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Model Behavior: Using Photogrammetry for Collections Storage Planning

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by
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Abstract

Proper and efficient collections storage is often a challenge for museums. As collections outgrow their facilities, institutions struggle to find additional space, often resorting to hasty moves of their objects into ill-fitting placements. A large-scale collections move is a slowgoing process, requiring manual measurement and countless trial-and-error sessions. An unnoticed support beam, a low entryway, or uneven flooring can derail even the most well-planned collections move, costing an organization unexpected additions in time and labor expenses. Advancements in emerging technologies, however, may soon eliminate this problem. This capstone explores the use of photogrammetry and 3D modeling to plan a collections storage move in a virtual environment. It examines the relationship between museums and technology through an analysis of museum studies literature, and showcases examples from the archaeology, architecture, and design fields to demonstrate the potential of photogrammetry. A collections move project using this technology for the digital modeling of storage spaces is proposed and detailed. Through the proposed project, I argue that the use of these technologies to design collections storage will greatly optimize a collections move.

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This capstone was further shaped by my exposure to the tech culture of San Francisco and by the increasing, though sometimes misguided, use of technology by the museum field. I am grateful to Chris Alexander and Sherri Nevins, whose class on Museums and Technology I took in the Spring of 2016, for exposing me to many of these uses and allowing me to think critically about them. I am also grateful to my siblings, Carrie and James Sundra, whose work with a 3D scanning company sparked some of my initial ideas on the potential for this technology in the museum world.

I am also thankful for those in my personal life who have provided support throughout this project and throughout my degree program. To my parents, for always believing in me and encouraging me to pursue my passions; to my boyfriend Andrew, for accepting my occasional tunnel vision while focusing on this project and for alleviating my stress; and to my classmates in the Museum Studies program, who have always provided good conversation and commiseration.

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Introduction

This capstone focuses on the use of emerging technologies by museums for internal purposes, particularly to aid in collections care and preservation. Currently, museums are adding interactive features to their galleries, such as touchscreens and smartphone apps, to enhance the patron experience. Innovative use of technology usually does not extend beyond a visitor-facing capacity, however, and behind the scenes, many museums are still very low-tech. Limited use of technology and computer literacy by staff leads to inefficient operations and errors in internal records. This capstone will explore the relationship between museums and technology, which is complicated and full of growing pains, and suggest ways to enhance their partnership. Two technologies in particular are emphasized for their potential benefit to Collections Management.

These two technologies, photogrammetry and 3D modeling, are defined here and explained in layman's terms. Several uses of these technologies in the archaeology field, where they have aided historic preservation and documentation, will be detailed. Photogrammetry has helped to create 3D models of at-risk ancient structures, in order to preserve their details in case they succumb to the elements, modernization, land development, or even threats from warfare. These technologies can also highlight structural defects, weak spots, and areas that have suffered the effects of erosion and other deterioration. Archaeologists have used 3D models to test hypotheses on ancient civilizations, manipulating the modeled objects to mimic their possible intended uses in the past. This allows for an exploration of ideas in a way that is simultaneously hands-on and hands-off, protecting the objects while still utilizing them.

This capstone proposes a sample project, which would use photogrammetry to aid Collections Management practices and enrich the relationship between museums and technology. The project was inspired by my experiences working as a collections intern and a contracted museum technician at the Golden Gate National Recreation Area's Museum Program. In my current role, I am redesigning a storage area to accommodate oversized architectural elements from the Museum Program's collections. The project has involved a great deal of manual measurement, guesswork, and mental gymnastics to visualize where and how objects might fit. As a result of this experience, I have decided to focus this capstone on photogrammetry and 3D modeling to aid a collections storage move. This capstone will demonstrate how these technologies can be used to eliminate the manual work and trial-and-error involved in planning collections storage, by allowing users to test storage configurations in a virtual environment instead.

This capstone is important to the museum field because it will enrich the scholarship available on this under-utilized technology. This project suggests new uses for photogrammetry in the museum field, specifically focusing on its potential for collections care and preservation. The sample project proposed within this capstone would greatly optimize a collections move, ensuring that objects are properly stored and spend less time in temporary locations where environmental conditions may not be suitable. By using this proposed project as a model, a museum can bring their collections storage up to best practices in a far shorter time than through traditional methods, and will use less manpower in the process. This will in turn free up employee schedules and allow them to conduct other collections care projects which may have been left unfinished for an extended period of time, such as cataloging and rehousing objects.

Beyond optimizing a museum's collections division and bringing its operations up to best practices, the technologies explored in this capstone are also important to the museum field for their abilities to preserve at-risk objects and structures in digital form. In many parts of the world, cultural heritage sites are threatened by warfare and by targeted destruction from radical groups. The archaeology field has already made several strides in using photogrammetry to create digital models of these sites. The museum field should aspire to this example by digitally preserving the numerous historical and cultural structures within their own care. In addition to providing a detailed record of a building in cases where physical preservation is not possible, a digital model would also allow interaction and manipulation, whereas the actual structure should be altered as little as possible. Digital models could be used to recreate the original appearance of an historic building, and show examples of its use over the years. This would promote scholarship while minimizing the impact on the structure itself. These social justice applications, as well as those of optimizing the efficiency of collections management and promoting better collections care, show that photogrammetry has immense potential for use in the museum field.

This capstone is divided into three major sections, followed by conclusions and appendices. First, the literature review will analyze existing writings on the relationship between museums and technology, and will explore photogrammetry and 3D modeling through case studies from the archaeology field. It will also draw on literature from the architecture and design disciplines to showcase the effect that digital models and virtual environments have on spatial perception. In the next section, these topics will be brought together in a project proposal for photogrammetry to be used in a collections storage move. Organization information on the Golden Gate National Recreation Area, where this proposed project will take place, will also be provided in this section. The third section is the proposed project's action plan, where timelines, activities, and budgeting for the project are explained. In the conclusion, I will reflect on lessons learned from reviewing the literature and designing this proposed project. I will also highlight further potential uses of photogrammetry in the museum field, specifically focusing on historic preservation applications. The appendices will provide an annotated bibliography of sources which were essential to my research for this capstone, as well as information on the stakeholders of the proposed collections storage modeling project.

Literature Review

I. Introduction: the Storage Problem

Museums frequently struggle with the problem of collections storage. Many simply do not have enough of it, having outgrown older facilities. As acquisitions and donations increase, museums have to get creative to keep up, utilizing every available space or leasing additional offsite storage (Wilsted, 2012). Often, offsite storage is intended to be a stopgap solution, and does not always have proper environmental conditions or controls. This can become a more serious issue if plans and budgets change and the storage becomes more permanent than anticipated. Some museums do not even have adequate environments on-site, being situated in a building that predates today's knowledge of requirements for proper collections care (Wilsted, 2012). Historical museums and societies, often located in period buildings that may be a collections object even as they store others inside them, have an even larger burden (Ascione, Ceroni, De Masi, de'Rossi, & Pecce, 2015). Finding space for collections objects and orchestrating moves to offsite storage is usually a time-consuming and labor-intensive process (Matassa, 2011), involving countless measurements, visual checking of spaces, and creative movement to avoid support beams, low ceilings, oddly-shaped corners, and wall ornamentation, to name a few potential hazards.

