Smithsonian X 3D
How to bridge the gap between having a hunch and knowing with certainty? In terms of the applicability of 3D technology to a museum setting, Smithsonian X 3D answers this challenge by launching a set of use cases which apply various 3D capture methods to iconic collection objects and scientific missions. Smithsonian X 3D projects indicate that this new technology has the potential not only to support the Smithsonian mission, but to transform museum core functions. Researchers working in the field may not come back with specimens, but with 3D data documenting a site or a find. Curators and educators can use 3D data as the scaffolding to tell stories or send students on a quest of discovery. Conservators can benchmark today’s condition state of a collection item against a past state—a deviation analysis of 3D data will tell them exactly what changes have occurred. While these use cases appear remarkable and extraordinary today, all of them are substantiated by Smithsonian X 3D projects and all of them may represent the ordinary tomorrow. However, this future is not our birthright—we will have to earn it. We need to find ways to adapt this technology so it can scale beyond a confined set of projects. Needless to say, not everything needs to be captured in 3D—Smithsonian collection consists of a daunting 137 million artifacts and specimen—but for the promise of 3D to become a reality, we need to invent rapid-capture workflows to acquire 3D data and dramatically decrease the time it takes to post-process this data into the compelling interactives we are presenting in our brand-new 3D viewer.

As we are taking a moment to celebrate what has been achieved, we also want to squarely face the remaining challenges. We have gotten this far working shoulder to shoulder with our corporate sponsors and benefiting from a growing community of like-minded individuals from museums and research universities. We hope to build on these relationships to move 3D capture at the Smithsonian from pilot to program and unleash the power of 3D technology in the museum community. Please join us!

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http://3D.SI.EDU
There are many ways to document objects and the world around us in 3D. Methods include the use of lasers, structured light, computed tomography (CT) and photogrammetry. These approaches vary in accuracy, range and capture speed, but they all result in a prolific collection of measurements in the form of XYZ coordinates. The 3D datasets can be used to make stunningly accurate physical reproductions with 3D printers, photorealistic image or video renders. Perhaps most important, the datasets can be viewed, researched, shared and disseminated digitally, providing access to Smithsonian collections like never before.

Anatomy of a 3D model
- **Point Cloud** a simple visualization of xyz coordinates
- **Polygon Wireframe** an interpreted surface from a point cloud
- **Surface Normals** a map of the unique direction for each pixel described in RGB color
- **Occlusion Maps** a grayscale map of varying surface curvature
- **Solid Model** a culmination of the above with digital lighting
- **Photo Texture** photographic color mapped on to the 3D model

Opposite, composite layer 3D renderings of the Livingstone gun, see page 17.
WHAT IS 3D PRINTING?

Once a model or environment has been documented in 3D, a precise physical model can be created using a variety of “rapid manufacturing” methods. Physical models can be produced using Computer Numerical Controlled (CNC) carving techniques that cut from solid blocks of material. 3D printers use an array of additive processes that “grow” a model layer by layer using anything from plastic to titanium.

Fossil whale found in the Atacama region of Chile. Opposite, full color 1:25 scale 3D print of fossil whale, for additional information, see pages 27–29.
In 1860, before he became the Republican nominee for president, Abraham Lincoln agreed to pose for a life mask with sculptor Leonard Volk. Lincoln was pleased with the results and declared it “the animal himself.”

In 1865, Lincoln sat for sculptor Clark Mills for another life mask. Aside from the beard, the most startling difference is Lincoln’s physical deterioration in five short years. Lincoln’s secretary and biographer John Hay wrote, “The first is a man of 51 and young for his years...the other is so sad and peaceful in its infinite repose that the famous sculptor Augustus Saint-Gaudens insisted, when he first saw it, that it was a death mask.”

The Lincoln life masks currently sit in a case in the National Portrait exhibition, America’s Presidents. This 3D view brings the objects to life and adds to an understanding of Abraham Lincoln’s life and the toll the Civil War took on him.

