Studio Unfold and Tim Knappen uses paste extrusion to print ceramics (Warnier et al. 2014: 48, 56ff.).

Eric Klarenbeek has experimented with the same 3D printing process. He mixed up powdered straw with water and coated it with a bio plastic polymer (Fig. 1). A mycelium of fungi then grew, substituted more and more water and stuck the printed substrate together (Warnier et al. 2014: 152ff.).

Figure 1: *Mycelium Project 1.0 - Myceliumchair* (2013/14) by Eric Klarenbeek.

Other designers have discovered simple natural materials for 3D printing and carried out experiments. *Saltygloo* by Rael San Fratello Architects is architecture printed with salt from natural deposits. *degenerate chair* by Daniel Widrig was created by binding together layers of a mixture of plaster and sugar with japanese rice wine (Warnier et al. 2014: 178f.; Widrig 2014).

The *SolarSinter* by Markus Kayser is another example of unconventional thinking with using silica sand, SLS, and solar energy to build glass objects (Fig. 2; Warnier et al. 2014: 47, 54, 188f.).

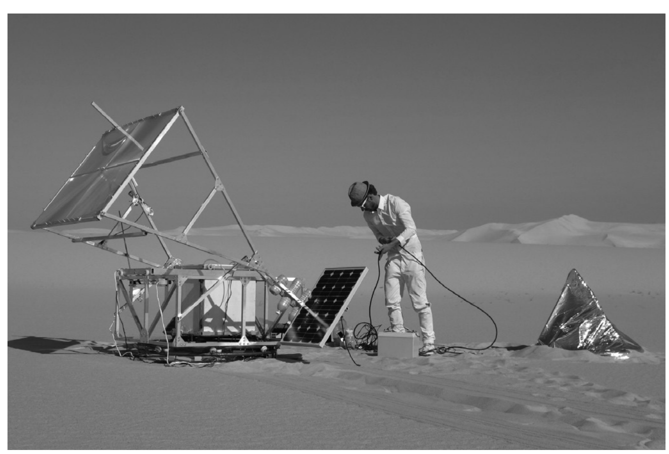


Figure 2: *SolarSinter* (since 2008) by Markus Kayser

Scott E. Hudson has modified a typical personal printer to invent a machine that is able to handle wool and wool blend yarn. In doing this he has combined the traditional felting of wool with modern 3D printing techniques.[6]

Nendo, a Japan based design studio, has created *Lacquered Paper Objects* made with LLM and has imitated a wooden surface by grinding manually and lacquering (Warnier et al. 2014: 116f.).

Another widespreqad trend within the 3D printing community is recycling plastic material from industrial products as well as 3D printed objects.

Dave Hakkens and Dirk Vander Kooij have created two different ways to reuse material from objects of every day life. Hakkens has build a series of small machines for recycling plastic material with a self-made shredder called *Precious Plastic*. PE, PP, and other thermoplastic polymers can be easily granulated and prepared for reuse with a 3D printer.[7] Dirk Vander Kooij has assembled a discarded robotic arm to extrude thick layers of melted plastic (from old refrigerators) via paste extrusion (Warnier et al. 2014: 120f.).

The Potato Eaters by DUS Architects works with paste extrusion as well, even though the material differs. Instead of plastics the architects use potato starch recycled from fries to produce tableware (Warnier et al. 2014: 163).

A further approach is the combination of different plastics by 3D printing. Form Nation and Jan Habraken have created the project *Chairgenics*. Their chairs are fabricated by SLA using epoxy resins and afterwards filled with polyurethane foam for stabilization (Warnier et al. 2014: 134ff.).

Marloes ten Bhoemer has combined two 3D printing technologies to assemble hard with soft materials (Fig. 3). Her *Rapidprototypedshoe* is made out of acrylic and elastic photopolymers with Polyjet and laser sintering techniques (Warnier et al. 2014: 128.).

Figure 3: *Rapidprototypedshoe* (2010) by Marloes ten Bhoemer.

Conclusion

3D printing is a very recent technology and technical developments are ongoing. It demands a high level of attention to current trends and tendencies in order to stay up to date. The results concerning the colour stability of 3D printing materials presented here should be understood as a snapshot of a fast changing and innovative technology.

The composition of 3D printing materials is complex.[8] In particular, minor components in the formulations (e.g. catalysts, ageing stabilizers, residual monomers in SLA parts) are not fully documented by datasheets or in specialized literature.

Furthermore, a 3D printed object by itself might not be a homogeneous material unit. Not only do designers and artists recycle, but also the industry recycles the support material, in the SLS process for example, and mixes it up with new powder. In addition, there are plenty of processing parameters during 3D printing (e.g. processing temperature, radiation energy) that the manufacturer can change.

This potentially influences the ageing stability of the finished part. Considering this complexity, it becomes obvious that it is not possible to make general statements about the ageing stability of 3D printing materials. Nevertheless, the study from 2011 shows results on the prospective behaviour of the materials used at this time and gives insight into expected deterioration phenomena.

Many of the tested 3D printing materials are not photo-oxidatively stable and tend to change colour in accelerated indoor light exposure. Moreover, a variety of the tested materials showed colour changes even if stored in the dark for a short time (84 days). This indicates the necessity of preventive conservation treatments to slow-down the materials' ageing by oxidation processes.

Possible ways to achieve this could be oxygen-free storage, the use of UV-A filters, or the reduction of illumination time and intensity.

Finally, it is important to note that the development of suitable preservation concepts for 3D printed objects also includes understanding the artists' and designers' position in regard to the desired durability of the 3D printed object, the acceptance of ageing phenomena, and the question of re-printability.

As part of a conservation strategy, it might be necessary to implement protocols to acquire the digital data of the 3D parts (CAD or STL files) and back them up in suitable archival formats.

Most 3D printing materials were originally developed for short-lived prototypes and models. They were not made to last several years. However, the requirements for the material's ageing stability can change drastically if a collector or a museum acquires a 3D printed object as piece of art or design. Then, as this article has shown, the preservation of 3D prints poses an extraordinary challenge.

Endnotes

(1) 3D printing is used as a generic term for all commonly so-called «generative manufacturing processes» which can be described as growing an object by applying and fusing material (e.g. liquid, filament or powder) layer by layer (Bonten 2003: 53 ff.). The term 3D printing must not be confused with inkjet powder printing (3DP).

(2) The thesis was written at the Conservation Department of the Berne University of the Arts in close contact with conservators, artists, designers, and technologists. The main goal was to enlarge the conservators' knowledge about the techniques of objects made by rapid technology and about the prospective ageing behaviour of some current materials in use. The term rapid technology is used to sum up rapid prototyping, rapid manufacturing, and rapid tooling.

(3) The high complexity of these materials is well documented in the patent literature, e.g. Pat. No. US 6,251,557 B1 «Photosensitive Resin Composition for Rapid Prototyping and a Process for the Manufacture of 3-Dimensional Objects» by Stephen Lapin and Michael Sullivan in 2001.

(4) See «Effects of Aging on Epoxy-Based Rapid Tooling Materials» by Xavier Ottemer and Jonathan Colton (2002, Center for Polymer Processing, Rapid Prototyping and Manufacturing, Institute and School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA), «Effect of long-term ageing on the tensile properties of a polyamide 12 laser sintering material» by R.D. Goodridge and R. Hague (2010, in: *Polymer Testing*. No. 29/2010, p. 483-493), and «A study of the impact of short-term ageing on the mechanical properties of a stereolithography resin» by S. Mansour, M. Gilbert, and R. Hague (2007, in: *Materials Science and Engineering* A. No. 447/2007, p. 277-284).

(5) The complete experimental set-up including manufacturers, material descriptions, method of measuring, and evaluation in statistics is published in Madsack 2013: 60 f.

(6) «Printing Teddy Bears: A Technique for 3D Printing of Soft Interactive Objects» by Scott E. Hudson, Human-Computer Interaction Institute, Carnegie Mellon University and Disney Research Pittsburgh, 2014.

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In Progress: 3D Laser Scanning and Reproduction of Taliesin's *Flower in the Crannied Wall*

by Nicole Grabow

Abstract

After over 100 years of continuous display outdoors, the stoneware sculpture *Flower in the Crannied Wall*, commissioned by Frank Lloyd Wright from the artist Richard Bock, was brought inside. The move followed conservation treatment by the Midwest Art Conservation Center (MACC) in Minneapolis, Minnesota to repair structural damage.

As part of this treatment, and in order to preserve Wright's vision of Taliesin as it was at his death, a reproduction of the sculpture is being created for permanent display in the outdoor location. 3D laser scanning and a combination of 3D printing and milling are being used for the reproduction, the installation of which is anticipated in September 2014. This paper discusses the techniques used.

Introduction

In 1909 Frank Lloyd Wright commissioned a sculpture that was completed by Richard Bock for the Dana House in Chicago. Two years later, Bock produced a second cast of the same work for Taliesin, Wright's estate in Wisconsin.

The sculpture, which depicts a standing female figure emerging from a crystalline obelisk, has been called the keystone of the Wright Style and was on display in various outdoor sites on the estate for 102 years, until it was deinstalled for conservation in 2013.

On the flat plane of the back surface are inscribed the words of Alfred Lord Tennyson's poem (1869) from which the artwork gets its name, spacing as on the sculpture:

Flower in the
Crannied wall
I pluck you out
Of the crannies
I hold you here
Root and all in my
Hand
Little flower
But if I could
Understand
What you are
Root and all
And all in all
I should know
What God
And man is

Flower in the Crannied Wall before deinstallation

The Taliesin sculpture, like the Dana House version, is 55 inches high and made of buff-colored stoneware ceramic cast into a mold with some details, such as the incised poem, worked by hand into wet clay before firing. The surface is dense and smooth, with a more gritty clay body revealed along break edges and on the hollow interior.

Physical damage to the sculpture prior to 1925 resulted in loss to a large section of the crystal at the front; and after 1938 the sculpture was broken into numerous pieces and repaired, but both arms were lost. Sometime after that the head was broken and repaired.

In 2013 *Flower* was deinstalled for conservation and brought to MACC, where it was cleaned, re-repaired, and then scanned for reproduction. In spite of the significant losses, the decision was made to scan it without recreating the arms or crystal top since their loss is now a part of the artwork's history. Following treatment the sculpture was returned to Taliesin where it is now on display in its new, less vulnerable indoor location: Wright's studio.

Wright's Studio

Why Scanning?

3D scanning was chosen to reproduce *Flower* both for ease-of-use and safety. Extricating a mold from the surface, particularly in the detailed undercut areas of the head and crystal, would have risked damage to the sculpture. Additionally, making a mold would have required moving the sculpture from the secure location of the conservation lab to an off-site workshop, presenting the physical risks of movement as well as increased vulnerability to theft or vandalism.

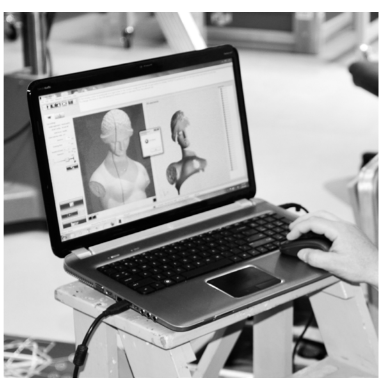
Scanning also provides an opportunity for wider accessibility to the sculpture's form. The scanned files are the property of the Frank Lloyd Wright Foundation, as stipulated in the treatment proposal, and can be used for a variety of purposes of their design and choosing. Possible examples include creating an educational web element, exploring interactive programming onsite, or printing smaller-scale reproductions for sale. In the event that anything should happen to the original or its reproduction, a digital record now exists; this information can be shared easily and used for as long as the software exists to manipulate it.

Procedure

Scanning was completed by outside contractor First Article Corporation using a Konica Minolta Range 7 Non-Contact 3D Digitizer, which they brought to the MACC Objects Lab.

Small clay dots placed on the sculpture enabled the different scans to be keyed together.

The scanning took approximately 3 hours and required recalibrating the scanner once to compensate for a subtle temperature drop in the lab. High resolution scans were completed for the text panel on the back. After scanning, First Article produced watertight Stereo Lithography (STL) files of maximum size, with no compression. There were two files, one of the overall sculpture and one detail of the text.



Next, the STL files were transferred to the 3D shop at the Minneapolis College of Art and Design (MCAD), where the reproduction is being fabricated. The scans were examined for polygon resolution to determine that they were dense enough with no gaps or thin areas of data. The more data, the more likely that printing/milling would be successful. Several small test models were printed to aid in this process.

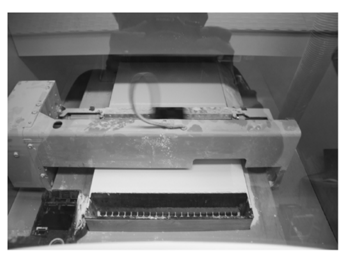
The goal of the printing/milling was to create an actual-size positive model of the sculpture from which a mold could be taken. Due to the size of the sculpture it was necessary to produce this model in several pieces. Since there are large flat planes and areas of the sculpture that do not have extensive surface detail, most of the model was cut on a milling machine with only the details of the head, front crystal, and back text panel printed out on the 3D printer.

To do the milling, the STL files were brought into the router's computer and viewed with Solid View software for manipulation and slicing. The advantage of this particular software is that it can cut the data, creating separate files for the head and body for example, while retaining the watertight STL format of both sections. Once the scan had been divided into 27 smaller separate sections, they were prepared for milling and printing.

The milling machine used was a Techno LC Series Computer Numerically Controlled (CNC) Router with Cut 3D software. This software enabled manipulation of the scan in space so that it could be positioned optimally for cutting and adjustment of the scale so the pieces fit together correctly and emerged the right size. Also, since the router cut in 2-inch slices, this software sliced each scan (already cut down from the main file) into 2-inch sections.

The pieces were cut into polyurethane sign board, which provided a nice toothy texture similar to that of the original sculpture. The cuts were first roughed out with 0.25" ball nose bits using a 27% step-over (the distance the bit moves from one cut to the next). After roughing out, the finishing tool pass was made with 0.125" ball nose bits and a 4% step-over. The roughing out pass was made along the y-axis, while the finishing pass was made along the z-axis to erase stepping lines.

Meanwhile, the head, crystal, and text were printed out on the ZCorp ZPrinter 150 3D printer using the ZPrint software. This printer has a 9" x 9" x 9" size limitation. It prints in gypsum which it lays down one line at a time, much like a 2-dimensional ink-jet printer.



When all the parts had been cut and printed, they were sanded lightly with 1000-1200 grit paper in some places (and the back of a brown paper bag in others) then glued together to create a whole. This whole forms a temporary positive, from which a mold will be taken using Polytech Polygel 40 and a fiberglas mother mold.