While museums often lag behind other industries in their adaptation of new technologies, especially for collections purposes, they have benefitted greatly from the semi-automation that collections management software and environmental control systems provide. Further automation for managing storage facilities would significantly decrease the amount of manual effort needed for collections moves. Since institutions with storage problems often also have many unfinished collections projects, the freeing of manpower from storage planning would allow more work and care to be put into the collections overall. Meanwhile, uses of new technologies by museums are often confined to patron interactives, ignoring the greater potential of these technologies beyond the novelty of new components in the gallery experience. In this literature review, I will examine the developing relationship between museums and technology. I will also explore some emerging technologies currently being used in the archaeology and cultural heritage fields, specifically focusing on two methods of obtaining spatial data. Using examples from the existing literature, I will suggest how these technologies can be adapted by museums to facilitate the management of collections storage.

II. Sleek, Soulless and Sinister: Museums and the Digital Frontier

Partnerships between cultural heritage institutions and digital technologies have been evolving since the 1980s, a decade which saw the first virtual building models (Champion & Dave, 2007), 360-degree gallery tours (Kenderdine, 2007), and touchscreen collections interfaces (Thomas, 2014). This relationship has not been without growing pains, however. The ubiquity of technology in everyday life continues to be a source of anxiety for many museums, and theorists frequently grapple with the changing nature of curation and museum authority in the twenty-first century. Susan Cairns and Danny Birchall noted in the 2013 Museums and the Web conference that the very definition of "curation" has shifted in today's society, with the term being used for everything from music playlists to automated Netflix recommendations (Cairns & Birchall, 2013). Unlike with traditional museum curation, the assumption with these new forms is that anyone can do it. One result of "D.I.Y." curation and personal choice in viewing museum content is that institutional and curatorial authority has been undermined, as exhibits are increasingly seen more as “fancy choosing” than as the result of meticulous study of collections and theory (Cairns & Birchall, 2013). In her thesis on the Google Art Project, Alanna Bayer summarizes:

> Art history does not represent a natural progression of all the world’s art, but rather a selective group of artists, artworks, and art movements legitimized by historians and academics. Yet it often takes on the appearance of innocence, as if the artists absorbed into the canon naturally fell into place there, neatly arranged in their art periods (Bayer, 2014, p. 32).

This has led to hard feelings from those who have dedicated their lives to the discipline, as some museums choose retaliation rather than adaptation to these growing cultural realizations. The tension between institutional authority and personal selection has often created animosity, rather than a willingness to utilize technologies that allow more user control (Cairns & Birchall, 2013). Bayer notes that new technologies, especially browsable online galleries, are often viewed through a binary dichotomy, labeled either as “democratizing space[s] that allow for increased access to cultural items, or as a commercializing space that commodifies cultural items” (Bayer, 2014, p. 12).

In addition to perceptions of a threat to the traditional museum authority, emerging technologies are also often seen as an uncontrollable and inexplicable intrusion into the gallery. The sudden explosion of Pokémon Go at cultural institutions and landmarks in the summer of 2016 is a prime example, as is the increased taking of selfies within museum galleries (Droitcour and Smith, 2016). Rather than try to understand these new phenomena, some museums choose to view them with distrust and annoyance. In a recent essay, Brian Droitcour and William Smith explore the institutional backlash against our world of ubiquitous personal devices. New technologies have made museums nervous and wary, perhaps of giving these superficial devices equal importance to the works displayed around them. The authors point out, however, that museums can no longer ignore these forces in today's digital world: "The question isn't *if* museums will participate in these exchanges [of culture online], but *how* they will" (Droitcour and Smith, 2016, p. 78). A museum that chooses to avoid the technological nature of contemporary society will increasingly seem disconnected and indifferent to the patrons using it to engage in fulfilling and personal meaning-making within their galleries.

Since browsable digital galleries allow more choice and variation than viewing a physical exhibit, many also believe that some of the aura of a museum is lost in the translation to a computer screen. Visitors to an online gallery are much more likely to detour to another site for more information, further eroding an institution's authority (Thomas, 2014). Bayer also notes that despite the appearance of democracy, large online collections repositories such as the Google Art Project are also guilty of promoting an agenda. While a user can theoretically view any of the thousands of pieces included in the database, they are much more likely to gravitate towards those displayed in headers at the tops of pages. These prominent spaces are always reserved for well-known works such as Vincent Van Gogh's *Starry Night*, a showcase that indirectly promotes the digital collections of large, famous museums rather than the handful of images digitized by small institutions outside of Western popular culture (Bayer, 2014). In addition, Google can also use its involvement with the arts to soften its corporate image and seem more like an institution for public good. The sleek, soulless, and occasionally sinister aura of online collections has made many institutions wary of adopting them.

Yet another challenge museums face in understanding and accepting technology is the rapid rate at which it develops. In the introduction of their anthology *Theorizing Digital Cultural Heritage*, Fiona Cameron and Sarah Kenderdine remind us that by the time a guideline or analysis of a technology has been published, the technology has usually evolved enough to make the writing irrelevant (Cameron & Kenderdine, 2007). Therefore, museums are not just struggling with how to use new technologies, but also with the very problem of conceptualizing them within the field's framework. This has led to an aversion of technology by some institutions, as detailed above. For others that do attempt to use digital tools, a common obstacle is discovering innovative applications for them. An array of similar museum apps and nearly-identical gallery touchscreens exemplify the creative-use problem that museums have with new technologies, as few institutions have purposes for them beyond eye-catching but ultimately superficial patron interfaces (Witcomb, 2014).

In most cases, museums add technological components to their galleries as a response to trends and patron preferences. It is extremely rare for a museum to instead take the initiative and utilize a technology that others in turn will respond to (Droitcour and Smith, 2016).A great need exists for technological innovation on the part of museums, rather than as a mere result of what has already been happening around them. In particular, museums need to find creative and fulfilling uses for emerging technologies that would benefit the institution on every level, rather than just public interfaces. Though these technologies can often be very costly, and many institutions are wary of investing in them for fear that they will soon be obsolete (Droitcour and Smith, 2016), one factor that is not often explored is the benefit these new systems can bring despite their pricetag.

Increased opportunity for technological interaction and personalization in a gallery could lead to heightened visitorship, for example. When the Renwick Gallery reopened in 2015, their pre-closure annual attendance figures were exceeded within just six weeks, largely a result of encouraging patrons to share their visits on Instagram (Judkis, 2016). Emerging technologies also have the potential to lower costs behind the scenes, just as modern environmental controls have significantly reduced conservation needs and expenses by simplifying the care process (Matassa, 2011). In the next section, we will explore two technologies that present extensive possibilities for museums to optimize their collections care.

III. Technologies of Heritage: Photogrammetry and LiDAR

As mentioned in section two, virtual technologies were first adapted for museum purposes in the 1980s. One of the earliest versions of a virtual gallery tour was accomplished with Apple’s then-new QuickTime Player. By stitching together panoramic photographs of museum galleries, the software created a 360-degree image, which users could drag with their mouse to view from all angles. Though not a true virtual reality experience, this process was known as QuickTime VR, and was an important milestone in the popularization of virtual touring and 360-degree images (Kenderdine, 2007).

In addition to photo-based virtual tours, some cultural sites created more immersive experiences by designing 3D models of places and objects. These projects also got started in the 1980s, when the Sulis Minerva Temple of Bath, England was modeled by consulting descriptions from ancient texts, guessing at dimensions, and designing a computer program to render it (Bentkowska-Kafel, 2006). This project was one of the first uses of 3D modeling to learn about a non-extant structure. Since then, the use of the technology for archaeological projects has grown significantly. While computers can be used to create digital models from scratch, as in the Bath example, other technologies are also used to gain better data about a site before it is rendered virtually. Two prominent examples of these technologies are photogrammetry and LiDAR.