3D models of the Lincoln masks will be the first 3D printable items made specifically for a STEAM (Science, Technology, Engineering, Art and Math) curriculum.
3D rendering from laser scan data of plaster life mask of Abraham Lincoln by Leonard Wells Volk, 1917 cast after 1865 original.

3D rendering from laser scan data of plaster life mask of Abraham Lincoln by Clark Mills, cast after 1865 original.
The fine details that cover this monumental standing Buddha provide a rare glimpse into early Chinese visions of the Buddhist cosmos. This symbolic map of the universe seems to arise like a magical emanation from within the limestone figure. Along with supplying some of the first evidence for such allegorical mapping, these reliefs reflect the amazing sophistication of Chinese narrative illustration and spatial illusion. Traces of pigment on the surface suggest that the dense design was originally painted, making the scenes easier to read.

To study such low-relief compositions, scholars traditionally have made rubbings with black ink on white paper, to give stronger contrast to the outlines. Digital scanning, used with a wide variety of imaging techniques, offers even more clarity to the designs. Scans are also useful tools for sharing research: source materials, related illustrations and interpretation can be easily attached to an online 3D model of the Cosmic Buddha.
As a globe can be unwrapped into a flat map of the earth, 3D scan data of geometrically complex objects can be unwrapped into 2D space. By digitally unwrapping the 3D model of the buddha figure, we are able to view the intricacies of the carving all at once. This is a valuable tool for researchers and the public alike.

Photo realistic 3D rendering of the Buddha Vairochana.

Opposite, digitally unwrapped rendering of the Buddha Vairochana.
Missionary David Livingstone dedicated most of his adult life to fighting slavery in eastern Africa and exploring the continent’s interior. He was the first European to see and name the magnificent Victoria Falls on the Zambezi River. In his explorations, he traveled with this gun, which shows extensive use and repairs. It was returned to England with his body after his death at Chitambo, southeast of Lake Bangweulu, on May 1, 1873.

The Smithsonian Libraries is an unexpected repository for a gun. The Libraries received it as part of the Russell E. Train Africana Collection, a trove of books, manuscripts, posters, watercolors and other items relating to the exploration of Africa. In the Smithsonian’s online 3D viewer, the scan of this fascinating item serves as a focal point and introduction to the treasures in the Russell Train Collection.
Stars are like people. They are born, live for a period of time, then die. When massive stars run out of fuel, they can explode in what astronomers call a “supernova.” Supernovas hurl elements—including those necessary for life—into space, where they eventually become integrated into future generations of stars and planets. A supernova remnant is the structure it leaves behind, a cloud of debris bounded by an expanding shock wave.

Cassiopeia A—a supernova remnant in the constellation Cassiopeia—is the strongest radio source in the sky beyond our solar system, but it is extremely hard to see optically. This three-dimensional visualization was constructed using numerical data that astronomers collected from various telescopes that used x-rays, infrared and visible light. That information was put into a medical imaging program adapted for astronomical use, then commercial software was used to create the final visualization.

Most of the data that astronomers get from their telescopes tell us about the universe in the two dimensions we see on the flat sky. When the “depth” of an object can be determined, scientists can examine it from all sides and understand it better.
A soldier and former slave named Prince Simbo, a resident of Connecticut, used this powder horn during the American Revolution. Simbo served as a private in the Seventh Regiment, Connecticut Line of the Continental Army. A close examination of the imagery on the horn reveals symbols that may reflect the owner’s background, perhaps spiritual beliefs and traditions of African origin. More research is needed to understand the symbols’ significance.

A 3D scan will make the horn more accessible to researchers trying to interpret the symbols carved into it. 3D images can be digitally “rolled out” flat for a comprehensive view in 2D space. Additionally, a scan and/or a three-dimensional replica of the horn would be excellent items for K-12 curricula or family activity both inside and outside the museum.