Although the scans were very high resolution, and the printing extremely accurate, the recessed surface of the detailed areas on the original sculpture were over 1/3-inch deep; and some undercut areas when printed still have a softer look than the crisp edges of the original sculpture, particularly the text on the back. As this project stands now, the lines are being sharpened by hand using dental tools and a scalpel.

Manually sharpened details are above the parting line.

When this is complete, the mold will be taken and the final reproduction will be cast in Hydro-Stone gypsum cement, tinted to match the original ceramic.

Conclusion

3D scanning and printing are emerging technologies that provide enticing solutions to many of the obstacles inherent in creating mid- to large- size reproductions of artwork. While this is not the first 3D scanning project MACC has undertaken, it is the largest and most complex to date and relied on the skills of a professional scanning team as well as experienced mold-makers/printers/millers/sculptors.

The safety of the technique for the artwork itself was excellent and represents a minimally interventive approach, while the accessibility of the digital information will be an asset to the client. However, the finishing work required calls to question the ease-of-use of the process. It brings an element of both subjectivity and craftsman's skill into a technique that was developed in part to avoid such things. Perhaps this is not entirely negative, and perhaps it should be no surprise that we find again and again, when working with objects of art, the human hand remains a necessity.

Acknowledgements

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3D Printer Technology and Violin Making Tradition: an Outlook on Potential Applications and Open Questions

Introduction

In recent years there has been growing interest in the area of musical instruments, stimulated by the marked rise in market values. In particular, most of the economic investments are focused on violins [1][2]. Their economic value is due to many factors such as their history, the intangible value of their sound, and the myths associated with the greatest lutherie's masters.

Many historical instruments made by Stradivari, Amati, Guarneri, and Guadagnini are still played, and many others are preserved within public museums. The particular sound of these instruments depends partly on the musician who plays them, but primarily on the intrinsic characteristics of the violin. This is closely related to the design, the making technique, the varnish finishing, and the set-up, established a priori by the violin maker.

The structural complexity of the violin and the difficulty of obtaining permission to perform scientific analysis have helped to maintain the mystery of what makes the sound of the historical instruments so suggestive, feeding the myths even more.

Currently there are only a few scientific contributions published by international scientific journals relating to antique musical instruments. However, in recent years a portion of the contemporary lutherie community has demonstrated great curiosity about the area of applied research, recognizing it could be a means to rediscover the "know-how" of the masters. They believe that non-invasive characterization of historical materials and the modeling of geometries and shapes, could enable the modern luthier to modify his or her technical approach, perfecting it more and more.

The aim of the scientific research is thus the reconstruction of working processes followed by the ancient luthiers through a comparison between the analytical results and the bibliographic historical sources. Today the new Museo del Violino in Cremona hosts two laboratories of applied research at the University of Pavia and the Politecnico di Milano. Their teams of scientists are involved in the study of the historical instruments of the museum collection in order to put the contemporary violin maker even more in contact with the knowledge of antique violin making methods.

The non-invasive diagnostic laboratory of the University of Pavia uses scientific facilities specifically adopted for these purposes, including VIS-UV photography, endoscopy, X-ray digital radiography, stereoscopy, FTIR reflection spectroscopy, X-ray fluorescence (XRF) spectroscopy, and 3D laser scanning. Of particular interest to the violin making community is the possible opportunity to obtain 3D models of historical musical instruments via the 3D laser scanner and create some parts of them using a low cost 3D printer. Information gained with these non-invasive techniques would change the rules for the enjoyment of these repositories of cultural heritage in the safest possible way.

The laboratory is currently developing a method for the acquisition of musical instrument 3D models and performing trials of printing sections of these models with a desktop 3D printer.

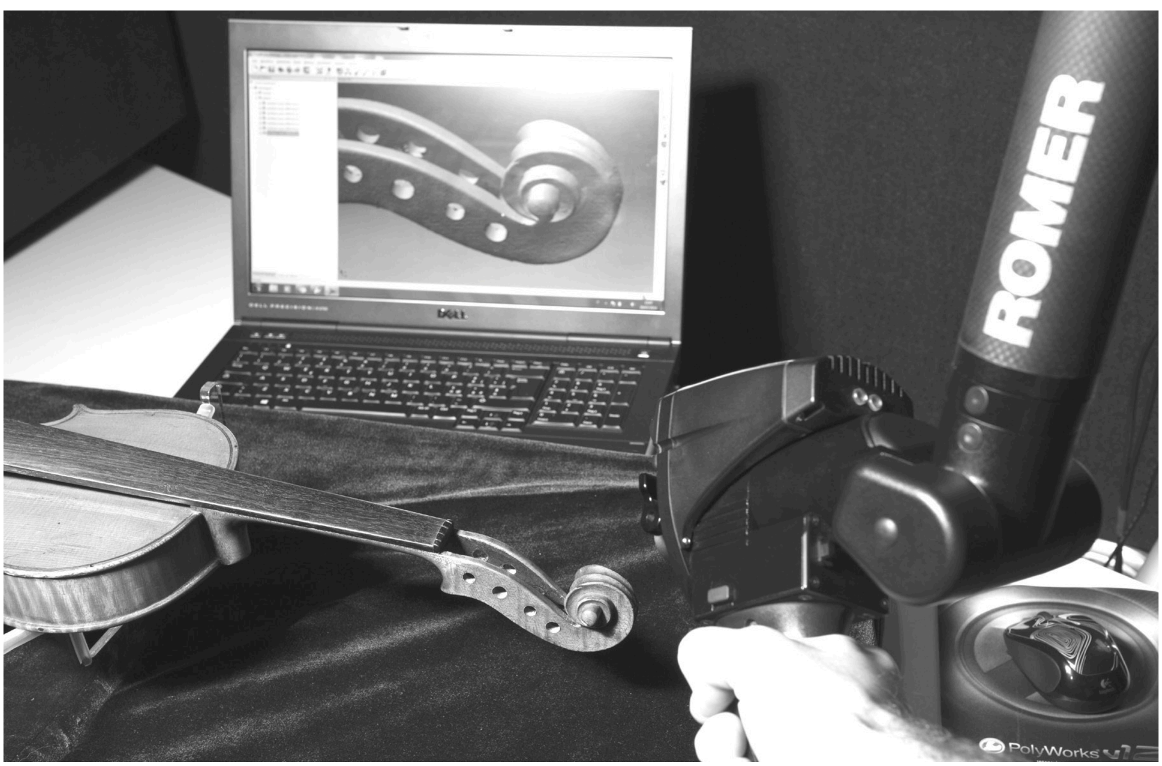

Fig.1.

3d scanning of the violin neck scroll.

by T. Rovetta, C. Invernizzi, M. Licchelli, M. Zilioli, F. Cacciatori, and M. Malagodi

3D Laser Scanner Modelling and Desktop 3D Printing in Lutherie

The 3D laser scanner of Hexagon metrology equipped with the ROMER absolute arm is a measuring instrument which allows the acquisition of a three-dimensional model of a musical instrument with a resolution of 20 microns. For scanning, the violin is located on two different plexiglass stands, protected by a sheath of silicone. The arm has a high degree of freedom of movement, thanks to the seven rotational axes. A measuring head which emits a pulsed laser line is used to scan like a brush stroke the surface of the violin (Fig.1).

The obtained raw data consist of a points cloud in a three-dimensional space, which is transformed by Polyworks software in a mesh of polygons (polymesh), which creates in the model. The final polygonal model is true to the original in size as well as in the tiniest features and surface discontinuities. These features make the models better than those acquired through structured light 3D scanners.

The device allows one not only to virtually document the conservation status of a musical instrument, but also to extrapolate sections, forms, archings, and “stylistic” references (like the neck scroll or the corners) simply from the three-dimensional model. And all of the data will be exportable in different extensions editable by other CAD or CAM softwares.

Such information has great importance for the violin making community, which is always referring to sections, archings, and forms that have been passed down from master to apprentice over time. Especially as these measurements are far more accurate than were previously possible.

In addition to the analytical studies and data archiving of the scans, the laboratory is also using a desktop 3D printer in order to investigate the potential of the 3D printing process to reproduce portions of musical instruments. To do this, the polymesh is edited, closing the open surfaces in order to obtain a solid model exported in the STL format. This is then processed by the open source software Slic3r [3] in order to convert it in the .gcode format, readable by the 3D printer software.

The team currently uses a “replicant” REPRAP Prusa Mendel 3D printer, a low-cost prototype 3D printer based on an open access project of REPRAP copyright [4] (Fig.2).

The device is a desktop 3D printer that works according to additive manufacturing through the FDM process (Fused Deposition Modeling), extruding an atoxic and biodegradable plastic polymer like PLA (polylactate). There are some limitations due to the dimensions of the plate and consequently the size of the object we can create.

For this reason we decided to print only small parts important from a stylistic point of view, like the neck scroll. The duration of the printing process can be changed by the user, determining the final resolution of the object printed. From a slow process (6 hours) it is possible to obtain the 3D shape of a neck scroll with horizontal slices of 100 μm in thickness and lateral resolution less than 100 μm. This allows us to get an object nearly identical to the original in details and size (Fig.3).

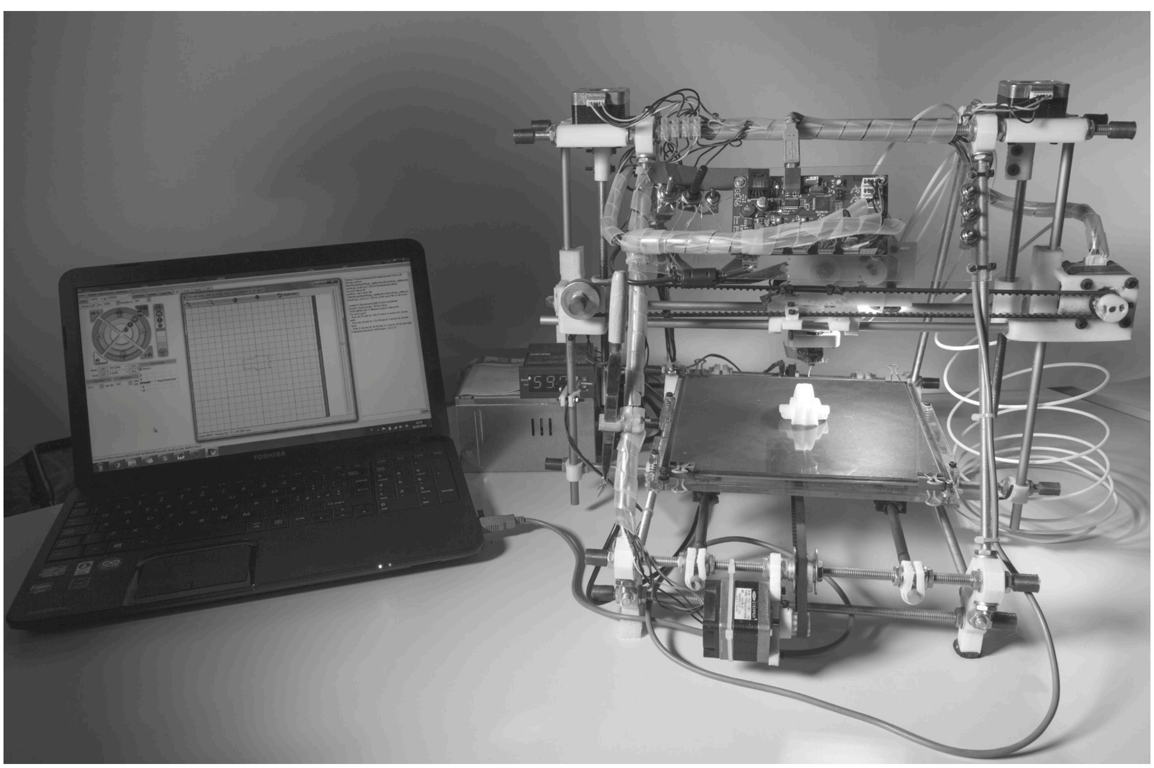

Fig.2.

The REPRAP Prusa Mendel 3D printer printing a small part of the neck scroll.

With printers of larger size it would be possible to print the soundboard, the back, the neck, or the set parts of the musical instrument. Complex three-dimensional objects can be also obtained with other technologies and at a higher resolution, but with much higher production costs (CNC, stereolithography etc.).

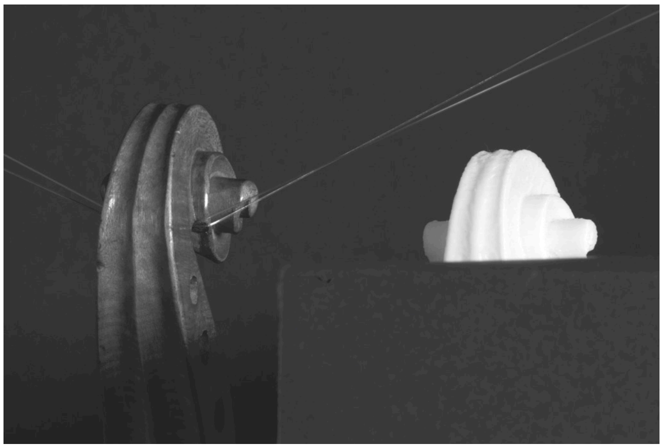

Fig.3. A violin neck scroll with its PLA printed copy.

Obviously, the ability to produce models or printed parts of important artworks such as portions of Stradivari or Guarneri violins can create problems depending on the use of this kind of data. For instance, with a printed model of a Stradivari neck scroll private luthiers could make a perfect copy of the original neck scroll giving them an evident commercial advantage compared to other craftsmen. It also creates a debate on the originality of the end product. This "open question" must be discussed by scientists, conservators, and owners of the violins, or other artworks, in order to regulate the commerce and to control the use of the data.

Potential Applications

One of the most important consequences of the digitization of cultural heritage lies in the possibility of setting up a permanent archive of data that describes the morphological characteristics of surfaces of three-dimensional objects. Currently many museums offer virtual tours for the remote enjoyment of their collections, and some of these already offer the download of 3D models which could be home-printed with a desktop 3D printer [5].

The opportunity to explore at home the smallest details of a Stradivarius violin would fascinate both the public and the community who work in the field of violin making. 3D technology allows the luthier to get closer to what he has always seen inside a museum glass case, and remote access democratically opens cultural heritage, including musical instruments, to all.

Introducing low cost 3D printing technology in the luthier's workshop could have a significant effect on the violin market. Such a scenario would require a strict ethical code for the use of the "printable" data, but simultaneously would open the doors to a new era for violin making.