Photogrammetry is defined as the science of measuring through photos (Linder, 2009). The process of extracting three-dimensional data from two-dimensional pictures is achieved by comparing the same points in photographs taken of an object from multiple angles. Through geometric equations, the object's measurements can be determined. Wilfried Linder, in a helpful introductory textbook to the science, explains the practice in simple terms:

> Obviously, from a single photo... you can only get two dimensional coordinates... This is a good moment to remember the properties of human vision... We are able to see objects in a spatial manner, and with this we are able to estimate the distance between an object and us... Our brain at all times gets two slightly different images resulting from the different positions of the left [and] the right eye... This principle, the so-called *stereoscopic viewing*, is used to get three dimensional information (Linder, 2009, p.1).

Since the 1800s, photogrammetry has been used in a surprising number of applications, including topographical map-making (Fujii, Fodde, Watanabe, & Murakami, 2009) and military field plotting (Kyle, Luhmann, Robson, & Boehm, 2013). As the above quote alludes to, the popular early photographic novelty of stereoscopes also represented a form of photogrammetry (Fig. 1). In the latter half of the nineteenth century, architect Albrecht Meydenbauer's efforts to measure the facades of Prussian monuments was one of the first projects using photogrammetry in relation to cultural heritage (Kyle, Luhmann, Robson, & Boehm, 2013).

Fig. 1
A stereo photograph of the Panama-Pacific International Exposition, held in San Francisco in 1915. When seen through a special viewer, these two photographs of the same scene taken at slightly different angles will appear as a 3D image to the human eye. (World of Stereo Views)

Since the advent of computers, the process of calculating photogrammetric measurements has become much easier, as specialized software now exists to automatically interpret photographs and extract geometric information from them. As a result of this dramatic reduction in skill and time investment, the discipline of photogrammetry has opened up to new audiences (Kyle, Luhmann, Robson, & Boehm, 2013). In the digital age, computers can use the geometric data from photogrammetry projects to create virtual 3D models of the objects or scenes which were photographed. (Kyle, Luhmann, Robson, & Boehm, 2013). Some museums have used photogrammetry to create digital models of objects in their collections, which visitors can view from all angles, zoom into, and manipulate through gallery interfaces and webpage applications (Carmo & Claudio, 2013). The Smithsonian Institution, for example, has partnered with AutoDesk, a developer of several different 3D modeling programs, to digitize objects from its vast collections (Fig. 2). This project represents an initiative to allow greater access to the Smithsonian's collections, since less than one percent are ever on view at any time. Digital display also ensures a safer presentation for fragile objects, and is a more culturally respectful alternative to the traditional display of some Native American objects, which tribal customs may not permit direct contact with (Autodesk, Inc., 2013). This project has scanned the famous Wright Brothers aircraft and the Apollo 11 Command Module, among many other objects (State News Service, 2016).

Fig. 2
3D models of two of Abraham Lincoln's life masks, displayed in the Smithsonian's X3D viewer. (Autodesk, Inc.)

Another counterpart to photogrammetry is Light Detection and Ranging, also known as LiDAR, or simply as laser scanning (Al-kheder, Al-shawabkeh, & Haala, 2009). In this method of acquiring spatial data, lasers are projected onto surfaces, and measurements of the surface are determined by recording how long it takes for light to be reflected back to the scanner (Fig. 3) (Al-kheder, Al-shawabkeh, & Haala, 2009). While this technology seems overall to be an improvement over photogrammetry, as it further simplifies and automates the process, there are benefits and disadvantages to either system. Wilfried Linder recommends that LiDAR be viewed as a "supplement" to photogrammetry, rather than a competing system, due to the shortcomings in both methods (Linder, 2009, p. 3). He specifically notes that LiDAR has an advantage over photogrammetry in mapping surfaces that do not have much variation in texture, as photogrammetric software can be easily confused by this and can produce models with errors as a result.

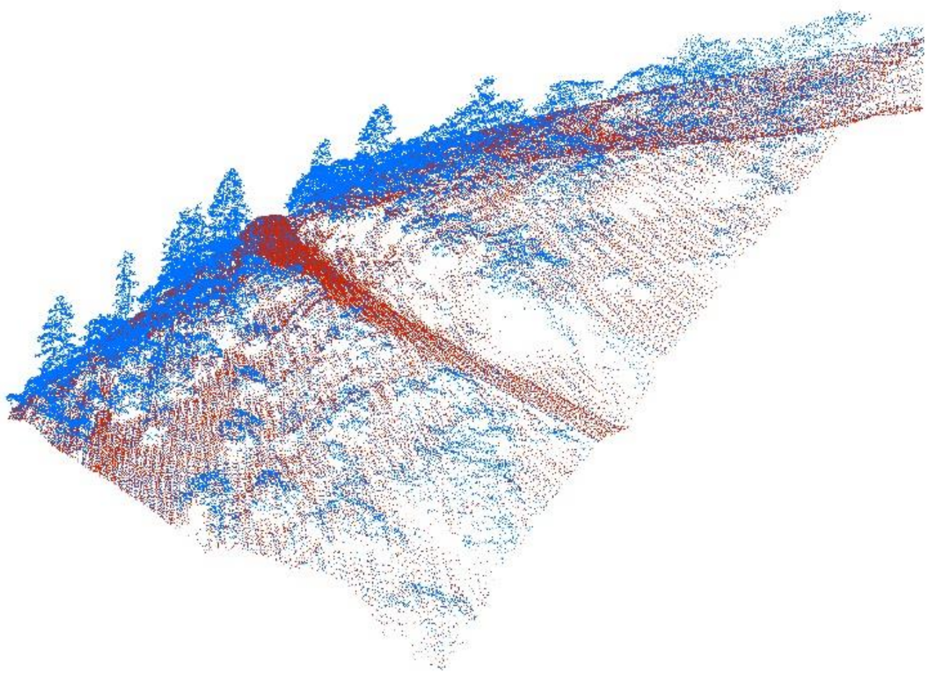

Fig. 3
Computer interpretation of a LiDAR scan of a cliff face in the Sierra Nevadas. The resulting image at this stage is known as a point cloud, to which additional layers of texture and photographic data can be added. (Phelps, 2007)

Laser scanners, however, are far more expensive than photogrammetric systems, ranging from $2,000 to an astounding $200,000 (Johnson, T.T., 2016). In addition, since LiDAR scanning requires direct contact between the objects being scanned and the lasers, photogrammetry has an advantage when working with water, clouds, and soft surfaces like sand, as photographs "freeze" these moving and malleable substances. Similarly, Linder also notes that photogrammetry is superior in gathering data from moving objects, whereas laser scanners would either omit this data completely, or produce an error-ridden point cloud. Photogrammetry also has an advantage over laser scanning in that resulting models can be photo-realistic and in full color (Linder, 2009).

To further explain the advantages, disadvantages, and capabilities of both of these systems, I will next highlight data from various mapping projects conducted within the archaeological sector. Space limitations do not permit a full examination of the case studies here, but activities from cultural sites in Jordan, Ireland, Tajikistan, Peru, Malta, and the United States will be briefly referenced. Interestingly, the US appears to be behind other countries in the use of these technologies for cultural heritage purposes, as Katharine Johnson and William Ouimet noted that their 2014 LiDAR study was one of only a few that had been conducted in the country (Johnson & Ouimet, 2014). In Johnson and Ouimet's project, aerial LiDAR equipment was used to scan areas in New England. The project's goal was to map the remains of colonial-era structures and Native American settlements, which have long since turned to ruin and left few discernible traces in today's landscape (Johnson & Ouimet, 2014) This work provides an example of how precisely LiDAR can map surface textures, as side-by-side comparisons of rendered scans and colonial-era maps showed the same roads and structures present (Fig. 4) (Johnson & Ouimet, 2014).