Below, 3D rendering derived from photogrammetry data of Prince Simbo’s powder horn. Opposite, Prince Simbo’s powder horn unwrapped.
On December 17, 1903, the Wright brothers inaugurated the aerial age with their Wright Flyer, the world's first airplane. Not only did the Wright Flyer achieve sustained, controlled, powered flight for the first time, its design embodied the fundamental elements of all subsequent successful airplanes. On that chilly morning in 1903, the Wrights essentially invented aeronautical engineering and with it a new world. The Wright Flyer is truly a seminal object.

After the airplane's fourth and final flight, a wind gust lifted it from the ground and severely damaged it. Broken pieces remained in storage until 1916, when the Flyer was repaired and publicly displayed at MIT. In 1928, Orville Wright loaned it to the Science Museum in London. After his death in 1948, it was donated to the Smithsonian.

A 3D scan of the Wright Flyer gives a broad audience an unprecedented opportunity to study the engineering details of the world's first airplane. Unpacking the details of its design and construction not only provides a window into the Wrights' inventive genius, but also an understanding of the principles of flight in general. The Wright Flyer in 3D scan is an invaluable teaching tool.
Built (and sunk) in 1776, the Gunboat Philadelphia is the oldest American man-of-war in existence. It is a symbol of the resourcefulness of those who established our nation’s independence. The Philadelphia was part of a squadron that constantly frustrated British efforts to occupy central New York in the early days of the American Revolution. It sank in Lake Champlain on October 11, 1776, when a 24-pound cannonball shattered numerous planks and frames.

Lorenzo F. Hagglund was a New York marine engineer who raised the Gunboat Philadelphia from the floor of Lake Champlain in 1935.

Few museum objects pose a greater preservation challenge than archaeological watercraft recovered from an underwater environment. The National Museum of American History undertook a preservation assessment of the gunboat in 2005–2006, to determine a conservation plan. Yearly 3D scans will enable the museum to track deterioration. When the opportunity arose to scan and digitize the entire object, museum staff realized this data could be used to let virtual visitors see the gunboat and allow for further educational use through 3D printing of scale models.
Cerro Ballena (“whale hill”) is the paleontological site where a spectacular collection of fossil marine mammals was excavated next to the Pan-American Highway in the Atacama Region of Chile. The scope of the site was revealed by road construction in 2010 and systematic excavations through 2012 showed that it preserves dozens of complete skeletons of extinct whales, seals and bizarre species such as walrus-whales and aquatic sloths. The density of fossil marine mammal skeletons at Cerro Ballena is unrivaled by any other fossil site in the world. But the hill was about to be buried under highway construction.

The site no longer exists. The fossil skeletons, embedded in rock, were removed and stored in a local museum. It may be decades before the bones are prepared for study and display. But before the fossils were moved, the Smithsonian’s 3D digitization team scanned the entire site, capturing essential data about the arrangement and condition of the skeletons. 3D documentation provided not only a snapshot of paleontological fieldwork, but also a rich data set that will allow future generations to study the anatomy and conditions of several of the whale skeletons, as they were originally found.

CERRO BALLENA | National Museum of Natural History

3D rendering of 26 foot long fossil whale derived from laser scanned data.
Walrus-whales are an extinct species of fossil whale from the west coast of South America that evolved a bizarre walrus-like face, including asymmetrical tusks not seen on any other marine mammal living or extinct. Walruses evolved in the northern hemisphere and walrus-whales are an example of evolutionary convergence in the southern hemisphere, several millions years ago. There are only a few known fossils and the Smithsonian holds the type specimen from Peru against which other walrus-whale fossils are compared. In 2011, Cerro Ballena excavations uncovered another. Using 3D digitization—3D and CT scans—we created digital avatars of these unusual specimens. The technology allowed us to visualize and replicate the walrus-whale fossils, which are too fragile to mold and cast using traditional techniques.
Fossils of this new species of dolphin, as of yet unnamed, were discovered on the Caribbean coast of Panama and excavated in collaboration with students and staff from the Smithsonian Tropical Research Institute. This specimen (USNM 546126) was collected from a site located in the tidal zone, which required rapid excavation to save it from further destruction by the tides. 3D scans of the skull, jaws and shoulder blade of this extinct relative of South American dolphins provided an important dataset for studying the evolutionary relationships and anatomy of this specimen. It also provided the basis for creating a 3D print of the specimen for the new BioMuseo in Panama City.
Isamu Noguchi’s Lunar Landscape (1944) is an illuminated wall sculpture comprised of a series of incandescent and fluorescent bulbs that shine through perforations covered with colored gels. The overall effect is a soft multi-colored glow against the gray moon-like magnesite surface, inspired in part by the landscape visible to Noguchi when he lived in a Japanese internment camp in Arizona during World War II. This sculpture is extremely fragile, but fully intact, with no structural damage.