Conclusions

Antique musical instruments, and in particular Cremonese historic violins, have always been a source of inspiration for violin makers, who study every smallest detail in order to understand the secret of their sound. The research team of the non-invasive diagnostic laboratory of the University of Pavia, hosted inside the new Museo del Violino in Cremona, is using new technologies for the analytical study of the museum's historical collection. In the interest of sharing with the artisans, all results are discussed with the violin making community.

One of the research activities within the laboratories is the 3D modeling of violins through a 3D laser scanner. Moreover we are experimenting with the possibility of 3D printing some parts using a low cost desktop 3D printer. All of the violins examined are subject to conservation authorization.

The future creation of a virtual data platform containing this extraordinarily useful information would also require discussion of the protection of the uniqueness of cultural heritage. Regulating access to information about the measurements and forms of historical musical instruments would meet the needs of the violin community to understand the style, the technology, and the shapes of the most important violins in the history of music.

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[3] http://slic3r.org

[4] http://reprap.org/wiki/RepRap

[5] http://3d.si.edu/

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3D Printing at The British Geological Survey

by Simon Harris

The British Geological Survey (www.bgs.as.uk), based near Nottingham, is the world's oldest national geological survey and the United Kingdom's premier centre for earth science information and expertise. We hold large collections of fossils, minerals, rock samples, and borehole material.

In late 2011, the Survey was able to acquire through project funding a number of laser scanners (Next Engine models costing ~$4000 each) and a MakerBot Replicator 2 3D printer.

Staff at BGS and a number of partner institutions across the UK digitised a large number of reference (or "type") fossil specimens, and these form the material on a new online reference website, www.3d-fossils.ac.uk.. Making digital versions of our type specimens available online is already helping to improve access to the collection for researchers worldwide.

The MakerBot printer has been used to produce replica fossils from the laser scans. The fused filament technology is easily the most cost effective available (both in terms of equipment and consumables). This has meant that we have been able to give away 3D prints as part of our outreach programme.

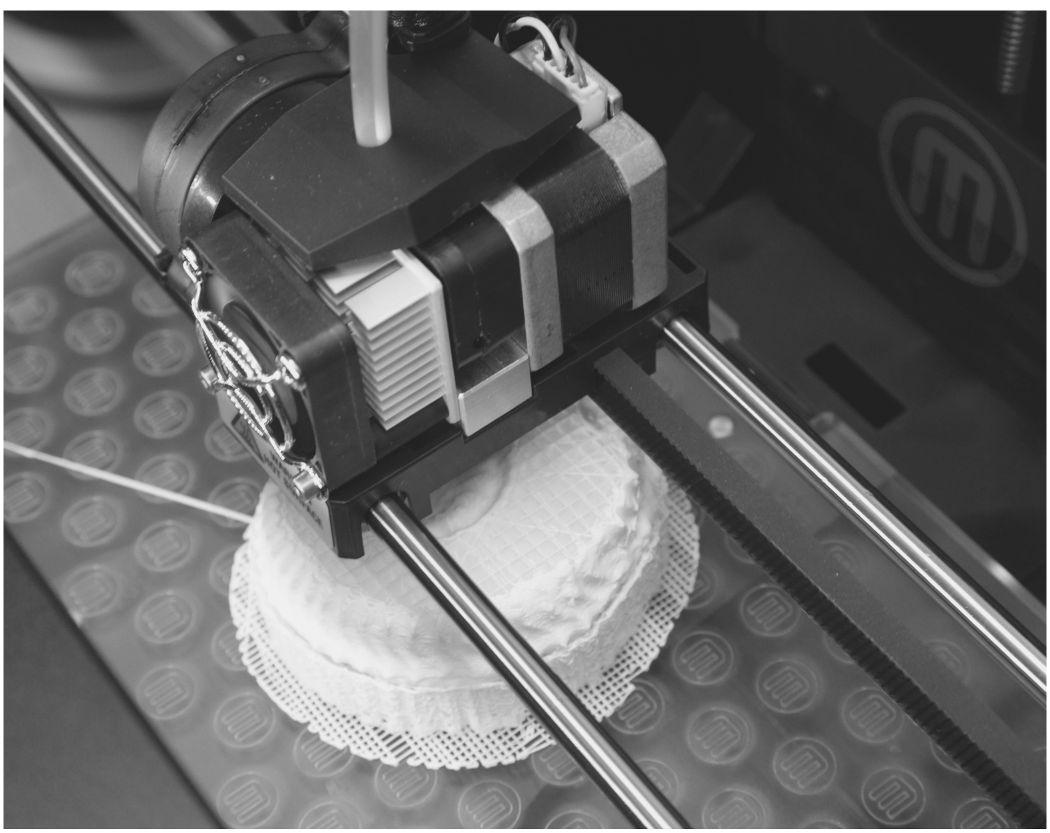
At least one local museum chose to paint their model with acrylic paints, and from normal viewing distances many visitors were not able to distinguish it from the original displayed next to it. Another museum has been able to use a print taken from a scan of an extremely fragile Rynchosaur skull during learning sessions with children.

Collections and Conservation are investigating further uses for the technology. Possibilities range from simple replicas to custom mounts, custom made tools, and tool-holders.

A number of free or open source products are in use for creating or editing models. Autodesk MeshMixer has been particularly useful in "fixing" scans for printing and OpenSCAD for modelling new parts.

One potentially worthwhile endeavour for the conservation community might be to build a shared library (along similar lines to the website "thingiverse.com") of models (3D plans) for manufacturing tools for conservators. Often we source our tools from diverse fields, be that medicine or horology, and a library of tools that others have found useful could prove invaluable for some treatments. Often much of the time is not spent in actually making the tool, but in the design process.

We see great potential in the use of a 3D printer in conservation, but we have also been made very aware of the relative infancy of the technology, at least for consumer use. A certain willingness to experiment is definitely required. We would suggest that new owners invest in a good set of tools and a supply of spare parts, for example, the extruder nozzle, which can become blocked with the remains of extruded plastic after a while.



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3D Printing a Cheetah: Integrating Photogrammetry, CT Scan Segmentation, 3D Modeling, and 3D Printing with Traditional Model Building

Abstract

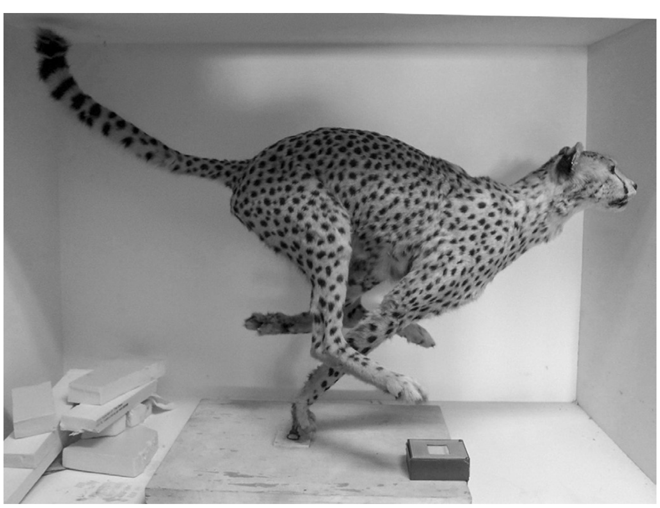
In 2013 we used 3D scanning, 3D modeling, and 3D printing to produce a life-size replica of a running cheetah, one side of which is cut away to show the cheetah's skeleton. We used photogrammetry of a mounted cheetah specimen to produce a 3D model of the body, selectively cut away the proper right side, and produced 3D printed skeletal elements derived from CT scanning an alcohol-preserved cheetah to show the skeleton. In this paper we discuss what we learned about photogrammetry as it applies to creating 3D computer models of large, furry, natural history specimens. We discuss the process of extracting models from CT scans and consider the difficulties and benefits of 3D printing as a replication method in a museum context. In particular, we focus on practical issues relating to the production of accurate 3D models, provide some commentary on the currently available software packages, and discuss what we would have done differently in the light of our subsequent experience using the various workflows which we developed.

Introduction

At the Field Museum we have been CT scanning objects for six years. For the past three years we have been 3D printing objects for research and exhibition and using various techniques (laser scanning, structured light scanning, and more recently, photogrammetry) to make 3D surface scans. In the summer of 2013 the exhibits department asked our help to make a life-size 3D model of a running cheetah for an international traveling exhibit on biomechanics. The request was for a model which showed the contours of a cheetah's body along one side, and revealed its skeleton on the other so that the adaption of the cheetah's skeleton to provide impressive running speeds could be illustrated. This meant that we would be working from two very different types of objects to produce the body and the skeleton.

The Field Museum has several cheetah skeletons and a taxidermy cheetah (mounted in a running posture, fig. 1).

Fig. 1. Taxidermy cheetah.



There were two reasons why these specimens were not used for the tour. Firstly, cheetahs are an endangered species, and it is a complex legal matter to move such specimens across international borders. Secondly, using real specimens of such value requires providing a climate-controlled vitrine for the specimen. To make and tour such a vitrine for an object the size of an adult cheetah is quite expensive. We preferred to save the cost of such a vitrine for other aspects of the exhibit.

Capturing the Body Model

We had three options to get a 3D model of a cheetah body from the mounted cheetah specimen: laser scanning, structured light scanning, and photogrammetry. Quick tests showed that laser scanning worked poorly on specimens with fur -- the laser light scatters in the fur and does not give a clean return. Our structured light setup could not be scaled up to the size required to image the full cheetah, and we suspected that similar problems of the light pattern being scattered by the fur would apply. The final remaining option was photogrammetry.

Photogrammetry is the process of extracting a three dimensional model from a series of overlapping visible light images of a surface. The scale-invariant feature transform (SIFT) algorithm (Lowe 1999) and its derivatives have made digital photogrammetry increasingly attractive for 3D surface capture. High-resolution digital cameras with high dynamic range have widened the possibilities for capturing suitable images. 64-bit computers and cheap software have made it quite easy to process these images into a 3D computer model.

The remaining problems relate to capturing the right sort of images for input to the photogrammetry software: lighting must not change during the shoot; focus should not change during the shoot; each feature to be extracted from the surface must be in sharp focus in at least three images.

Because photogrammetry was a new technique for us, we made some tests with smaller specimens (a cuddly 'Tigger' toy and a mounted marmot). What we found was that

- The object must not move relative to its surroundings.
- All areas of the object, from front to back, must be sharp focus in each image.
- The object should fill the frame, so far as possible.
- Light sources should not appear on the field of view. Where capturing a light source in an image is unavoidable (as when shooting at an upward angle), the light source should not be partially obscured by any of the object's edges. Exposure should be adjusted for the object surface, and the light source should be overexposed.
- More images are needed than intuition suggests. Taking images in a circle at 10° intervals is generally sufficient for objects with little occlusion, but taking images every 5°, or even 2°, may be necessary if complex geometry with deep relief needs to be captured. At least three – preferably four – different heights are required.

- The distance from the camera to the object should be about the same as the image dimension.
- Images should be as noise-free as possible.
- The focus of the camera lens should stay the same during the entire photographic capture process.
- The object must be evenly lit (no harsh shadows), and the position of shadows must not change during the shoot. This implies that you must move the camera around a fixed object rather than using a fixed camera and rotating object.

These constraints need careful planning to get a useful image set when photographing an object in the round. Although we did some planning and got a usable result, this was our first attempt at photogrammetry of a large, furry, three-dimensional natural history specimen. It is instructive to compare what we did for the cheetah to what we would do now that we have more experience.

What we did

The mounted cheetah specimen (fig. 2) measured 1.7 m nose to tail, stood about 1 m high, and was about 0.5 m at its widest point. Getting well-focused images over an extended distance requires using a midrange f-number (aperture setting) on the camera lens. If the f-number is too low (aperture wide open), then the depth of field is too small and not enough of the object is in focus. It would seem, then, that using the largest available f-number (smallest aperture) would be best, but there are two problems with this solution.

First, if the f-number is too high then diffraction effects from the small aperture reduce image sharpness. Second, a small aperture allows less light into the camera, and so we must either increase exposure time or ISO sensitivity, but both these options increase image noise. In our experience, the best f-number for sharpness with an extended depth of field turns out to be between f/8 and f/11.

Keeping lights out of the field of view while providing even lighting can be a problem. Using an aperture of f/11 implies that you need bright lighting or a high ISO number (at or above 800 ISO). To get images of the underside of the mounted cheetah's belly we needed to shoot from low down at an upwards angle. We calculated that we could not raise lights on stands high enough to exclude them from the camera's field of view in these upward shots.

We considered shooting outside on a cloudy day, or under the big skylight ceiling of the museum's central atrium, but these options had the same problems of light in the field of view. Also, members of the public would be walking through these locations and would not have a consistent position in the different images. We thought that having people's position in the field of view change might confuse the photogrammetry software (or, at least, introduce unwanted noise).

In the end we selected one of our smaller galleries (lights at about 5 m), excluded the public for two hours, and turned on all the fluorescent work lights. The average light level at the cheetah was about 300 lux, and we were able to shoot f/8 at 1/5s at ISO 800.

Our camera was a Nikon D7100 (3/4 frame DSLR, 14 bit raw files, 24 MPixel resolution). We prepared the gallery by laying out sheets of white paper on the floor to help reflect light up underneath the cheetah. We wheeled the mounted cheetah on a flatbed cart on top of the paper.

Using the cheetah as a center point, we measured out a 2.5 m radius 'shooting circle' and marked it with pieces of blue painter's tape. We mounted an 18-55 mm zoom on the camera, set the camera to autofocus and manual exposure, mated it to a wheeled studio stand for stability, and used a remote release to minimize camera shake during shutter release.

We moved the camera around the shooting circle taking between 60 and 70 photos at each of three different heights (looking up, looking straight on, looking down). We then mounted the camera on a 2.5 m mobile ladder and took another series of images looking down on the cheetah from a high angle. During photography we varied the zoom level of the lens to ensure that part of the gallery was in each image along with the cheetah (which we thought at the time would help the reconstruction). The focal length of the zoom was typically between 20 and 24 mm. Part of the overall process is shown in figure 2.

Fig. 2. Image capture for photogrammetry of the mounted cheetah specimen, shooting straight on and showing the shooting circle.

What we would do now

Given that the best compromise of depth of field and sharpness was in the aperture range f/8-f/11, we would calculate the depth of field and image size for lenses of different focal lengths using an online photographic calculator (e.g., Lyons 2014) to get a distance which filled the frame with the cheetah. To fill the frame at a 1:1 subject-to-camera-distance vs. imaged width, we would calculate that a 20 to 24 mm focal length would give the best results on our Nikon D7100 camera. (The D7100 is a 3/4 frame camera, so a 20 or 24 mm lens on this camera corresponds to around 30 or 38 mm focal length on a full-frame DSLR.)