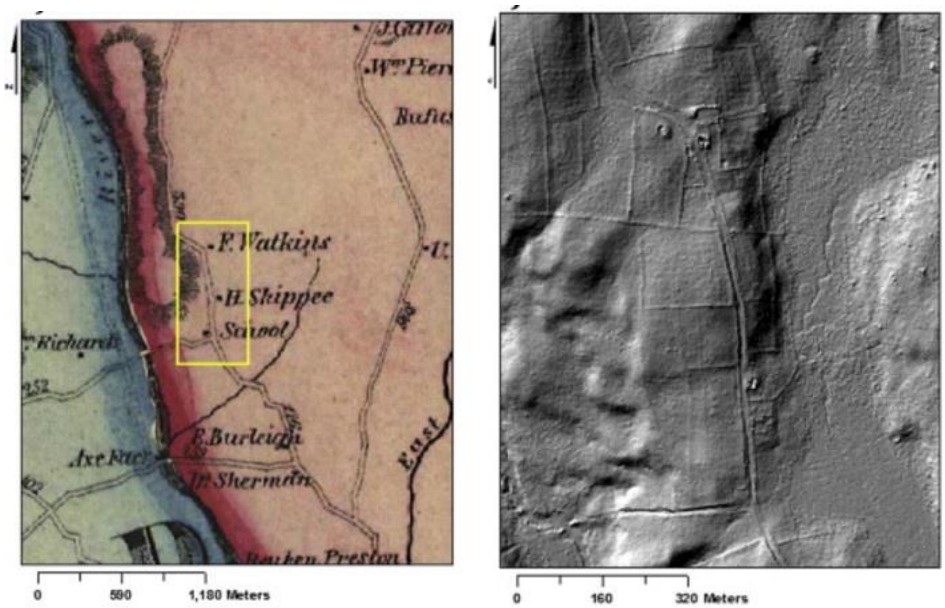

Fig. 4
An historic map of a now-abandoned and overgrown area in New England, compared to an aerial texture map produced from LiDAR scans of the same region. The area marked in yellow on the historic map is detailed in the texture scan. The same curvature in roads is present in both. Additionally, the LiDAR scans reveal remnants of the homesteads marked on the historic map, picking up features such as stone wall formations and building ruins. (Johnson & Ouimet, 2014)

While this project seems to reveal incredible capabilities of LiDAR technology, it is important to remember that scanners are still only registering surface data from the first solid substance their lasers come in contact with. Gary Phelps further explains in his thesis on mapping the Sierra Nevadas with LiDAR technology:

> In areas of dense vegetation or canopy cover, only a small portion of lidar pulses will penetrate the canopy; most reflect off the top and within the vegetation canopy. The laser pulses penetrating to the ground, classified as “ground-hits,” are important because they enable accurate determination of ground elevations. (Phelps, 2009, p. 7)

Therefore, while even scans of forest canopy alone are important, a clear line of sight between LiDAR equipment and a scanning target is necessary for interpreting texture and geometric information accurately.

Johnson and Ouimet also highlighted another benefit of LiDAR technology in their report, which can likewise apply to photogrammetry projects as well:

> Examining LiDAR data prior to an archaeological... site visit would... serve as a useful tool in planning [an] impact statement, thus allowing for a more cost-effective approach. Examination of LiDAR data has also preliminarily shown to be a powerful tool in identifying historic archaeological sites in inaccessible areas (Johnson & Ouimet, 2014, pp. 16-17).

This quote alludes to other possibilities for these technologies, including the ability to study data from a site remotely. By having an archaeological site available in "digital form," for example, data could be shared much more quickly and with many more archaeologists, scientists and consultants around the world. Aerial scans can also allow models to be created without needing to first set foot on a site. If an archaeologically-significant feature is suspected to exist in an area, this technology could be used to map the landscape and remotely analyze whether a dig might be worthwhile, without harming or otherwise disrupting the surface.

Similar to Johnson and Ouimet's LiDAR project, photogrammetry can also reveal hidden details in an object or structure. In a 2005 UNESCO project, an ancient Buddhist monastery in Tajikistan was mapped using the technology. By comparing historical photographs with the new data, archaeologists were able to record erosion and changes in the shape of the monastery walls. (Fig. 5) They proposed the use of photogrammetry to track damage and predict collapses of structures (Fujii, Fodde, Watanabe, & Murakami, 2009). Similar purposes were recommended by scientists who created a photogrammetric model of Chan Chan, the largest pre-Columbian adobe building in Peru. Due to the structure's mud construction, its continued preservation is difficult. A digital model of the building will be valuable not only for structural study, but also for posterity in case it is lost to the elements (Fig. 6) (Pierdicca, Frontoni, Malinverni, Colosi, & Orazi, 2016).

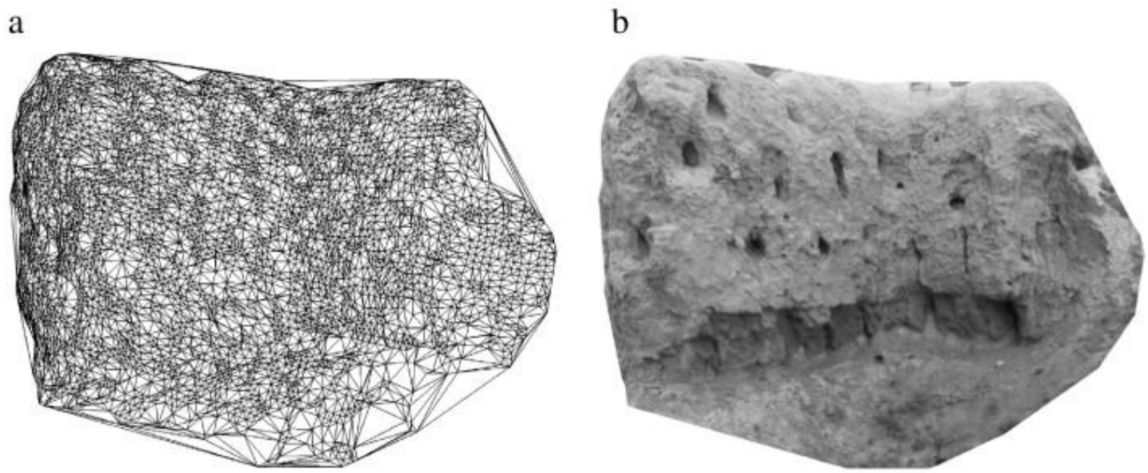

Fig. 5
An example of texture mapping capabilities with data obtained from photogrammetry. This Digital Terrain Model of one of the monastery walls in Tajikistan precisely shows curvatures in the rock and can highlight any structurally-weak areas. (Fujii, Fodde, Watanabe, & Murakami, 2009)

Fig. 6
Digital Terrain Model of one of the walls of Chan Chan overlayed with photographic data, showing digitally-preserved ornamentation. (Pierdicca, Frontoni, Malinverni, Colosi, & Orazi, 2016)

In Jordan, photogrammetry and LiDAR were both used to map early Islamic palace structures, to assess their condition and conservation needs (Al-kheder, Al-shawabkeh, & Haala, 2009). Authors of the project's report examined many advantages and disadvantages of each technology, and concluded that the most effective project would utilize them together, in order to obtain the greatest degree of both "geometric accuracy and visual quality" (Al-kheder, Al-shawabkeh, & Haala, 2009, p. 1). The surprising capabilities of photogrammetry have also been highlighted in other projects, including 3D models of an underwater Phoenician shipwreck near Malta (Fig. 7) (Drap et al., 2015), and of Neolithic boulders in Ireland (Johnson & Solis, 2016). In the latter example, a hypothesis that two boulders were previously one formation was tested by creating a 3D model from photogrammetric data and using animation software to move the digital pieces (Fig 8). The project successfully demonstrated how the two stones may have fit together (Johnson & Solis, 2016).