Magnesite is a very brittle material, prone to cracking. At some point in the past, a plywood board was fastened to the back of the piece, lending some structural support. But it is occasionally necessary to remove the board in order to change the light bulbs, putting the sculpture in a vulnerable state. In addition, the uneven surface, taut strings and suspended cork on the front make it difficult to support the sculpture when it is placed face down. Using a 3D scan of the artwork and digital fabrication techniques, a custom cradle was created from plywood, cardboard and archival foam. The cradle safely and evenly supports the brittle material in its risky state when the backboard is removed and the light bulbs are exchanged.
The Blue Crab is an icon of the Chesapeake Bay region. Its scientific name, Callinectes sapidus, means “savory beautiful swimmer.” Blue crabs are sensitive to environmental and habitat changes. Because overharvesting and significant habitat losses have occurred in the Chesapeake Bay, blue crab populations have experienced a severe decline. Crab tagging is just one way Smithsonian scientists track blue crab migrations up and down the Chesapeake. Female blue crabs journey to the mouth of the Bay every year to spawn. For a small reward, watermen who catch the crabs can call the scientists and report their location.

Scientists at the Smithsonian Environmental Research Center (SERC) in Edgewater, Maryland, are actively researching movement patterns of females migrating to saltier waters at the mouth of the Bay. In the Bay and in rivers south of Annapolis, SERC has monitored the abundance of blue crabs over three decades, documenting the degree to which blue crabs respond to environmental changes. A 3D model of a blue crab can be used as a precise anatomical teaching tool.
Woolly mammoths are iconic mammals of the Ice Age. Although they have been extinct for tens of thousands of years, collections of their bony remains continue to provoke questions about how they lived and why they went extinct.

3D scanning of the mammoth in the Ice Age Hall at the National Museum of Natural History provides a valuable set of data for studying the biomechanics and paleobiology of very large mammals, whose bones are cumbersome and logistically difficult to manipulate.
The Embreea herrenhusana orchid has a fascinating pollination biology: the elaborate five-inch flower emits an incredibly complex fragrance, which is secreted through special glands in its labellum (central petal). This fragrance is collected by male Eulaema bees, which use it to attract and sexually excite choosy female Eulaema bees. Here is the mystery: how did a bee’s sex pheromones evolve in an orchid? Did the bee evolve to fit the orchid, or did the orchid evolve to fit the bee?

Using micro CT-scanning technology, one can explore and measure the interior geometry of complex objects. This allows scientists to investigate the geometric relationship between the Embreea herrenhusana orchid and the Eulaema bee.

This recently discovered orchid species is rarely grown in cultivation and biologists are still figuring out its ecology. A process that can be assisted by such 3D scans.

Opposite, 3D renderings of orchid and bee derived from CT data.
This wooden hat belongs to the Tlingit Dakl’weidi (Killer Whale) clan of southeast Alaska. The hat was made in 1900 in Angoon, Alaska and belonged to Gushdeiheen a Dakl’weidi clan leader (SI catalog number E230063). It is a clan crest hat in the form of a killer whale rising out of the ocean. The hat is both a sacred object and an object of cultural patrimony, which the National Museum of Natural History repatriated to the clan in 2005.