With a 24 mm lens at f/11 on a 3/4 frame camera, the hyperfocal distance is a little over 2.75 meters. With the lens focused at the hyperfocal distance, everything between around 1.4 m and infinity should be sharp. The focal distance and horizontal field of view are about equal for a 24 mm lens on a 3/4 frame DSLR, so the horizontal field of view will be about 2.7 m. Since the length of the mounted cheetah was 1.7 m, we would get closer to fill the frame.

The best distance would seem to be around 2 m from the center of the object to the camera. At this distance, with a 24 mm lens at f/11, the horizontal field of view reduces to 1.9 m and the sharp focus zone runs from about 1.2 to 7.1 m. Given this zone of sharp focus, Rather than laying out a shooting *circle*, it might have been better to lay out a shooting *oval* -- closer to the side of the cheetah, and further away at the head and tail.

Since the optical path should stay invariant, we should avoid changing focus on the lens (switch off autofocus and tape the focus ring of the lens to prevent movement). We would also set the camera to use aperture priority rather than full manual; in this mode the camera keeps the aperture constant and only the exposure time varies. Varying the exposure time does not cause a change in the camera's optical path and so does not affect photogrammetry (except that long exposure times may introduce noise).

We would also turn off all the camera's image sharpening, lens correction, and noise reduction features to get images which are as free of imaging artifacts as possible. Where we needed to alter exposure value, we would change the exposure compensation value in the camera rather than adjusting the aperture.

Processing the Body Images

Having acquired the images, we then needed to select photogrammetric software to convert them to a 3D model.

We had evaluated four software options:

 - AutoDesk 123D Catch is a free, cloud-based, photogrammetric reconstruction service which also offers desktop and mobile versions. You convert the images to JPEGs and upload them to a project page as a reconstruction job. At some later point a status indicator on the page tells you that the job is completed, and you can download the resulting 3D files.

The number of image files which you can upload to the free version is limited to around 70 JPEGs, and these images are, apparently, down-sampled during transmission to the site. The terms of use for the site require granting AutoDesk unlimited rights to any content that you upload. The quality of 3D reconstruction provided by this 'high quality' option on this service is often quite good. For many museum purposes, though, the terms of use are unacceptable.[1]

 - Visual SFM is a photogrammetry program developed by Changchang Wu (Wu et al 2011). The program is free for personal, non-profit, or academic use. Visual SFM provides a GUI and a sparse reconstructor. An extra package such as the open-source PMVS2 (Furukawa and Ponce 2010) must be downloaded and copied to the program directory to allow the program to produce dense reconstructions.

The final product of Visual SFM with the additional package is a dense point cloud which can be further processed with such packages as MeshLab or Cloud Compare to produce a surface mesh. Images in Visual SFM are limited to a widest pixel dimension of 3,200 (larger images will be down-sampled, sometimes severely). Visual SFM only accepts JPEGs and requires a decent graphics card to operate at reasonable speed.

Sparse reconstruction with Visual SFM is reasonably fast, but the necessity to install another package for dense reconstruction makes installation a little cumbersome, and using another program to convert the dense point cloud to a mesh, makes the workflow less streamlined than the other packages reviewed here.

 - Agisoft Photoscan is a commercial photogrammetry package, and the software price has deep discounts for educational users. The Standard edition currently costs $179 without discount. A 30 day trial version is available. Photoscan is a complete package (sparse point cloud to textured mesh) and is relatively easy to use.

Three particularly useful features are the ability to crop to a region of interest after sparse reconstruction, the ability to manually mask out features in the images to prevent their being considered during the pattern recognition phase, and the ability to set up batch processes which can run unattended. Photoscan can handle TIF and BMP as well as JPEG. We did not experience any image size limitations. Photoscan gave consistently better results than the Visual SFM + CMVS/PMVS + CloudCompare workflow.

 - Acute3D Smart3DCapture Scanner. At the time of writing, Acute3D Smart3DCapture comes in several different editions (including a somewhat limited free edition), and it is not clear which of the current offerings corresponds to the 'Scanner' package that we tested in 2013.

The software we tested was complicated to use, but gave very good results and could ingest native RAW files as well as TIF. We were given a quote of $9,750/year for the software. Some of the offerings in Acute3D's current range of packages are cheaper than this figure. Interestingly, the Acute3D website says that AutoDesk's 123D Catch system uses Acute3D's algorithms (Acute3D 2014).

One notable difference between Smart3DCapture and Photoscan, other than Smart3DCapture's ability to ingest RAW image files directly, was that the final meshes produced by Smart3DCapture appeared better optimized than those produced by Photoscan. Smart3DCapture also

Fig. 3. Photogrammetric model reconstruction using Agisoft PhotoScan:
a. sparse point cloud; b. dense point cloud; c. mesh model; d. textured mesh.

coped better with areas with little texture such as the top surface of the wooden podium on which the cheetah was mounted; in Photoscan areas with no texture tended not to get reconstructed. This may be due to Smart3DCapture using images with a higher dynamic range than PhotoScan.

The price-performance difference of Smart3DCapture compared to PhotoScan did not seem to justify the difference in cost for our application, so we went ahead with PhotoScan.

The 14-bit raw images of the cheetah were converted to 8-bit color TIF using Adobe's Camera RAW utility in Adobe Bridge. We adjusted only color balance and exposure during the conversion, in all cases trying to get a nicely equalized exposure histogram with no clipping at the top or bottom exposure range. All sharpening effects in RAW were turned off or set to zero.

The TIF images were then run through Photoscan to produce the cheetah model. The batch feature of PhotoScan was extremely helpful: after reconstructing the sparse point cloud, we were able to select the cheetah as a region of interest, set the program options for dense reconstruction and mesh generation, and then leave the program running overnight. In all, the reconstruction from loading the images to final, textured model, took a little over ten hours running on a PC with Intel Core i7-3960X Extreme 6-core CPU, 64 GB RAM, and an ASUS GeForce® GTX Titan GPU with 6 GB RAM.

Results are shown in figure 3.

The usefulness of the batch processing feature present in both the Agisoft and Acute3D software is worth emphasizing. You can collect images during work hours and then run the reconstruction overnight. With a little practice tweaking the software options, very satisfactory results can be obtained.

One feature of SIFT-based photogrammetry in general which is also worth mentioning is that, unlike laser and structured light scanning, the resulting models are not inherently scaled to life-size. That is, the proportions of the model will be correct, but actual dimensions will be an arbitrary fraction of the true size. It is necessary to have at least one, preferably two, known dimensions in the scene, provided by scale bars or reference marks placed in the scene so as to appear in several of the images. In our case we measured the dimensions of the painted wood podium on which the cheetah was mounted and used these to scale the model to life-size in MeshLab.

Once the model was scaled to life-size we repositioned the tail slightly in software to conform more closely to what we were advised was the natural tail position of a cheetah in mid-gallop. I have to say that we did not make a particularly good job of it -- we were using sculpting features of the Blender software package which, at the time, were unfamiliar to us.

Capturing the Skeleton Image

Choice of specimens and scanning technique

The Field Museum's mammal collection contains several prepared cheetah skeletons. Some of the skeletons are held in partial articulation by residual connective tissue, others are fully disarticulated. The collection also contains one alcohol-preserved cheetah -- a specimen that died in a zoo in the 1970s.

We considered casting copies of the bones, but the intricate structure of many of the bones (especially the skull and the vertebrae) made casting look like a lengthy and possibly damaging process. Producing 3D models by laser, structured light, or photogrammetry also looked like a long, though somewhat less damaging, process. We decided to use medical CT scanning to produce models of the bones.

Since we worried about our ability to articulate the resulting models correctly in software, we decided not to scan individual disarticulated bones. Rather, we used the partially articulated skeletal elements together with the pickled cheetah as a reference for how the bones should articulate in life.

We reviewed the prepared skeletal elements looking for groups with a high degree of articulation. In the end we selected the legs from one cheetah and the spine, tail, ribcage, neck, and skull from another.

We have used medical gantry CT scanners to examine cultural property and natural history specimens on many occasions over the last six years, and we have found that it is important to ensure some separation between the object we are scanning and the bed of the scanner. Sheet foam materials with low x-ray attenuation such as polyethylene, polystyrene, or polyether foam provide such separation.

The density of the foam is not usually important since the cell walls of any foamare much thinner than the resolution of the scanner. If the object being scanned has *very* low x-ray attenuation (textiles), then we use phenolic florist's foam covered with polyethylene wrap to give a very low attenuation separation layer.

To mount the bones for transport and scanning we followed a protocol developed by our colleague Shelley Paine. After measuring the bones, we made acid-free corrugated cardboard trays of the correct size to allow longitudinal orientation of the bones. We made individual boxes for the legs, thorax, cranium, mandible, and pelvis, and for the bones of the tail. We lined the bottoms of the trays with 1 cm thick low-density polyethylene foam, friction-fitted to the interior of the trays. We laid the bones on the foam in the trays, securing them to the foam with strips of washed Tyvek tucked into the foam with the tip of a steel micro-spatula. The strips secured the bones in the correct orientation for CT scanning, the foam provided good x-ray separation of the bones from the cardboard, and the trays allowed specimens to be transported and handled with little likelihood of damage.

The alcohol-preserved cheetah is normally stored in a wheeled stainless steel container of alcohol. For transport, we lined the interior of a large polypropylene storage bin with alcohol-soaked cotton sheets. We lifted the cheetah out of the tank into an enameled steel tray to drain off the excess alcohol (fig.4), and then transferred the cheetah to the polypropylene bin, wrapping the loose ends of the sheet over the specimen to prevent drying. The bin was then slid into a large polyethylene bag which was sealed to prevent evaporation of the alcohol during transport.

Fig. 4. Draining the alcohol-preserved cheetah specimen.

We moved the mounted bones and the cheetah by wheeled cart to the museum's parking lot and then loaded them into a van for transport. We took the bones to a CT scanner at the Department of Oncology at the Duchossois Center for Advanced Medicine (DCAM) facility of the University of Chicago.

Shooting straight on CT scanning

As with laser and structured light scanning, x-ray CT scanners are sized for a particular range of imaging volumes. Medical gantry CT scanners are sized for humans from children up to adults. For natural history specimens this equates to specimens from the size of 20 lb dogs and up. Although smaller natural history specimens such as birds and reptiles can be imaged in medical gantry CT scanners, the results are not nearly as good as the results from using a large volume micro-CT scanner. Nonetheless, one may choose to use medical gantry CT scanning, even if the results are less than optimal, because the equipment is much more widely available than large volume micro-CT scanners.

There are two sizes of medical gantry scanner. 'Standard bore' scanners – the most commonly encountered type – have an aperture from 70 to 78 cm wide with a field of view of 50 cm (ImPACT, 2009a). 'Wide bore' scanners, as the name suggests, have a larger aperture -- 80 to 85 cm in diameter -- and a reconstruction diameter which varies according to model from 50 cm up to 72 cm (ImPACT, 2009b).

Wide bore scanners are less common and are used when patients must be scanned with accompanying supports or medical equipment which would not fit through the narrower aperture of a standard scanner. Wide bore scanners do not necessarily have a wider field of view than standard bore scanners. Thus, though a larger object can be passed through a wide bore scanner, the volume which can be imaged may be somewhat narrower than the size of the aperture suggests.

Fig. 5. Scanning of prepared cheetah bones at DCAM.

We scanned the prepared cheetah bones, and the pickled cheetah using a Phillips Brilliance Big Bore in the Department of Oncology at DCAM (helical scan protocol at 120 kVP with a slice thickness of 0.8 mm and a slice spacing of 0.4 mm). The boxes of prepared bones were lined up on the scanner bed, and each box was scanned individually (fig. 5).

Reconstruction diameter and pixel spacing for the prepared bones varied according to the specimens being scanned. The posture of the alcohol-preserved cheetah (back hunched with legs extended at an angle) necessitated three overlapping scans: one for the hind legs and tail, one of the chest and abdomen, and one of the forelegs and head. The scans of the bones and the alcohol-preserved specimen were reconstructed twice, once with a bone filter and once with a smooth filter.

We copied the scans to a portable hard disk and took it back to the museum along with the specimens. We then copied the scans from the portable disk to network attached storage and reintegrated the specimens into the collections. Our experience is that, when multiple CT scans are taken during a single visit, copying the data from the medical workstation to hard disk may take over an hour; we always try to build in time for the data transfer at the end of the scanning visit.

Processing the Skeleton Images: Segmentation

Segmentation is the process of defining three-dimensional regions of interest within a CT scan. If the segmentation software allows, the outer surface of a region of interest can then be exported as a 3D mesh. (For more on CT segmentation and associated software see Brown & Martin, in press.) The scans of the mounted bones were easy to segment, because the difference in x-ray attenuation between the bones and the surrounding air (or the polyethylene foam) was large.

We used VG Studio Max for the initial segmentation, exported 3D models as STL files, and then brought the scans and STL models into Mimics for further refinement. In general, we found the smooth reconstructions easier to segment, and the outer surfaces of the bones were easily found with automated segmentation tools.

When we had completed the initial segmentation and extracted 3D models of the bones, we roughly positioned the individual skeletal elements in Blender – a free, open source animation package (fig. 6).

Blender offers many advantages when working with 3D models that include related sub-models of independently moving parts. The most important of these advantages is the ability to define parent-child relationships between parts. For instance, we could make the femur the parent of the tibia and fibula, and the tibia, in turn, the parent of the foot. With these relationships defined, when we repositioned the femur, the tibia, fibula, and foot would move with it, maintaining their position with respect to each other.

Without these parent-child relationships, repositioning one bone model means that you must then reposition each related bone, one-at-a-time. With so many individual movements it becomes easy for associated elements to get left behind, or for the spatial relationships between parts to become progressively distorted.

Once we had roughly assembled the models from the prepared bones, we found, unfortunately, that we had a mismatched set of bones. The legs, which came from one cheetah, were too long for the body which came from a

Fig. 6. Prepared bones roughly associated. Image rendered in Blender.

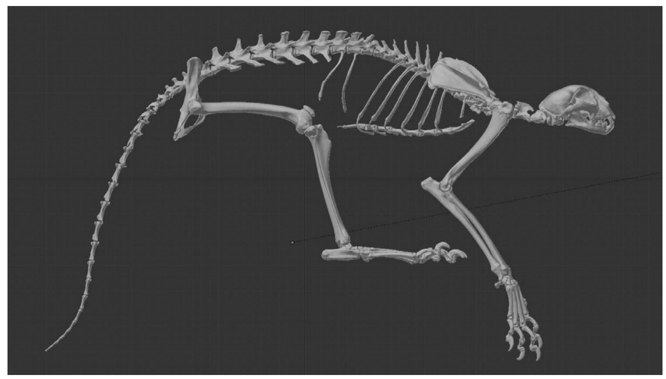


Fig.7. Segmentation of the bones from the alcohol-preserved cheetah specimen.