Fig. 7
Digital models of underwater artifacts, generated from photogrammetric data. (Drap et al., 2015)

Fig. 8
Manipulating scanned boulders to demonstrate how they may have fit together in the past. (Johnson & Solis, 2016)

These examples showcase the remarkable capabilities and varied potential uses of these two technologies. In the case of the Phoenician shipwreck, the authors declare photogrammetry “an essential tool for archaeological survey” (Drap et al., 2015, p. 2). LiDAR, though also valuable in many ways, has been explored in far fewer studies, leaving room for future development. Its higher cost, however, may limit its exploration by museums to only larger institutions. Neither of the two technologies have yet been widely adopted by the museum field, despite their many beneficial applications, especially for institutions that manage or operate within a historic building. Discovering imperceptible details, detecting and monitoring structural defects, and mapping the dimensions of a space are just a few of the ways in which photogrammetry and 3D models could benefit museums.

IV. Visualizing the Virtual

Of course, beyond the potential uses of these technologies lies the fundamental question of purpose. An old adage reminds us that just because something can be done, it does not always mean that it should. Photogrammetry is a labor-intensive progress, requiring hundreds of photos to be taken to generate a single model (Kang & Lee, 2016). While it can be conducted rather inexpensively, the quality of the resulting data increases with the quality of equipment and software used. LiDAR, in comparison, is exponentially more expensive. Small institutions, which often have the largest challenges in collections care, also work with the smallest budgets. The benefits of these technologies must outweigh the cost if an institution could instead attend to its storage manually, for no cost beyond employee pay. Certain advantages have already been detailed above, such as the freeing of manpower for other backlogged projects. By studying examples from the architectural and design fields, we can also uncover further values of 3D modeling in relation to storage planning.

Anyone who has designated museum storage areas for specific objects, only to transport the object to the space and discover it to not fit, knows how difficult it can be to simply imagine how things might go together. Unfortunately, even careful measurement and mockups leave room for error. The chief advantage to virtually mapping a space is that it gives users much better perceptions of an environment than mental visualization or traditional sketching does. In a paper from the 2013 International Conference on Virtual and Augmented Reality in Education, Wael Abdelhameed details the results of a study wherein architecture students used a virtual reality program to create digital models of the buildings they were designing. The study noted that after seeing and interacting with the three-dimensional digital models, many students altered their original designs. The models allowed students to more effectively perceive their ideas than line drawings had, and gave them a better understanding overall of where supports should be placed, how certain features would appear, and other factors (Abdelhameed, 2013). A similar study showed the effect that virtual environments had on students' ability to comprehend the size and shape of objects, noting an increased likelihood to correctly ascertain dimensions from augmented reality models (Shin, Park, Woo, & Jang, 2013).

As we saw in the Irish case study using Neolithic boulders, digital models can be animated to simulate how objects and spaces would fit together. These additional examples from architecture and design studies suggest that digital models of collections storage could assist museum staff in determining object placement within a space. The ability to test a storage configuration virtually would save costs in time and effort, as more accurate models would eliminate the hassle of transporting objects multiple times, altering original plans, and purchasing extra storage materials to accommodate miscalculations.

In addition, strategies for making photogrammetric and LiDAR scans more cost and time-effective are constantly being developed. Earlier this year, a method which would significantly reduce the number of images needed to obtain data through photogrammetry was tested. This project used a stereoscopic camera to ensure that comparative points would be present in each set of images, and a rotating base to automate the process of scanning an interior space from all angles. While the results were low-quality, the study shows the potential for making photogrammetry more affordable in the future (Kang & Lee, 2016). Similar potential exists for LiDAR, as a report last year highlighted the possibilities for Microsoft's Kinect technology to be used in place of more-expensive equipment (Fuan, Tzy-Shyuan, I.-Chieh, Huan, & Su, 2015). While the price tag on some forms of photogrammetric and LiDAR equipment might be shocking, these experiments show that cost-effective options are possible. To truly enhance museums' willingness to use these technologies, however, more experiments will need to be conducted to showcase their potential uses and benefits.

V. Conclusion

This literature review has explored four different topics: museum storage, museums' relationship with technology, LiDAR and photogrammetry in cultural heritage projects, and the benefits of digital visualization. To more concretely demonstrate these topics' possibilities for development and improvement within the museum field, however, a self-contained photogrammetry project will next be explored and analyzed.

Proposal of a Museum Solution

I. Introduction

After an examination of sources from multiple disciplines and perspectives, I propose the use of photogrammetry to create digital models of collections storage spaces in order to optimize a collections move. This project would expand the relationship between museums and technology beyond current gallery interactive uses. It would also facilitate the movement of objects into storage, and give museums a new level of understanding on their storage spaces through easily calculating geometric data and revealing structural anomalies. The Golden Gate National Recreation Area (GGNRA) is an ideal organization to test this use of photogrammetry. Currently, the GGNRA's Museum Program division is planning for a major move of their primary operations and collections storage into a new building. Photogrammetry can be used to plan this move in a virtual environment. The following paragraphs will provide background information on the GGNRA Museum Program and give an overview of this proposed modeling project.

II. Organization Information

The Golden Gate National Recreation Area is one of the largest units within the National Park Service (NPS), and has the second-largest collection of objects within the entire park system (Ewing-Haley, 2016). These collections reflect the diverse lands within the GGNRA, which include Muir Woods, the Marin Headlands, San Francisco's Ocean Beach, several recreational lands to the south in San Mateo County, and former military sites such as the Presidio, Fort Mason, and Fort Point. Alcatraz and Angel Islands are also a part of this large, non-contiguous recreation area. The GGNRA Museum Program, operating out of a tiny building in the Presidio which was originally built as a mule stable, is responsible for the care of over six million objects (Golden Gate National Recreation Area, 2016). The organization adheres to the mission statement of the National Park Service:

> The National Park Service preserves unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations (National Park Service, 2016).

Despite the name "Museum Program," the GGNRA does not actually have a physical, permanent museum to showcase its vast collections. The Museum Program largely conducts behind-the-scenes work in cataloging and caring for the park's collections. The facility itself is only open to the public twice a week for research purposes, and during special open house events (Golden Gate National Recreation Area, 2016). The Museum Program is also responsible for the curation of several pop-up exhibits and display cases located throughout the park and the city of San Francisco, but the potential for public interaction with the GGNRA collections is largely underexplored.

Though technology presents a way to fill this gap, the Museum Program is still very low-tech. Its website contains few features for the public to interact with the collections, currently amounting to a repository of finding aids for research purposes, text summaries of past exhibits, and some small digital photo galleries (Golden Gate National Recreation Area, 2016). While cataloged objects are entered into a digital collections management database, and photographs are frequently scanned into digital form, this largely represents the extent of technology's use in the Museum Program's activities. This is an area with a high level of opportunity for growth in the organization, which photogrammetric models could help to fill. Potential uses for these models beyond this initial storage planning project will be detailed in section three.

Since the GGNRA is a mixture of military sites, previously-established National Park lands, and newly-formed recreation areas, the management of its cultural resources is much more complex than at a traditional museum. The GGNRA's Museum Program was not established until 1994, over twenty years after the park's original founding (Ewing-Haley, 2016). In many cases, the Museum Program inherited collections from former museum and archival operations within the lands, such as the Presidio Army Museum. Consolidating these former collections frequently poses challenges to the Museum Program, as the quality of records and object care differs based on provenance. Storage spaces for the GGNRA collections have also been obtained piecemeal, and the Museum Program still struggles with finding ideal storage for many of its objects (Ewing-Haley, 2016).