The hat was scanned with the clan’s permission to allow the Smithsonian to make an exact replica for education and exhibition purposes. A digital fabrication tool (CNC mill) carved the hat from alder wood, which was painted and inlaid with shell in consultation with the clan. This project shows we can return culturally sensitive objects so they can be used in ceremony while retaining exact replicas to teach about their cultural significance—and the importance of repatriation.
A magnificent limestone cave on the Indonesian island of Flores, Liang Bua is the place where the fossil human species Homo floresiensis—the so-called “hobbits” of human evolution—was first discovered in 2003. More than a dozen scientific articles have been published based on analysis of the original skeletal remains and hundreds of scientific papers and news stories about Homo floresiensis have appeared since this amazing discovery.

Since 2010, excavations at Liang Bua have continued as a collaboration between researchers from the National Center for Archaeology in Indonesia, the Smithsonian’s Human Origins Program and the University of Wollongong in Australia. 3D scans of the cave will allow researchers to better understand the geological structures of the cave. They will also give the public virtual access to an extremely remote dig site.
Plan view of the cave, Liang Bua.

Opposite, elevation view of cave.
This elaborate carved chair is based on the designs of Michelangelo Pergolesi, an Italian decorative artist who flourished in London in the late 1700s. There, he published Designs for Various Ornaments (1777–1801), which contained designs for interiors, furniture, silver and other objects in a neoclassical style. English craftsmen adopted these designs, but this chair, with its delicate legs and intricate carving, is more in the style of northern Italy, where Pergolesi’s designs must have circulated as well.

The use of classical motifs in very carefully crafted objects was popular in the late 18th century in much of Europe. The chair back depicts two griffin heads emerging from crossed cornucopias. This chair represents an innovative use of ornamentation as structure, which makes it very relevant to Cooper-Hewitt’s mission of finding innovation in decorative objects of all periods. Through the use of 3D technologies, we can now give students of furniture and design the opportunity to closely examine this important historic piece.

Photograph of side chair in the style of Michelangelo Pergolesi, Italy, late 1700s.

Opposite, 3D renderings of chair with normal maps.
This flight suit was worn by Amelia Earhart (1897–1937), the first woman to fly solo across the Atlantic. After early flights in a men’s suit, Earhart had suits like this made to ensure comfort, safety and style. This example at the National Postal Museum dates from the 1920s.

Earhart, a collector herself, helped fund her record-setting flights by carrying mail on board for collectors. Such items would gain significance and value by traveling with her.

In 1968, donor Elsie M. Williamson, assisted by stamp dealer Jacques Minkus, gave Earhart’s personal collection of flown souvenir mail, photographs and leather flight suit to the Philatelic and Postal History Division of the U.S. National Museum. Williamson acquired the collection from Earhart’s husband, George Palmer Putnam.

The museum sought a 3D scan so that a comprehensive record of the flight suit would be available for study without taking it off display.

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AMELIA EARHART FLIGHT SUIT | National Postal Museum

Photo realistic 3D rendering of Amelia Earhart’s flight suit.

The museum sought a 3D scan so that a comprehensive record of the flight suit would be available for study without taking it off display.
The Digitization Program Office supports 19 museums, nine research centers and the National Zoo in its quest to increase the quantity and quality of Smithsonian digital assets. The challenge and opportunity can be measured by the total number of collection items: at 137 million objects, artworks and specimens, capturing the entire collection at a rate of one item per minute would take over 260 years of 24/7 effort. At the present moment, the Smithsonian has prioritized the digitization of about 10% of its collections for digitization.

To rise to this challenge, the Digitization Program Office is promoting rapid capture photography workflows for two-dimensional collections and exploring innovations to speed up the capture of our three-dimensional collections, preferably in glorious 3D. With only 1% of collections on display in Smithsonian museum galleries, digitization affords the opportunity to bring the remaining 99% of the collection into the virtual light. All of these digital assets become the infrastructure which will allow not just the Smithsonian, but the world at large to tell new stories about the familiar as well as the unfamiliar treasures in these collections.

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