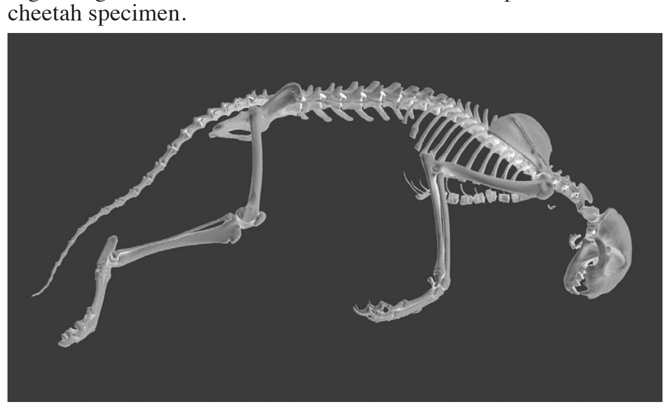
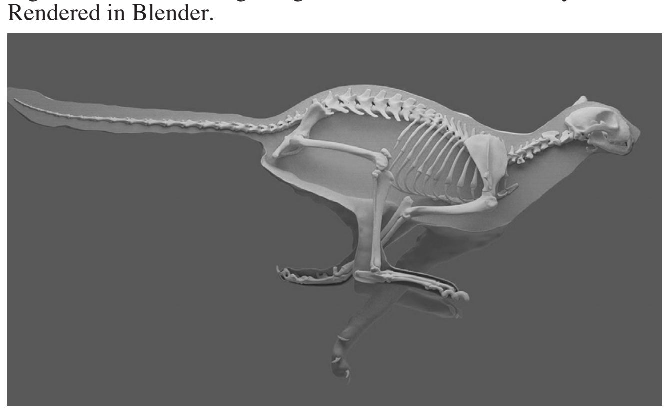


Fig. 8. Final model integrating skeletal elements and body volume. Rendered in Blender.



different cheetah. (Also, we also realized that we had neglected to scan any of the claws.) So we turned to segmenting out the bones from the alcohol-preserved specimen since these would all be the correct relative size (and the claws were in place). Segmenting the bones from the alcohol-reserved cheetah was difficult in some cases since there was little difference in x-ray attenuation between the smaller bones and the alcohol-preserved flesh.

In particular, we had to segment parts of the skull, vertebrae, and tail bones by hand, and we could only approximate the outline of the costal arch of the ribs (fig. 7).

"Posing" the Bones

Having completed the segmentation of the bones from the CT scan of the alcohol-preserved cheetah, we then reposed them in Blender to fit the model of the cheetah body, enlarging the body model slightly to fit the bones. The proper right side of the body model was then selectively removed in 3-matic to expose the bones, and the bone models were posed and superimposed to match the contours of the body model.

One of the more difficult problems in posing the bones was the correct alignment of the vertebral and tail bones. These bones are separated by cartilaginous discs which change shape according to the curve of the spine. Since the alcohol-preserved cheetah was in a slightly twisted posture with its legs outstretched and tail tucked in (rather different from the gathered posture of the body model with the outstretched tail), we had to reposition each vertebral bone (with associated ribs where appropriate) to achieve curves for the spine and tail which matched the body model. It turned out to be extremely difficult to align the vertebrae correctly by eye.

After some experimentation we solved this problem by cutting the vertebral models in half along the long axis and, looking from the proper left side, used the line of the hollow through which the spinal cord runs (vertebral canal) to estimate the correct the alignment between adjoining bones. Again, Blender's parent-child relationships were enormously helpful in positioning the elements.

We then used Blender and the digital modeling program ZBrush to model in the cartilaginous discs between the vertebral elements and the costal arches of the ribs. Zoology department staff reviewed the model periodically for correctness (fig. 8).

3D Printing

Choosing the process

Having produced a credible 3D computer model of the proper right half of the skeleton, we had to determine how to convert it to a three-dimensional reality. The two main types of automated three dimensional production are additive ('3D printing') and subtractive ('CNC cutting').

CNC cutting is performed by cutting away excess material from sheet stock using computer-numerical-control (CNC) machines. CNC cutting is fast and can use a wide variety of conservation-safe stock materials. Build volumes in CNC can be large (machines can operate on 4'x8' boards). Unfortunately basic 3-axis CNC cutting has difficulty with undercuts and large build heights. When 3-axis CNC is used, it is usual to decompose the model into multiple layers, machine them individually, and then adhere the layers together.

3D printing works by building up the model in very thin layers, one layer at a time, the current layer being deposited on top of the previous layer. There are a wide variety of techniques, four of which will be described here:

- Fused deposition modeling (FDM) works by extruding a thin layer of molten thermoplastic material from a heated extruder onto a print bed. A computer controls the distance between the extruder and the print bed and can instruct either the bed or the nozzle to move front-back and left-right.

An initial layer of polymer is laid down with the extruder just above the bed. After the first layer of polymer has cooled, the extruder is moved slightly further from the bed (either the extruder moves up, or the bed moves down), and the next layer of polymer is deposited on the previous layer. The process is repeated until the model is fully built.

FDM can be nicely conceptualized as a super-stupid robot glue gun. Printing with FDM is cheap but is limited to thermoplastics; ABS, PLA, and PET are all printable by this technique, although only PET is likely to give a good indication of long-term stability on an Oddy test (equivalent to a result of Permanent in Schiro 2011).

- Stereolithography (SLA or SL) uses a UV laser to selectively harden a liquid photopolymer. Again, the first layer is adhered to a bed which is initially just below the surface of a bath of liquid resin. Once the first layer has been laid down, the bed moves so that the previously deposited layer is just covered by liquid resin and the laser hardens the next layer. The process is repeated until the model is complete.

SLA is more expensive than FDM, but reproduces fine detail better. The photopolymers used probably have intermediate longevity at best, and some of these polymers may cause allergic contact reactions in some people.

- Selective laser sintering (SLS) uses a laser to fuse a fine powder in a heated chamber. A layer of powder is scraped into the chamber and rolled flat. The laser selectively fuses the powder where the model needs to be solid. A piston at the bottom of the chamber moves down slightly, a new layer of powder is scraped into the chamber and rolled into place, and the laser selectively fuses the new powder to the previous layer. Materials with good stability are available including nylon 6 (cheap), stainless steel, and tungsten (very expensive).

- 3DP, which goes by a variety of commercial names ('Colorstone,' 'Multicolor,' 'VisiJet'), is a method similar to SLS. Again, printing is performed in a chamber using a powder, which, in this case, is gypsum. Rather than using a laser, the areas of powder which need to be solid are fused with one of four colored liquid adhesives jetted into the surface from an inkjet print-head.

The main advantages of the technique are low cost (comparable to SLS nylon) and the ability to print surfaces in full CMYK color. Anecdotal evidence is that the permanence of this color is not high (some manufacturers add a UV-filtering coating to reduce photodegradation).

Also, 3DP models are quite friable when removed from the printer and, after the excess powder has been removed, must be treated with an 'infiltrant' (conservators would say a 'consolidant') to improve mechanical properties.

Two consolidants are offered: a cyanoacrylate for normal use, and a 2-part epoxy for greater mechanical strength. Both infiltrants improve the saturation of the color printed on the model. 3DP printed parts have a weight and texture somewhat similar to sandstone and the least 'plastic-y' feel of the materials discussed here.

Our Oddy tests of 3DP parts indicate that they are intermediate at best, although it is not clear whether this result is dues to the colored adhesive binder or the infiltrant. If the latter, it should be possible to arrive at an infiltrant which gives a satisfactory test.

The main overall features of these 3D printing techniques are as follows:

- 3D printing is slow. Print rates of one vertical inch per hour are considered fast. Printing a high resolution copy of something the size of a human skull takes around 8 hours on a decent commercial machine.

- Build volumes are limited: a build volume of 18" x 12" x 8" is considered large. The limited build volume implies that large prints must be decomposed into smaller parts and assembled to a finished piece. Our experience is that you need to design 0.4-0.5 mm clearance between parts to ensure that they will assemble without binding.

- All 3D printing systems produce some step pattern between vertical layers. The step effect can be reduced by sanding, tumbling, or by selectively dissolving the surface of the part after it has been printed. Unfortunately, all these actions also reduce fine surface detail.

- In general, at the time of writing, the colors used in 'full color' 3D printing fade quite rapidly on exposure to light -- for museum purposes it is going to be better to print natural and paint it yourself. Some manufacturers add a UV filtering coating to colored prints to reduce fading rates.

- Of all the materials we have experimented with so far, SLS nylon is the most satisfactory for the production of actual parts in museums – it is cheap, reasonably inert, takes paint, can print fairly high detail (better than the best FDM), and is robust (you can drop parts on the floor with minimal damage). The sintering produces a fine-grained micro-porous solid; parts which will be handled or displayed in dusty locations should be finished with a protective surface coating to allow easy cleaning.

- Accessioning 3D printed objects made from the currently available materials is likely going to lead to some Naum Gabo-type permanence headaches.

As stated above, our preferred material for 3D printing for museum purposes is laser-sintered nylon. This material has a good balance of cost and mechanical performance with excellent Oddy Test results. However, in this application we opted to use 3DP since one of the requirements of the project brief was that the skeletal elements should be 'bone-colored.'

Before printing the models, there were three factors that we needed to address. The first was a purely engineering problem: the 3DP material has a specific minimum wall thickness (ca. 5 mm) below which large parts cannot safely be removed from the chamber. Where possible, we wanted to reduce wall thicknesses to this limit to reduce both the weight and cost of the parts.

The long bones were therefore hollowed out to this wall thickness in 3-matic and two 10 mm diameter holes were inserted on each part, in unobtrusive locations, to allow excess powder to be blown out from the interior of these bones. Aside from the cost issue, we felt that this hollowing out would promote better and more consistent infiltration of the consolidant after the parts were removed from the printer.

The second issue was a more general one of ensuring the printability of the mesh models. There is a wide and important difference between a mesh which can be displayed on screen, and a mesh which can be physically printed. Imperfections in the mesh such as missing polygons, non-planar polygons, or self-intersecting surfaces may be visually imperceptible, but will nonetheless make a mesh unprintable.

Whilst it is possible to heal these defects by hand, automated detection and healing are generally much quicker and more satisfactory. We have found only one free package (AutoDesk MeshMixer) which is reasonably effective at healing meshes with low polygon counts (< 0.5M faces).[2] As the number of polygons in the mesh increases, one must switch to commercial software packages such as netfabb, Magics, Geomagic, or 3-matic which are generally quite expensive (low to mid $1,000s).

We used 3-matic since it is tightly integrated into the Mimics CT segmentation package which we were using. In many cases it may be easier and cheaper to have the computer models refined on an agency basis by an outside company (look for companies which provide 3D printing services).

Our final problem was to make the parts 'bone-colored.' The color of prepared bones varies considerably over their surface. Our attempts at reproducing this color pattern by painting the various hues onto the vertices of the meshes using the Blender, MeshLab, and ZBrush software packages were not very successful, due mostly to our inexperience with using the coloration tools in these packages.

If we were doing it now, we would likely take multiple digital images of the bones and paint the color from these images onto the models' vertices using the ZBrush's Spotlight tool. At the time, we talked with the exhibits department about the problem and, it was decided that, since the model was didactic, we would color the bones white.

Fig 9a. Scans. Merged skeletal assemblies. Rendered in Blender.

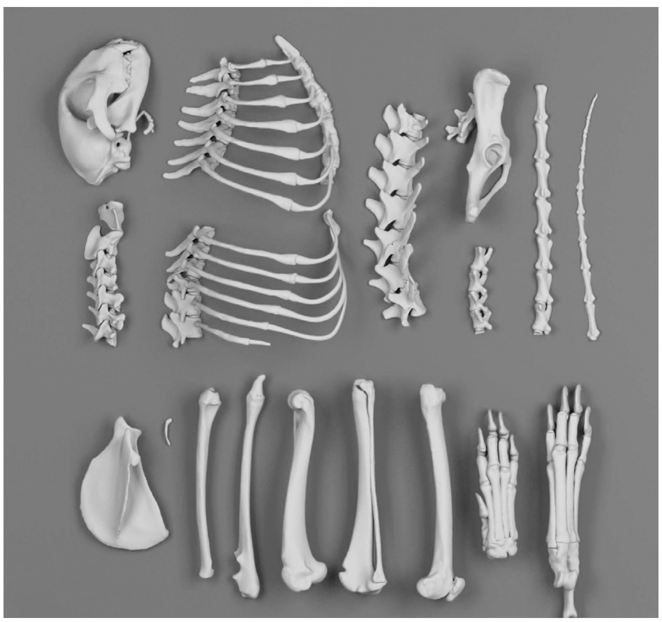
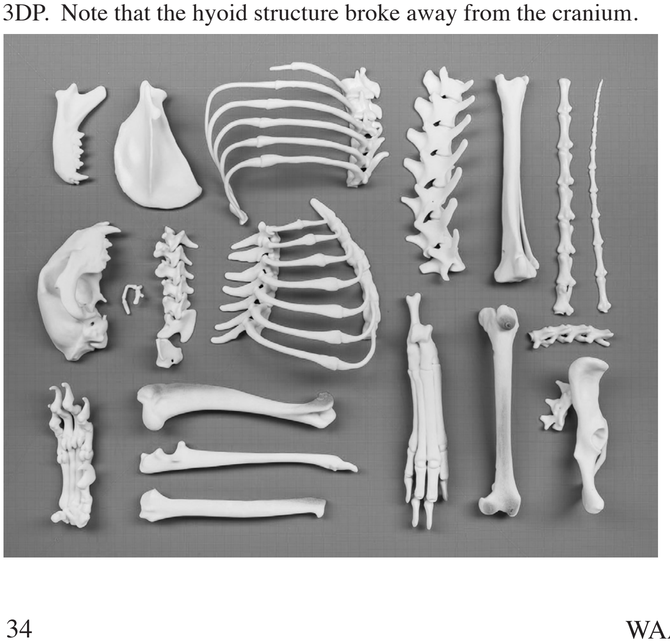


Fig. 9b. Printed models. Merged skeletal assemblies as printed in 3DP. Note that the hyoid structure broke away from the cranium.