The organization's current storage facilities represent an ongoing transition from haphazard object placement to museum best practices. Some areas include a variety of impressive features, such as museum-quality shelving and cabinets, custom housing for objects, earthquake protection, environmental controls, pest abatement equipment, and the separation of objects by material and condition. Other areas, however, store objects that have remained uncataloged for years in conditions that were meant to be temporary. Many of these objects lean against walls or sit under plastic tarps. While the Museum Program has made impressive progress in preparing their various buildings for optimal museum storage, this work is hindered by the organization's small staff size and the large number of projects each employee is responsible for.

Currently, the Museum Program is in the early stages of moving its main operations in the Presidio into a new building. While this new building, like the current home of the Program, was not purpose-built for museum storage, the Museum Program will have much more control over the renovation of this space than it did with its current building. The Museum Program plans to implement modern space-saving features such as modular shelving, but the majority of this moving project is going to be traditional in many ways, including manual measurement and assessment of the space. This new building presents an excellent opportunity to test new methods of storage planning that could save the organization time and resources.

III. Project Overview and Goals

Three-dimensionally photographing and modeling the new collections storage and operations building before moving objects into it would serve many purposes. These purposes are referred to in this text as goals of the proposed project. The project's first goal is to provide staff with more detailed information on its new building. This will be accomplished through two main objectives: taking photographs of the rooms in the building, and creating digital models from their data with photogrammetric modeling software. Though the process of photographing the building will be time-consuming, it is less labor-intensive than manually measuring the space would be.

In addition to room dimensions, a digital model can also reveal structural defects and other areas of concern that staff may not be able to detect through visual inspection. When photogrammetric data is converted into three-dimensional information, even the smallest dent or deviation is recorded in the resulting model. By having this information in advance, staff can take the necessary precautions to keep the project moving smoothly. For example, if the software reveals that the floor of the building is not level, extra equipment can be purchased in advance to prevent objects from leaning once they are transferred. Identification of weak spots in walls can alert staff to the need for insect and leak monitoring, and similar spots in flooring can be flagged so that engineers can be consulted, supports added, or heavy objects restricted from being placed there.

The second goal of this project is to virtually design the storage configuration for the new building. This will be accomplished first through the objective of using the digital models to test arrangements of furniture and objects, and next by surveying staff on the advantages, disadvantages and their personal comfort level with the digital modeling software. Since photogrammetric data gives the exact dimensions of a room, the Museum Program team can use the digital models to determine the best use of their storage spaces without the trial and error of physical object placement. Similar to the project conducted with Neolithic boulders in Ireland, Museum Program staff can use digital modeling software to place “objects” within the virtual environment of a scanned room, which can then be moved around. These objects can be as simple as artificial shapes representing the size of a cabinet or oversized object, or as detailed as additional photogrammetric models of objects and furniture. For time and simplicity’s sake in this trial project, I propose creating simple shape representations of storage elements to test space configurations, rather than conducting additional time-consuming photogrammetry to capture these objects.

Virtual tests of space configurations will eliminate common unforeseen problems in collections moves, such as an uneven floor, an unnoticed support beam, or a low doorway, which often complicate even the most well-laid plans. Due to the size of the GGNRA park and collections, objects are housed in many different and far-off locations within the park’s 80,000 acres. If objects are brought from multiple storage locations before their ability to fit into a new space is confirmed, those which do not fit would have to be returned to their former location until a new option is finalized. This is an expensive and time-consuming setback. For certain oversize, fragile, or otherwise specialty objects, professional moving teams may need to be hired for transportation. An error in planning spaces for these objects would add a particularly large and unanticipated cost to the project. The ability to finalize a storage plan before moving any of the objects would benefit the GGNRA, where the lack of centralized storage and operations increases the need for streamlined project activity whenever possible.

Since research from other fields also indicates that virtual models increase people's ability to visualize additions to a space, part of this project will also involve surveying Museum Program staff on their perceptions of changes in ability to "understand" how the space will look before it is actually set up. Employees will be asked whether the models aided them in conceptualizing the space, detecting special concerns such as low ceiling beams, and choosing the most appropriate and efficient spaces for objects and storage furniture. The results of this survey will be used to generate qualitative as well as quantitative data on the effectiveness of photogrammetry for this purpose, and will be included in a final report of this project's activities.

Though the use of digital software will allow for a finalization of room configurations without the need for manual movement, a better mental visualization can still be beneficial when staffmembers have to make quick decisions away from their computers. Some example scenarios include employees suddenly coming across an uncataloged object while conducting the move and not having time to return to the digital model to test its placement, or when new objects are being donated and need a storage space prior to full cataloging. Having a good idea of space configuration can make the transition of these objects into storage spaces easier, even if they have not yet been properly measured and otherwise documented. The GGNRA could also use the digital models to work more efficiently with storage planning consultants. Instead of visiting areas on-site with museum staff, which would be costly and divert manpower from other projects, a consultant could review the virtual models remotely. This would further reduce the project's overall time and expense.

In addition to the main goals, an auxiliary goal of this scanning project will also be to promote a better relationship between the Museum Program staff and emerging technologies. Though this project may sound complicated, the equipment used in photogrammetry is relatively straightforward. A large portion of the process involves the familiar work of taking photographs. Photogrammetry only requires a good-quality DSLR digital camera and a rotating tripod, ideally equipped with GPS technology, to be conducted successfully. The inclusion of GPS is recommended to obtain accurate scaling information when the software processes received images (Ferguson, 2016). Assistance with photogrammetric software can also be obtained through organizations such as Cultural Heritage Imaging (CHI), who work to promote understanding of computational photography technologies amongst cultural heritage professionals. Located in San Francisco, CHI offers beginner classes in photogrammetry, as well as many other resources for individuals to become comfortable with the technology and utilize it to its fullest potential (Cultural Heritage Imaging, 2016).

Although LiDAR, wherein a room is mapped through laser scanning, was explored as well as photogrammetry in the literature review, I recommend that the

GGNRA project use photogrammetry alone to create their digital models. This is because photogrammetry can be conducted much less expensively than LiDAR scanning. Many of the companies behind photogrammetric software provide free trials and discounted versions for nonprofit institutions. As explained above, the learning curve is also relatively small for photogrammetry, and additional training courses and materials can be obtained easily. Mastering LiDAR and its related equipment is a more complicated process. After this project, once staff is comfortable with photogrammetric technologies and has assessed the quality of the models created through it, decisions can be made on investing in the more expensive and specialized LiDAR equipment in the future.

Even if the Museum Program is satisfied with the level of detail provided by photogrammetry and does not continue on to LiDAR scanning, this would not equal a rejection of technology overall. It is hoped that the use of photogrammetry for this project will lead to a greater comfort level and willingness to utilize emerging technologies by Program staff. Better technological literacy can in turn lead to the development of new projects which would engage GGNRA patrons with the park's cultural resources in innovative ways. For example, one possible outcome of this project would be the use of the virtual models in other applications. While visitors to the GGNRA website today can only see a few low-quality images of the object storage rooms in the Museum Program building, they may be able to take a virtual tour in the future.

Similarly, this technology can also be used to create much more meaningful collections records for the many historical buildings within the GGNRA. Instead of simply describing the building in its catalog records, a model could also be created to serve as a well-rounded and compelling record on the historic structure. As the GGNRA is vast and many of the buildings within its lands were not well cared-for before falling under National Park jurisdiction, this technology could also document the most structurally unsound buildings in the GGNRA, effectively preserving a digital copy of these structures and their cultural and historical significance, even after the physical objects may be lost to the elements.