Printing the Skeleton

After healing the individual models, the skeleton was divided into printable sections to fit inside the build volume of the printer. Long bones were printed individually, except the tibia and fibula. (The fibula is so attenuated in cheetahs that it made sense for mechanical stability to merge it with the tibia.)

In all, 18 different models were produced (fig. 9a). The parts were printed off-site by on a 3DSystems ProJet x60 series printer, infltrated with two-part epoxy, and shipped to the Field Museum. On receipt of the parts we found that some of the long bones were incompletely infiltrated and that the thinner tail sections had warped slightly away from a flat plane. Clearly, application of the epoxy infiltrant is a matter of individual user skill and requires some attention to detail.

The warped and incompletely infiltrated parts were re-printed at no cost until a satisfactory result was achieved. The parts were then painted white with acrylic paint. (In retrospect, it might have made sense, once the need for full color was abandoned, to switch to manufacture in laser sintered nylon rather than the 3DP process since the nylon would have been both stronger and lighter.)

Building the Body and Assembling the Model

After being used to correctly pose the bones, the 3D body model derived from photogrammetry was sent electronically to Blue Rhino Studio to provide a basis for the body half of the model and the printed and painted bones were shipped. On the basis of the model and the printed bones, Blue Rhino cut a profile of the cheetah from 1/2" plywood and mounted most of the bones to one side, mounting the board upright on a base. From there an undersized rough shape of the fleshed out half of the cheetah was sculpted in foam and then fiberglassed so that clay could be added.

Using the bones as a guide, the fleshed-out side was sculpted in clay. The leg bones were mounted in the correct locations via wood and steel armatures and sculpted with clay as well. Once the entire sculpture was complete in clay, a mold was made of just the sculpted clay area. This was cast in fiberglass, mounted to the original boards with bones (after the clay was removed), and the final tie ins and details were finished prior to adding a glass eye and painting.

Conclusion

Given adequate space and lighting, photogrammetry can be used to create 3D computer models of large, furred natural history specimens which cannot be successfully imaged with laser or structured light scanning. Photogrammetry also provides excellent surface color information.

Assuming one already has a DSLR and a computer, photogrammetry with the Agisoft PhotoScan software package has a low cost of entry compared to laser scanning (systems for larger objects start at $4,000 and go up to $50,000) and structured light scanning (systems start at $10,000 and go up to

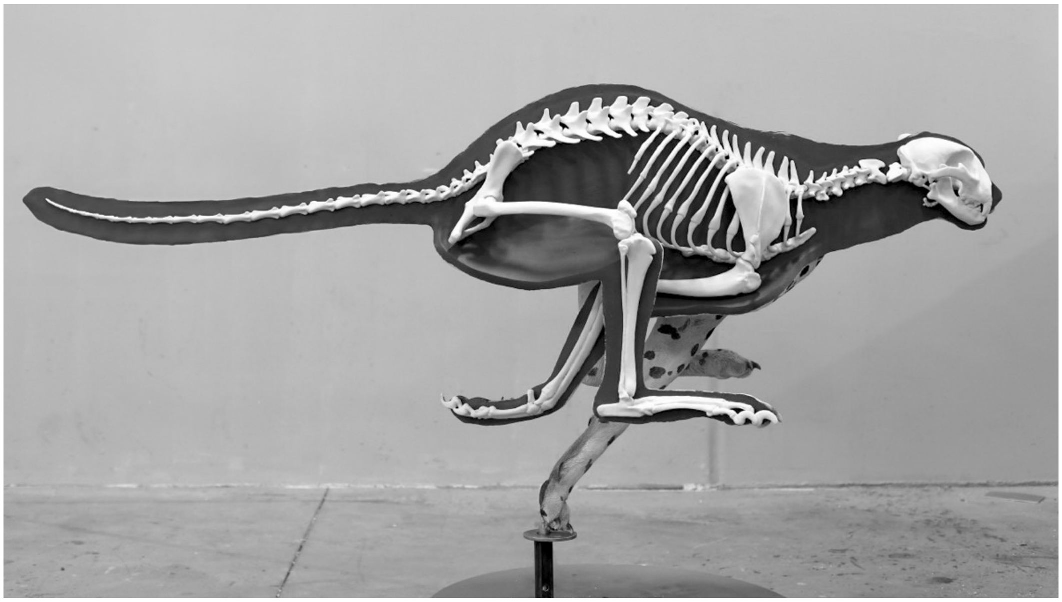


Fig. 10. Final anatomical model of the cheetah at Blue Rhino Studio. Image courtesy of Tim Quady, Blue Rhino Studio.

$50,000). Capturing images during the day and reconstructing the computer models from the images using an overnight batch process is a successful and satisfactory workflow.

Of the photogrammetry packages we tested, Smart3DCapture gives better results than PhotoScan when there are surfaces with little apparent texture. The better performance of Smart3DCapture in these areas of low texture may well be a result of the software's ability to use the higher dynamic range of 14-bit RAW camera files where PhotoScan is limited to 8-bit images.

A perfectly satisfactory 3D model of the mounted cheetah specimen was derived using the Agisoft PhotoScan software even though the images capture methods we used were not optimal. It appears that, provided that lighting stays invariant, there is visible texture, and the depth of field is sufficient, photogrammetry can produce useful results even with less than optimal images (e.g., captured using a zoom lens rather than a fixed focal length lens and with some noise due to long exposures at 800 ISO). Consideration should be given to placing scales, or obtaining known dimensions, during photogrammetric image capture so that models can be scaled correctly.

Medical CT scans of prepared bones and alcohol-preserved specimens can be segmented to produce useful 3D computer models of skeletal elements for larger natural history specimens. When performing medical CT scanning with a view to 3D model extraction, it is important to mount specimens with their long dimension parallel to the scanner bed and on a low x-ray attenuation layer to give good separation between the objects and the scanner bed.

Segmenting dry bones is much easier and quicker than segmenting bones from alcohol-preserved flesh. 3D models can be produced from the segmentation with appropriate software.

Conversion of the computer models to 3D printable models can be very time-consuming if done manually, but automated software solutions exist for this process. Coloring models to give a life-like appearance when 3D printed can be difficult.

3D printing is relatively slow and build volumes are relatively limited when compared to CNC cutting. Within these constraints, many options exist for 3D printing objects for museum display. Some of these are more suitable for long-term museum use than others.

The major advantages of 3D printing compared to CNC cutting are the excellent fine detail reproduction and the ability to handle arbitrary shapes (especially with powder-based printing such as laser-sintering and 3DP). In particular, the chemical stability of some 3D printing materials is not suitable for long-term use in museums, and color in 3D-printed parts may have low permanence. These points require consideration when producing 3D-printed objects for display or when accessioning artifacts which are 3D-printed or contain 3D-printed components.

Laser-sintered nylon powder appears to provide a useful balance of low cost, good mechanical properties, and good chemical stability compared to other materials that we have tested. At present, this material can be dyed some solid colors, but cannot be produced in full color. The porous surface that results from laser sintering requires a paint layer to prevent grime accumulating in the pores if objects will be routinely handled.

Parts produced with 3DP gypsum are heavier and more mechanically fragile than equivalent parts made in laser-sintered nylon, but have a slightly cool, gritty feel which more closely approximates bone or ceramic. Oddy Test results on the 3DP materials we tested gave intermediate results. 3D printing can be successfully integrated with more traditional modeling techniques to produce replicas in museums.

Notes

1. AutoDesk also provides a professional, fee-based version of photogrammetry service as part of its ReCap offering, which we did not evaluate.

2. Online printing services such as shapeways.com often include mesh repair as a free, automatic service once the model has been uploaded. There are also dedicated cloud-based mesh repair services such as the Microsoft model repair service at https://modelrepair.azurewebsites.net/

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Tom Skwerski, Pamela Gaible, and Daniel Breems from the Exhibits Department, together with Rebecca Banasiak from Zoology Collections and CT Segmentation Intern Katy Kaspari assisted the author with image capture for photogrammetry of the mounted cheetah specimen.

John Phelps and Anna Goldman from Zoology Collections provided the cheetah bones and alcohol-preserved cheetah for CT scanning. Anna Goldman provided transport of specimens to the CT scanning facility.

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Dr Charles Pelizzari, Professor of Radiation and Cellular Oncology at University of Chicago Hospitals, provided CT scanning facilities and conducted the CT scans of the cheetah specimens.

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The cheetah skeleton models were printed and shipped to the Field Museum by MasterGraphics, Inc., Madison, WI. The final cheetah replica was fabricated by Blue Rhino Studio, Eagan, MN. The lead sculptor for Blue Rhino Studio was Jim Burt. Tim Quady of Blue Rhino Studio provided the account of the final build out of the replica.

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SOURCES OF SOFTWARE

123D Catch: Autodesk. www.123dapp.com/catch

3-matic: Materialise. http://biomedical.materialise.com/3-matic

Blender: Blender Foundation. www.blender.org

Bridge: Adobe. http://help.adobe.com/archive/en/bridge/cs6/bridge_reference.pdf

CloudCompare: Daniel Girardeau-Montaut. www.danielgm.net/cc/

CVMS/PVMS2: Yasutaka Furukawa and Jean Ponce. Windows port by Pierre Moulon. http://francemapping.free.fr/Portfolio/Prog3D/CMVS.html

Geomagic: 3D Systems. www.geomagic.com/en

Magics: Materialise. http://software.materialise.com/magics

MeshLab: Visual Computing Lab – ISTI – CNR. http://meshlab.sourceforge.net

MeshMixer: Autodesk. meshmixer.com

Mimics: Materialise. http://biomedical.materialise.com/mimics

netfabb: netfabb, Gmbh. www.netfabb.com

Photoscan: Agisoft. www.agisoft.ru

ReCap: AutoDesk. www.autodesk.com/products/recap/overview

Smart3DCatpure: Acute3D. www.acute3d.com

VG Studio Max: Volume Graphics, Gmbh. www.volumegraphics.com

VisualSFM: Changchang Wu. http://ccwu.me/vsfm/

ZBrush: Pixologic. www.pixologic.com

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When Rapid Prototyping Meets Electrochemistry: The PLECO, An Electrolytic Pencil for the Localised Cleaning of Tarnished Silver & Gilded Silver

by Romain Jeanneret, Gaëtan Bussy, Christian Degrigny, Carole Baudin, and Hélène Carrel

Abstract

The aim of this paper is to give a quick overview of rapid prototyping possibilities in the conservation of cultural heritage. This technology enables the manufacturing of complicated elements or objects using 3D printing in combination with laser cutting, etc. Previously, such devices were expensive and rather inaccessible but today specialised laboratories, such as FabLabs,described here, offer such equipment for rent at low cost. After introducing some possible uses for rapid prototyping and FabLab technologies applied to cultural heritage, this paper will present a special conservation tool that has been recently designed and fabricated in a FabLab – the PLECO.

The PLECO is an electrolytic pencil used for the localised cleaning of tarnished silver and gilded silver composite artefacts combined with inseparable elements (for example wood, enamels, or precious stones). It was developed by the University of Applied Science – Arc and its conservation division (HE-Arc CR) in partnership with one of the engineering divisions, the Edana Laboratory (EDANA). Developed as part of the "Saint-Maurice" research project, it enabled the cleaning of some of the composite masterpieces of the Treasury of Saint-Maurice Abbey in 2015 before their installation in a new exhibition hall for the Jubilee (1500 years) of the creation of the Abbey.

Rapid Prototyping & the Fablabs - State of the Art

At the beginning of the 21th century, rapid prototyping technology and more particularly 3D printing have undergone almost explosive development. Everyday new uses of these technologies can be seen in unexpected domains. Low-cost prostheses are being produced in the medical field, and in a near future it will be possible to print human tissue and organs. The European Space Agency is at work on a giant 3D printer to build a lunar base using only salt water and the sand available in the moon soil. Artists and designers are increasingly users of 3D printing, the reduction of manufacturing constraints allowing them freedom to create.

For most applications mentioned above, the use of expensive and large printers is required. Cost is a major issue in the dissemination of a new technology, particularly in the conservation field. Fortunately many new developments are occurring in this domain because of the presence of a large, active, and networked community of professionals. Low cost does not mean low level technology, and the use of such 3D devices enables the conservator to count on 0.1mm precision for a basic printer.

The FabLabs

As suggested by its name, a FabLab is a fabrication laboratory. More precisely it is a place with computer controlled equipment that can produce different types of objects in various materials and for different purposes. In a FabLab, we can make "almost anything." Based on the "makers" movement and the "Do It Yourself" philosophy, the aim of these laboratories is to offer the possibility to anyone to make his or her own personal and everyday objects or technical systems. It is also a place of co-working and net-working.

There are more than 200 FabLabs all around the world (addresses available from the following site: www.fabloab.io). All FabLabs are connected and share their knowledge about digital manufacturing. This network is also based on the "open source" and "open hardware" philosophy. With the exception of some FabLabs built around specific fields like biology, chemistry, or specific means of manufacturing, the most common instruments in a FabLab are 3D printers (fig.1), laser cutters, milling machines, and some electronic devices. They are often based on a low-cost technology concept and should be replicable in any FabLab.

With the typical machinery available in a local FabLab, someone can produce anywhere an object designed in another country. The FabLab network can be used as a new way to distribute products. FabLabs are also helpful during the design process of a product. The different machines of rapid prototyping can be used to test, modify, and validate the shape and the function on the basis of an iterative process.

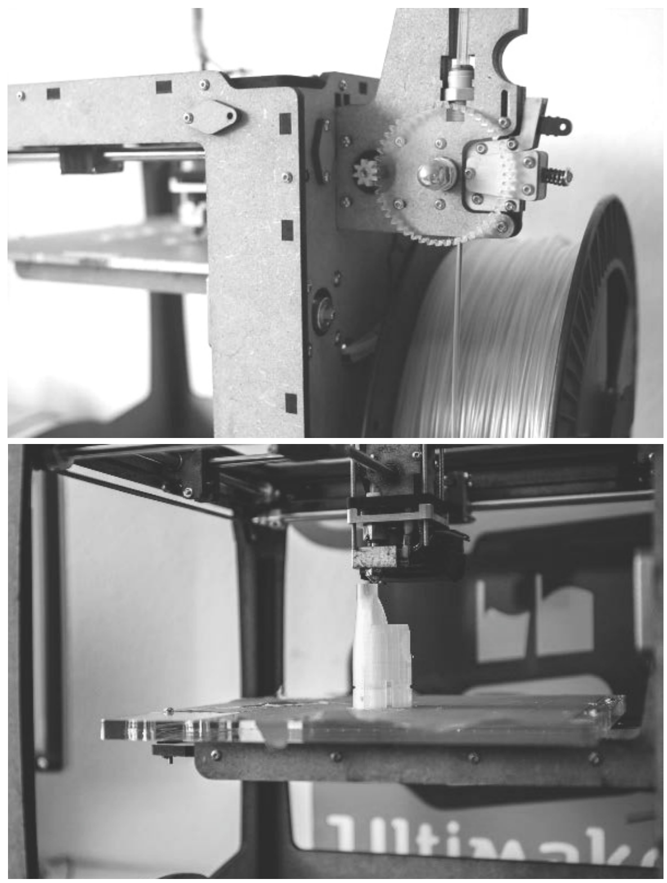

Fig.1: View of the Ultimaker®: a 3D printer used for the manufacturing of the PLECO. ©FabLab-Neuch.

In addition to being open to the public, FabLabs often organize workshops on specific themes or products: learning 3D modelling, electronic prototyping, programming, or manufacturing of objects of all kinds. The goal is to teach everybody the different techniques and possibilities of digital manufacturing.

Table.1: Review of the different technologies and related materials of 3D printing.

Technique	Materials	Specificities
Fused layer Modelling (FLM)	ABS, PC, HD-PE, PLA, PPSF, and PCL	Functional pieces, various colour in one piece
Selective Laser Sintering (SLS)	PA, PC, PS, Acrylate, Methacrylate, PVC, PBT, Polyacetal, Elastomer, and Metal	Rapid manufacturing possible
Stereo Lithography (STL)	EP, Acrylate, Methacrylate, and Vinyl Ether Resin	Good surfaces, various colour in one piece
Layer Laminate Manufacturing (LLM)	Paper, PS, PVC, EP, Acrylate, Methacrylate, and PE	Plate-like construction
Three Dimensional Printing (3DP)	PMMA, PVA, PLA, and PCL	Rapidity

3D Printing in Conservation

Depending on the final use of the printed elements or objects, it is important to choose the proper techniques and materials. As indicated in Table 1, different techniques of 3D printing use specific materials according to the application foreseen.

The suitability of each printed plastic element needs to be considered such as transparency, cost, accuracy, texture, mechanical property, rapidity of fabrication, toxicity, handling, etc. For cultural heritage applications, the neutrality and the long term chemical stability are undoubtedly essential parameters to consider. As a fledgling technology, a lot of new polymers are developed with no background on their behaviour.

For example, the UV resins are not considered stable materials due to the polymerization process occurring during exposure to UV radiation. Accuracy and rapidity of polymerization are prioritised for a commercial use rather than the long term chemical stability of the final product. We need to be really careful and critical when using such material. Some research needs to be carried out to assess the compatibility of these materials with cultural heritage.

Still, there are a lot of potential application for using rapid prototyping technology (especially 3D printing and laser cutting) in the cultural heritage field. The laser cutter can be used to cut PE foam for housing quickly and with precision. For exhibition purposes the same techniques can be used on wood, PMMA, PE, or other plastics to cut aesthetically appropriate stands to display objects. It is also possible to consider laser cutting techniques to replace or refill missing parts of a wood marquetry.

In the same way 3D printing can be used to manufacture fill materials for an incomplete ceramic or to replace broken pieces of a furniture. The advantage of using this technique is that the joining operation can be carried out without any adhering material such as glue. This technology can be very powerful in addition to 3D scanning. It offers the possibility to create a copy of an object without any physical contact and to recreate its original appearance if needed.

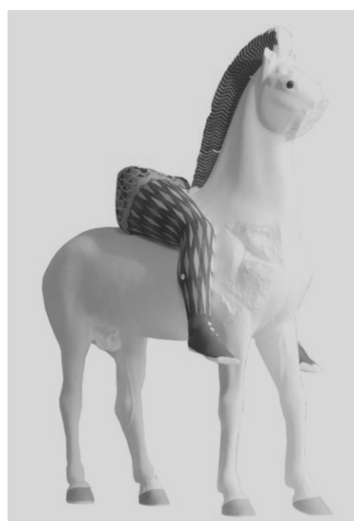

Fig. 2: View of the Replica of the Persian Horseman presented at the Libegshaus in Frankfurt ©Alphaform AG.

As an example we can mention the copy of the Persian Horseman made at the Liebegshaus in Frankfurt. Printed in a PMMA materials the replica was painted (fig.2) according to the colours of the original.

An object or parts of an object can be produced as positives or negatives that allow building the product directly or indirectly. For example a mold can be printed from a scanned objet. A copy using loss wax molding is also possible using the proper printed polymer. This extends considerably the choice of materials – metals or acrylic resins - used to build the replica while still being achievable with a low-cost printer. We can also imagine manufacturing models that can be sold as souvenirs in a museum shop.

Finally rapid prototyping techniques can be used in a different way to develop innovative tools. In the next section, we will give an example of such an application.

Saint-Maurice Project – The PLECO

Electrolytic cleaning is a less invasive and safer way to clean silver tarnish compared to more traditional mechanical and chemical cleaning. The latter abrade the metal surface or might provoke new forms of tarnishing due to inappropriate rinsing processes. Electrolytic cleaning uses more neutral and less concentrated solutions to prevent any unwanted effects.

Until now, electrolytic cleaning on silver and gilded silver was conducted by immersion. Other applications of electrolytic processes have been developed such as the stabilisation of active corrosion on lead artefacts, the stabilisation of copper chloride, and the cleaning of marine iron based artefacts.

The electrolytic cleaning of composite artefacts made of inseparable tarnished silver/wood components cannot be carried out by full immersion. With localised cleaning being the only reasonable option, we had to develop a portable, easy to use, and safe electrolytic pencil.

Some metal conservators - including ourselves - had tested in the past rudimentary versions of an electrolytic pencil with limited success (re-tarnishing of the cleaned spot due to a high concentration of sulphur at the tip of the pencil). The PLECO was designed to solve these problems by providing a constant renewal of the electrolyte and enabling a thorough control of the potential applied. It is built using (fig.3 & 4)

3D printing elements: 1. tip 3. piston head 5. cover
and assembled laser cut pieces: 2. envelope 4. piston

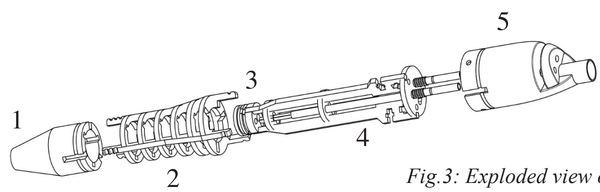

Fig.3: Exploded view of the PLECO ©EDANA.

Fig. 4: View of the PLECO ©HE-Arc CR.

The PLECO, How It Works

As noted, the PLECO is used for the localised electrolytic cleaning of silver/gilded silver tarnishing. It is equipped with a 3 electrode cell – a platinum counter electrode, a vitreous carbon rod used as a reference electrode (both situated inside the PLECO (fig.5), and the object to clean being the working electrode. The PLECO and the object are connected to a stabilised power supply, the object being plugged as a cathode and the platinum wire as the anode. A voltmeter is added to control the potential between the reference electrode and the object. Therefore the conservator can follow and control precisely the parameters of the electrolytic reduction.

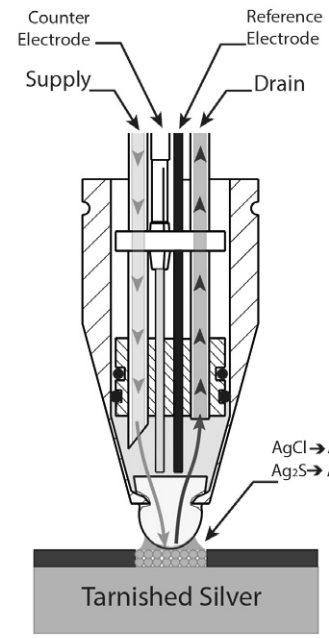

Fig. 5: Sectional view of the PLECO electrolytic cells. ©HE-Arc CR.

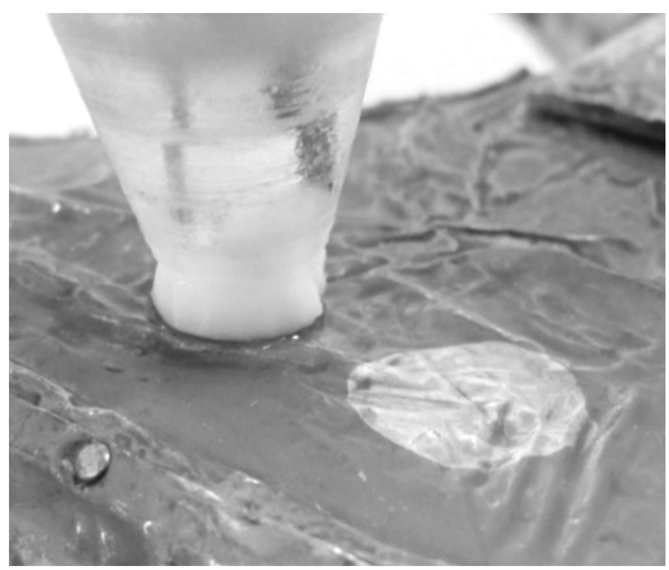

Fig. 6: Detailed view of a cleaned spot and reduction in progress with the PLECO. ©Abbaye Saint-Maurice.

Conclusion

Through the example of the fabrication of the PLECO we see that the FabLab technology is not limited to designers, engineers, and artists. The conservation field has many potential uses for 3D printing, laser cutting, etc. In addition to the PLECO itself we plan to manufacture the pumping system using similar tools. This should decrease tremendously the cost of the PLECO. Furthermore more research has to be carried out to investigate the compatibility of printed polymers with cultural artefacts.

The PLECO project shows that such a tool can be disseminated and modified by the professional conservation community, and we expect a self-appropriation of the tool by end-users to optimise it. As an example, an HE-Arc CR masters student has chosen to apply the PLECO for the stabilisation of active corrosion on lead artefacts.

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Glossary of 3D Printing Terms (compiled from seversl online sources)

ABS
Acrylonitrile Butadiene Styrene. One type of plastic filament used in the Fused Filament Fabrication 3D printing process. Lightweight, high heat resistance. Sometimes filament sold as ABS is in fact mixed with other thermoplastics, thus altering its characteristics.

Additive Metal Manufacturing (AMM)
Any 3D printing process which builds up metal objects in layers, often refers to the process of binding or fusing powdered metal together.

Alumide
A mixture of aluminium and plastic powder which is used to produce objects with a metallic look and feel but at a much lower cost than pure metal.

Build Plate
The surface on which the 3D printed model is formed. Also **Bed.**

Build Platform
The part that supports the build plate.

Build Envelope
The measured limitations of a 3D printer's space, which determines the maximum physical size of a 3D model that can be produced.

Cubify
Website run by 3D Systems based around their Cube printers. Not only does it sell printers but it provides a 3D printing service, sells a range of objects, and supports the Cube owning community.

Direct Metal Laser Sintering (DMLS)
Using a laser to selectively heat and fuse a vat of metal powder, in order to build up a 3D object in layers.

Directed Energy Deposition
Similar to DMLS except metal powder is deposited from a print head before fusing it together with a laser. This allows the repair of objects as well as their manufacture.

Digital Light Processing (DLP) Projection
The solidification of a photocurable polymer liquid using a DLP projector. This solidifies the liquid one layer at a time and can be used to produce very high resolution objects in a very short time.

Dual Extrusion
The ability to print in two colors at once. The 3D printer with dual extrusion capabilities is equipped with two extruders, each feeding its own spool of plastic filament and depositing on the build plate.

EVA
Ethylene Vinyl Acetate. Several early RepRap research experiments used off-the-shelf EVA glue sticks in hot-glue guns. Those glue sticks are mostly EVA which melts around 85°C.

Extruder
A group of parts which handles feeding and extruding of the build material. Consists of two assemblies: a cold end to pull and feed the thermoplastic from the spool, and a hot end that melts and extrudes the thermoplastic.

Fab@Home
An open source 3D printer which uses a syringe type extrusion mechanism. This means it can be used to produce objects out of a range of materials including: silicon rubber, cake icing, cheese, PlayDoh, and clay.

Filament
The plastic material that is melted and extruded to create the 3D printed object in the Fused Filament Fabrication method.

Fused Deposition Method (FDM)
The Stratasys Inc. trademarked term for Fused Filament Fabrication.

Fused Filament Fabrication (FFF)
An additive manufacturing process in which a spool of plastic filament is heated to a melting point and deposited, built from the bottom up one layer at a time until a 3D model is created.

Infill
The interior structure of a 3D printed model. Rather than printing a solid interior, which is a waste of plastic, a model is typically printed with a patterned internal "mesh." In the 3D print settings this is usually represented by a percentage (ex. 10% infill).

Heated Bed
A build surface warmed in order to keep the base of an extruded part from cooling (and shrinking) too quickly. Such shrinking leads to warping internal stresses in RP parts. The most common result is corners of parts lifting off the build surface. Heated beds usually yield higher quality finished builds. They commonly consist of glass, ceramics, or metal.

Heated Build Chamber
A heated build chamber is typically sealed and heated to prevent warping during the printing process.

HIPS
High Impact Polystyrene, a thermoplastic used as a 3D printing material. Similar to ABS in material properties and can be dissolved using limonene. HIPS is also BPA-free and less inflexible than either ABS or PLA.

Hot End
The heated nozzle portion of the extruder mechanism, which gets hot enough to melt plastic (or potentially other materials). Hot end parts use materials that withstand temperatures up to ~240 °C (and higher for newer all-metal designs). The diameter of available nozzle orifices ranges from about 0.15mm to 1.0mm, with sizes in the range 0.3mm-0.5mm currently being the most common.

Layer Height
The thickness of a particular layer in a 3D printed model.

Laywood-3D
Composition of wooden fibres mixed with a polymer binder used to 3D print wooden objects.

Material Extrusion
Any technology which extrudes a material in order to build up an object. Examples would be thermoplastics which are heated first using an element or even cheese which is extruded though a syringe. All are forms of material extrusion.

Material Jetting
Any technology which builds up an object by jetting a photopolymer though a print head before solidifying it using a UV light.

Mesh
The surface area of a 3D model in digital form. In curved shapes this is typically represented by a series of flat triangles. The smaller the triangles the finer the printed results will be.

Glossary of 3D Printing Terms, continued

Multiphase Jet Solidification (MJS)
Ceramic or metal powder is mixed with a binder and extruded to build up an object in layers. The binder is then removed by heat or by chemicals before the object is densified by heating it in a kiln.

Nozzle
The part of the extruder that deposits the melted plastic material.

Nylon
Nylon or polyamide is an engineering grade thermal plastic used in extruder based and laser sintering systems. There are different versions providing a range mechanical properties in either filament or powder form. These include nylon-6,6; nylon-6; nylon-6,9; nylon-6,10; nylon-6,12; nylon-11; nylon-12, and nylon-4,6.