In summary, this project will focus on two major goals: achieving a better understanding of storage spaces, and virtually planning a storage move. An auxiliary goal is also to increase staff comfort with new technologies. These goals will be achieved through conducting photogrammetric imaging, using specialized software to create virtual models, testing storage configurations through these virtual models, and administering employee surveys to gain perceptions of the technology's effectiveness. This project will advance the mission of the GGNRA by leading to more effective care of its collections. Better object care and space utilization will open up new possibilities for exhibition opportunities. This project will also create a higher comfort level with digital technologies, which can lead to new initiatives by staffmembers to better showcase the collections. This project aims to facilitate collections moves and optimize collections care, so that organizations can further enrich and build upon the connection between their patrons and the objects in their stewardship.

Action Plan and Project Timeline

Project Title: Collections Move Modeling Project

Project Purpose: To obtain a better understanding of storage spaces through the use of emerging technologies, and more effectively plan an error-free collections move.

Background and Strategic Context

The GGNRA Museum Program is in the early stages of moving its main operations and collections storage into another building within the Presidio of San Francisco. Previous Museum Program moving projects have been conducted manually and in stages, leading to errors and improper object storage. This new building represents a "clean slate" opportunity to test out more efficient methods of moving collections objects and planning storage configurations. By using the emerging technology of photogrammetry, an optimal storage configuration can be chosen without the need for manual trial and error. Photogrammetry will be used to create digital models of the new building's rooms, which staff can then use to test different placements of objects and shelving units. This will lead to a more efficient use of Museum Program staff time and will allow the move to be conducted more smoothly and quickly. This project will also provide the Museum Program with detailed information on the new building, including information on its structural integrity. Digital models of the buildings' rooms also have the potential to be used as a cultural preservation tool, or as a virtual interactivity tool for visitor engagement. Currently, the Museum Program's website is lacking in features which explore new technologies and which allow patrons to interact with the collections. This is an area with a high opportunity for growth, which this project aims to enrich.

Priority: This project will facilitate the activities of a related high-priority collections and operations move and will allow the overall move to be completed more efficiently. However, since the larger move project could also be completed without the input of this project's activities, this project has been given a medium priority.

Other Related Projects

This project is closely related to a high-priority project, a move of the main operations and collections storage of the GGNRA Museum Program from its current location into a new building. This larger Collections and Operations Move (COM) project will allow Museum Program staff to more efficiently allocate space for collections, employee workspaces, and other needs than the current building's configuration allows. The timeline of the COM project, however, is not well known. The project is still in the early planning stages and no schedule or completion date for the move has yet been established by Museum Program staff, or by Presidio or NPS administration. Therefore, the Collections Move Modeling Project does not currently have any other deadlines outside of the project's own to adhere to.

Project Goals and Objectives
The goals of the Collections Move Modeling Project are to achieve a better understanding of the new Museum Program building, to plan a storage move as virtually as possible, and to increase the use of emerging technologies by Museum Program staff. Goals will be accomplished through the following objectives:

- Conducting photogrammetry on the new building's rooms
- Using photogrammetric software to build virtual models of the spaces with this data
- Testing different storage configurations in a virtual environment with these models
- Administering employee surveys to gauge perceptions on the technology's effectiveness and aid in visualizing the space
- Putting at least one room's storage configuration recommendation into practice in the new building
- Highlighting potential avenues for future uses of photogrammetry and modeling software technologies by the Museum Program

Project Scope
In-Scope:

- Photogrammetry and digital modeling of one building in the Presidio of San Francisco
- Identification of structural problems and other areas of concern in the building, if found
- Testing of various storage configurations in the building through use of the digital models
- Surveys of Museum Program staff on their perceptions of this technology's aid to a collections move
- A trial of one proposed storage configuration in one room in the building
- A final report on the activities of this project and the benefit this technology provides to museums for moving purposes

Out of Scope:

- Finishing the GGNRA Museum Program's related COM project
- Photogrammetry and modeling of other buildings in the GGNRA
- Use of the digital models for virtual tours or other uses beyond the storage project
- Photogrammetry of objects within the GGNRA collections for use in other storage configuration projects, or for virtual collections interfaces
- Sharing of digital models with outside figures for architectural consultation, insurance coverage, or other purposes
- Major architectural renovations as a result of structural issues highlighted by the digital models, or the process of choosing an alternative building for the new home of the Museum Program if the need arises
- Training of Museum Program staff in other new and emerging technologies for collections or visitor-interfacing purposes.

Assumptions:

- This project will be conducted in conjunction with some activities for the related larger COM project. Some of these activities, such as inventory of objects considered for moving into the new building, and a finalized list of objects to be moved, are imperative to the success of this project.
- A contracted employee will be hired by the GGNRA Museum Program to work part-time (average 20 hours/week) on this project. This employee will require an orientation to the buildings, collections and operations of the Museum Program, and will also likely require training in photogrammetry. The Museum Program will be prepared to pay for a short, off-site course in photogrammetry for the benefit of the Contractor.
- Regular Museum Program staff as well as the Contractor will contribute to this project. Regular staffmember roles will primarily entail the inventory and moving of objects, cleaning and otherwise preparing the new building spaces, and interacting with the digital models and recommended storage configurations as prepared by the contractor. Staff will also submit to surveys related to this project and will answer questions on their opinions truthfully.
- This project may be halted if serious structural defects in the new building are discovered through the project's activities. To ensure safety, arrangements to correct defects or to alter the move to another space will be made before this project can be resumed.
- Data from previous collections and operations moves will be made available to the Contractor for study and comparison.
- Museum Program staff will provide the Contractor with necessary transportation and access to the new building and to current offsite storage areas if necessary. The government vehicle provided by NPS for Museum Program staff will be the primary mode of transportation for this project, though personal vehicles are permitted when use of the government vehicle is not possible.
- In the event that the Contractor enrolls in an off-site photogrammetry class, the Museum Program will provide a small stipend to cover travel costs to and from the class.
- The Contractor will consider Collections Management best practices, such as grouping objects by material and condition, in addition to space efficiency when designing the storage configurations.
- Necessary equipment, such as cameras, tripods, and software, will be purchased by the Museum Program for this project. This cost will be factored into the project's budget.
- The Contractor's stipend will also be included in the project's budget, while regular Museum Program employees will be paid their regular salaried amounts from the Museum Program's operating budget.

Constraints

- This project is planned to be completed within a 25-week period (schedule will be detailed below). Completion time for this project is flexible, though funding is not.
- Activities related to the project cannot exceed the allotted budget, even if the project is unfinished when the funding limit is met.
- While the Museum Program can negotiate an extension of the project contract and additional funding, it is unknown whether this extension will be granted by park administration. Staff should plan to complete this project within the time and funding constraints of the original contract.
- Regular Museum Program staff will divide their time between this project and their regular duties. When other duties take priority, these staffmembers will delay their contributions to this project.
- One government vehicle is provided for the GGNRA Museum Program. If an employee is using this vehicle for another purpose, staffmembers will have to use personal vehicles for transportation related to this project, or must postpone the project's activities. If project activities require travel across the Golden Gate Bridge, the use of a personal vehicle will incur the bridge toll and this expense cannot be reimbursed.
- This project has a lower priority than the greater COM project, as well as a lower priority than many regular operations activities of the Museum Program. The project may be delayed or halted if it is deemed extraneous and if resources are required elsewhere.
- Though the larger COM project does not currently have a firm deadline, this project will have to operate within the constraints of the larger project's timeline if one develops.
- Objects with special storage, conservation or other related needs will take priority when their storage configuration is disputed by more efficient methods.
- Employees will be surveyed on their opinions of the technology's usefulness, and thus the survey results may not correlate with other data gathered during this project. For example, the contractor may conclude that the project was completed 20% faster than previous moving projects, but Museum Program staff may perceive that the added technology did not effectively speed up the project.
- The quality of available data from previous moving projects may vary. Projects at the Museum Program are often completed by contractors, who all have different organizational systems and have produced work of differing qualities. Some data may not be usable for this reason.
- The contractor who is hired for this project will state their availability during the hiring process. Unless special circumstances are made, the contractor will not be

available outside of this set schedule. Requested days off made in advance must also be honored.