OBJ
Short for Object file. A file format from 3D modeling programs commonly used in 3D printing.

Overhang
A part of a 3D model where there is no support below it. Parts that jut out at an angle of over 45 degrees are generally considered overhangs.

PLA
Polylactic Acid. Corn-based plastic filament used in the Fused Filament Fabrication 3D printing process. Biodegradable and doesn't give off fumes like ABS. Used in applications such as medical implants, compostable packing material, and disposable garments.

Photopolymer
Photopolymers are used in light reaction systems either with ultraviolet or visible energy. The liquid material is cross-linked or hardened when exposed to light. Photopolymers are used in both Digital Light Processing(DLP) and Stereolithography(SLA) systems.

PolyJet Matrix
A technology which mixes polymers together during the creation of an object allowing up to 14 different materials to be used while 3D printing a single object.

Raft
To prevent warping during printing and to ensure successful prints of models with minimal area on their base surfaces, a flat layer of support material will print below the model on the build plate. Raft supports are constructed to be removable, either by dipping in a chemical bath or pulling apart

Resolution
The minimum feature size that can be expected to be reproduced. On the Makerbot Replicator 2x, the highest resolution available is 100 microns (0.0039 in).

Selective Heat Sintering (SHS)
Created by a company called BluePrint and similar to selective laser sintering. However, it uses a thermal print head instead of a laser to selectively fuse together layers of powder together.

Selective Laser Melting (SLM)
A technology similar to SLS, but which uses a high powered laser to selectively and completely melt together powdered metal.

Selective Laser Sintering (SLS)
A powder bed technology which uses a laser to selectively fuse/sinter together powder to build up a 3D object in layers.

Shapeways
An online company which provides 3D printing services and allows users to share their 3D designs.

Sintering
Heating up powdered material in order to fuse the granules together by slightly melting the outside of the granules.

Shell
The outer layer of a 3D printed model. In 3D printing programs this is represented by the number of layers of plastic used to create the outer layer (ex. 2 shells).

Slice
A single layer of the 3D printed model. Slices vary in thickness depending on the design (ex. 0.1 mm). Most 3D printer programs automatically generate or "slice" your 3D digital model into the layers to prepare for printing.

SLA
Stereo Lithography Apparatus. SLA is a registered trademark of 3D Systems Corporation. SL or stereolithography is commonly used in place of SLA.

SLS
Selective Laser Sintering. SLS is a registered trademark of 3D Systems Corporation. LS or laser sintering is commonly used in place of SLS.

Stereophotogrammetry
The process of estimating the 3D coordinates of various points on an object. These are calculated by processing multiple photographs taken of the object from different angles.

STL
File format used by stereolithography CAD software originally developed by 3D Systems in 1987 and still used by most 3D printers today. What it actually stands for is debatable, but it's most likely to be either Stereo Lithographic or Standard Tessellation Language.

Supports
Models that have large overhangs or gaps between parts require support material to be printed. With the Makerbot Replicator 2x, the material used for supports is the same as the material used to print the model itself. Support material is constructed to be removable.

Two-Photon Polymerization (2PP)
A technology which uses a femtosecond pulsed laser to selectively solidify a special photopolymer that solidifies when hit by two protons. Allows X and Y axis resolutions of down to 100 nanometers, making it the highest resolution 3D printing technology currently known.

Vitamin
Any part of a RepRap printer which it is unable to print itself. Examples being nuts, bolts and electronics.

X, Y, Z axes
3-dimensional coordinate system. Z axis represents what would typically be considered "vertical."

Articles You May Have Missed

Susanne Friend
column editor

"Michelangelo's Fame Built on Forgery, Claims Author," *The Independent*, 02/09/2014

He is known as a Renaissance great – but Michelangelo was also a skilled forger who made copies of major works before ageing them with smoke and swapping them for the originals. The little known details of his penchant for forgery were revealed by art historian Thierry Lenain at the Institut Français in London.

According to Mr Lenain, author of Art Forgery: The History of the Modern Obsession, the Italian frequently forged artworks in order to obtain the originals from their owners by giving them the copies. This is not the first time rumours of the artist's forgeries have emerged. According to Mr Lenain, Michelangelo's copies earned him great notoriety, which helped launch his career.

Significantly, the perception of art forgery in the Renaissance era was very different to the negative attitudes which developed in later centuries. "In late-modern forgeries, the main goal consists not so much in the creation of a work of art than in the construction of a trap," said Mr Lenain. "The most important authors on art, from the Renaissance to the 18th century, had a completely different approach to the issue," he explained. "Far from condemning those who performed that kind of trick, they hailed them with the utmost enthusiasm."

"Unesco Stops Unauthorised Reconstruction of Bamiyan Buddhas," *The Art Newspaper*, 02/06/2014

The international community has reacted furiously to news that a German-led team of archaeologists has been reconstructing the feet and legs of the smaller of the two Bamiyan Buddhas, the monumental Afghan sculptures blown up by the Taliban in 2001.

News of this reconstruction, which has taken place without Unesco's knowledge or permission, was revealed during the 12th meeting of Unesco's Bamiyan working group, in Orvieto, Italy, in December.

A team of archaeologists from the German branch of Icomos spent most of last year rebuilding the smaller Buddha's lower appendages with iron rods, reinforced concrete and bricks, an operation that Francesco Bandarin, Unesco's assistant director-general for culture, describes as "wrong on every level".

Andrea Bruno, the architectural consultant to Unesco for the past 40 years, confirms that the work was carried out "against Unesco's decision [taken in 2011] not to rebuild the Buddhas" and says the organisation was never made aware that the project was going ahead. Bruno says the work has caused "irreversible damage, bordering on the criminal".

Destruction of the buddhas was a disaster for the local population of Shia Muslims, who have been persecuted by the Taliban, because it deprived them of what little income they had from foreign visitors. A Unesco-led project aims to encourage visitors in the future with four projects: a cultural centre and museum devoted to Buddhist and Muslim history; a underground viewing chamber at the foot of the larger Buddha; a bazaar along the remains of the ancient Silk Route, and restoration of three interconnected caves in the nearby ancient site of Shahr-i Ghulghulah.

"Dallas Museum of Art Makes a Major Play for Painting Conservation," *Dallas Morning News*, 02/07/2014

Officials announced last week that the first four paintings from private collections to undergo conservation treatment in the Dallas Museum of Art's new Paintings Conservation Studio are now on view.

One of the four, The Blacksmith Cupids by Charles-Antoine Coypel, has become part of the museum's permanent collection. The remaining three, along with the Coypel, are, according to DMA officials, "part of the museum's new conservation program to collaborate with private collectors on the study and care of their collections," before presenting the works in the galleries for public viewing.

"Ancient Buddhist Caves in China Could 'Turn to Sand'," *The Art Newspaper*, 02/25/2014

Urgent conservation work is needed to save a series of caves in northwest China containing ancient murals by Buddhist monks, which are threatened with destruction from the forces of nature.

The network of 236 sandstone caves extend over an area of two to three kilometres in the autonomous Xinjiang region of China, along the ancient Silk Road. The caves were inhabited by Buddhist monks and used as temples between the third and the eighth centuries, and are lined with murals providing a rich picture of early Buddhist culture.

The caves are prone to deterioration, particularly from moisture, because of their geological composition, which includes many soluble salts. Although the region is very dry, any rainwater could have "distastrous consequences", according to Giorgio Bonsanti, an expert in wall painting preservation. Bonsanti said that there have been efforts to buttress the mountains with cement and horizontal metal poles, which anchor the external layers of stone to more solid rock, but these fortifications are proving insufficient in the bid to save the caves.

The murals are particularly significant because of their stylistic similarity to Indian, rather than classical Chinese, art.

In the early 20th century, many of the paintings were removed by Western archaeologists, notably the German expedition of Albert von Le Coq in 1906, and are now housed in museums including the Museum für Asiatische Kunst in Berlin and the Musée Guimet in Paris.

"How 3D Printers Forge New Art from old Etchings," *New Scientist*, 03/17/2014

When does restoration work become downright forgery? A new exhibition at Sir John Soane's Museum in London is full of pieces that purport to be by the 18th-century Italian artist and etcher, Giovanni Battista Piranesi. Their date of manufacture: 2010.

The works are by Factum Arte, an Italian design company that straddles the worlds of museum conservation and contemporary art. Right now they are printing and sculpting a meticulous life-size facsimile of Tutankhamun's tomb, to take visitor pressure off the original.

Sited in Soane's famously cramped museum of antiquarian curiosities, the exhibition is called *Diverse Maniere* after one of Piranesi's most famous collections of engravings, published in 1769.

The exhibits show Factum Arte exploring the middle ground between serious restoration and pure fantasy. They have worked from Piranesi's etchings of ancient Roman artefacts and created life-size, three-dimensional sculptures, realising forms that previously only existed on the page.

Assembled using the CAD package ZBrush, the exhibits were prototyped using the largest stereolithographic printers in Europe, then assembled using more familiar technologies like routing, milling and laser cutting.

"Monuments Man in War, Conservator in Peace," *New York Times*, 03/19/2014

By now, much of the movie-going

world is familiar with "The Monuments Men," an art-historical film that sees George Clooney, Matt Damon and other stars swashbuckling around Europe during World War II, trying to save masterpieces from bombs and the clutches of German and Russian troops.

Mr. Clooney's debonair, mustachioed role was inspired by the real-life exploits of George L. Stout, the American conservator who traveled to the front as part of the Monuments, Fine Arts and Archives Section of the Allied military effort.

But like so many other veterans of the war effort, Mr. Stout rarely tooted his own horn about his wartime feats. In fact, his posthumous outing as a boots-on-the-ground war hero seems to have taken many conservators by surprise. In their world, Mr. Stout, who died in 1978, is already revered, but for a very different achievement: being a pioneer and promoter of the scientifically grounded conservation methods that define the field today.

In 1928, together with the chemist Rutherford J. Gettens, Mr. Stout established America's first conservation research laboratory at Harvard University's Fogg Museum. After the war, Mr. Stout became the founding president of the field's first international professional association, now called the International Institute for Conservation of Historic and Artistic Works.

He also produced seminal publications and textbooks, served as director of two major museums, helped establish America's first graduate conservation program (at New York University's Institute of Fine Arts in 1960) and generally led a vast range of efforts to modernize and professionalize the way art was restored and preserved.

"Bayeux Tapestry: The Islanders who Finished the Final Scenes," *BBC News*, 06/30/2014

The Bayeux Tapestry is arguably the most famous piece of embroidery in history. Yet, when it was rediscovered 300 years ago, the final section appeared to be missing. Until now.

The tapestry, chronicling the Norman conquest of England and that battle in 1066, is regarded as a marvel of medieval Europe. However, since it was "rediscovered" by scholars in the 18th Century, its original final scene has been missing.

Instead, the final scenes showed the death of Harold Godwinson, the Anglo-Saxon king, and his unarmoured troops fleeing following their defeat at Hastings. No one is certain how much longer the original tapestry was or what it showed, but most experts believe it was an 8-10ft piece including a depiction of William's coronation on Christmas Day in 1066.

Now, a team of embroiderers on Alderney, a small island just off the coast of William's native Normandy, have "finished" the job. The project took a year to complete and every effort was made to ensure it fitted in with its famous forebear. Embroiders used the same techniques, fabrics, colours and similar types of wool to the medieval original.

The new tapestry is the same height as the original and 3m (10ft) long, with four panels showing events following the Battle of Hastings, culminating in William's coronation. The finished work is set to be displayed in the room next to the original tapestry at the Bayeux Tapestry Museum in Normandy.

"United States Museums Provide Emergency Support for Syrian Museum Collections," *Art Daily.org*, 07/17/2014

In addition to the high toll that Syria's four-year-old civil war has had on its people and infrastructure, Syria's cultural heritage has been and continues to be destroyed at an unprecedented rate.

World Heritage sites like the historic city of Aleppo and Krak des Chevaliers, as well as medieval Christian cemeteries and numerous archaeological sites and museums, have been subjected to extensive raiding and looting.

In an effort to help stem the loss of the region's significant cultural heritage, Penn Museum's Penn Cultural Heritage Center, Philadelphia, Pennsylvania, and the Smithsonian Institution, Washington, D.C., in cooperation with the Syrian Interim Government's Heritage Task Force, have come together to offer assistance for museum curators, heritage experts, and civilians working to protect cultural heritage inside Syria.

A three-day training program, "Emergency Care for Syrian Museum Collections," focusing on safeguarding high risk collections, was completed in late June; additional training programs are being planned, pending funding.

"IS militants Destroy Ancient Mosque in Mosul," *Arab News*, 07/25/2014

Islamic extremist militants blew up a revered Muslim shrine traditionally said to be the burial place of the Prophet Jonah in Iraq's second-largest city, Mosul.

The residents said the Islamic State militants, who overran Mosul in June and imposed their harsh interpretation of Islamic law on the city, first ordered everyone out of the Mosque of the Prophet Younes, or Jonah, then blew it up.

The mosque was built on an archaeological site dating back to 8th century BC and is said to be the burial place of the prophet, who in stories from both the Bible and Qur'an is swallowed by a whale.

It was renovated in the 1990s under Iraq's late dictator Saddam Hussein and until the recent militant blitz that engulfed Mosul, remained a popular destination for religious pilgrims from around the world.

"This Flipped Class Is Studying Biology with a $10 Microscope and a Smart Phone," *Campus Technology*, 08/19/14

Take a smartphone, add $10 worth of plywood and Plexiglas, a bit of hardware, laser pointer lenses and LED click lights from a keychain flashlight and you have a DIY microscope worthy of use in college classes.

At least, that's the idea of an instructor at the Missouri University of Science and Technology who is adding the do-it-yourself technology in her biology lab courses.

The project is part of a larger research endeavor at the university to explore the design of instructional labs for science and engineering courses that can be delivered in a blended or online format.

The goal of theresearch is to develop e-learning models to redesign traditional lab courses to work in a hybrid format and to create a handbook for use by instructors that explains how to apply the new models.

The microscopes were designed during the spring semester by Daniel Miller, a graduate student in biological science who served as a teaching assistant in the biology class taught by Associate Teaching Professor Terry Wilson, where the scopes were used.

Wilson had been hunting for a commercial kit, but she wasn't happy with what she was finding. Then Miller showed her his own prototype: "I was blown away by it," she recalled. "I was really shocked by how good a job it does." The devices are impressive. They can magnify samples up to 175 times with a single laser pointer lens — nearly 400 times when stacking two lenses, Miller said.