- The National Park Service is an extension of the US Department of the Interior, and thus GGNRA operations may be affected by Federal holidays, Government shutdowns, employee furloughs, and other occurrences.
- Contracted projects must fall under a larger category of activities in order to secure funding from GGNRA and Presidio administration. (i.e., facilities management, object cataloging, records reconciliation, etc.) This project's activities must be confined to the larger purpose that funding is provided through, and cannot exceed this scope.
- Current catalog records and object storage may not be up to museum standards. Backlog cataloging, remedial rehousing, and other activities may need to be conducted on certain objects before they can be inventoried and moved for this project.
- Once the final report and recommendations from this project are delivered, the larger COM project may be limited by its own timeline and budget in its abilities to adhere to these recommendations.

Deliverables:

- Photogrammetric imagery of every room in the new Museum Program building
- 3D digital models of each room derived from photogrammetric data
- Test storage configurations for each room, including multiple options for a room when possible/applicable
- One "optimal" storage configuration for each room, included and delivered in a report of recommendations for the new building storage plan
- Staff surveys on opinions and perceptions of photogrammetry and modeling technologies
- Objects and shelving moved into one room in the new building, following the recommended optimal storage plan
- A final report of the project's activities and further recommendations

Project Client/Owner: National Park Service/Golden Gate National Recreation Area

Project Department: GGNRA Museum Program

Project Manager: Contracted Employee

Managers of the Project Manager: Supervisory Curator & Reference Archivist

Project Team Members and Percentage of Time they will Work on the Project:
Contracted Employee – 100%
Supervisory Curator – 20%

Reference Archivist – 20%
Museum Specialist – 20%
Archives Technician – 10%
Archives Clerk – 10%

Schedule
This project will be completed over a period of 25 weeks, and will include three phases. Each phase will be detailed below. In Appendix C, Gantt Charts are provided which further detail the task workflow, assign staffmembers to each task, and estimate the amount of time each task and overall phase will take to complete.

Phase One

- Job announcement for Project Contractor
- Contractor selection & interview process
- Inventory of objects to be moved to new building
- Correction of errors in inventoried object records/object rehousing if needed
- Contractor orientation to GGNRA & training on-site
- Training of Contractor in photogrammetry and digital modeling (may require attending an off-site course)
- Cleaning of rooms and otherwise preparing the new building for the project
- Purchase of necessary equipment (i.e. cameras, tripods, etc)
- Purchase of digital modeling software; installation and configuration on staff computer(s)
- Finalized inventory of objects that will move to new building

Phase Two

- Testing of photogrammetry by taking photos of one room in the new building
- Test input of photos into digital modeling software
- Correction of any errors detected by software, either through use of Photoshop or by re-taking photos as necessary
- Creating one test model of the room using the digital modeling software
- Check-in/progress report between Contractor and Museum Program Managers
- Photogrammetry of remaining rooms in the new building
- Input of these photos into the digital modeling software
- Correction of any errors in photos/re-taking photos if necessary
- Digital modeling of all remaining rooms

- Identification of problem areas/structural defects in the building through analysis of the digital model
- On-spot correction of problem areas/structural defects or purchase of equipment and arrangement for future corrections

Phase Three

- Virtual testing of various storage configurations for different rooms using the digital models
- Check-in/progress report between Contractor and Managers
- All staff interaction with the digital models and survey on perceptions of their usefulness for visualizing spaces and planning storage configurations
- Selection by Contractor of most efficient storage configurations for each room
- Interaction by all staff with the configurations deemed most efficient
- Second survey on staff perceptions of digital models and usefulness as a move project tool
- Contractor’s report of storage recommendations
- Test setup of one room’s storage configuration by moving objects and shelving into the new building
- Final report of project activities, survey findings, and conclusions on the technology’s usefulness for storage planning
- Final check-in with Museum Program Managers and future recommendations for new projects and/or uses for the digital models

Resource and Cost Plan

This project will have an overall budget of $24,000. Other than the Project Contractor, staff salaries will be paid from the Museum Program annual operating budget, and thus will not be included in the contract’s amount. Cleaning supplies for preparing the new building will also be paid for from the operating budget, if they are not already available on-site, as will transportation costs when the government vehicle is used. Personal transportation costs are not covered, though a small amount has been included in the budget allotment for photogrammetry training, as that will likely occur at an off-site location. While most of the costs related to moving the collections, such as purchasing storage furniture and hiring movers, will be included in the budget for the larger COM project, funds are included here to cover the cost of the test storage configuration of one room at the end of the project. A portion of the budget has also been set aside to cover minor structural support equipment for defects that this project may discover in the building, as well as other incidental costs. The budget will be detailed on the following page, with costs identified by phase and dependent tasks highlighted where applicable. Dependent tasks are portions of this project which must be completed before the funding for a particular activity can be released.

Resource/Task	Associated Phase	Cost	Dependent Tasks
Contractor Salary (Part-Time)	1-3	$12,000	Job announcement and hiring of contractor. Completion of project objectives, check-in meetings with managers, and written reports.
Photogrammetry course & transportation	1	$2,000	Hiring and on-site orientation of contractor at Museum Program facilities.
Photogrammetry equipment & software	1	$2,000	Completion of photogrammetry course by contractor. Cleaning and preparation of new building spaces.
Collections move for one room	3	$5,000	Photogrammetry of building, modeling of rooms and testing of storage configurations in virtual environment. Selection of optimal storage configurations and report of recommendations.
Structural defect funds and other project incidentals	2-3	$3,000	Photogrammetry and digital modeling of rooms. Analysis of the digital models to uncover structural defects.

Total Cost: $24,000

Quality Management Plan
The quality of this project will be ensured through multiple methods. The most direct method is the participation of all Museum Program staff in various tasks throughout the project. Check-ins and progress reports between the Project Contractor and Museum Program Management are also required to ensure that contractor-only tasks are being completed on schedule and to the standards outlined in the terms of the contract. The contract mandates three check-ins between Management and the Project Contractor throughout the course of this project, though more may be included if staff sees the need. When submitting invoices for hours worked, the Project Contractor is also required to detail work performed within the contract on each invoice. Invoices will be reviewed by Museum Program management as well as GGNRA administration. Park administration staff will be updated on the progress of the project through periodic reports sent by Museum Program management, as well as through information shared at any division-wide or other staff meetings scheduled to occur during the course of this project. The Project Contractor will issue a final report at the project's conclusion, which will comprehensively detail all of the project's activities, findings and observations, and list recommendations for future courses of action. Some potential projects which could be undertaken in the future as an extension of this project are briefly listed below.

Future Related Projects
Collections & Operations Move (COM) Project
Photogrammetry & modeling of other GGNRA storage spaces
Photogrammetry & modeling of other Presidio buildings or park structures
Photogrammetry & modeling of museum objects
Use of digital models for other purposes (i.e. virtual tours, exhibit components, etc.)

Summary and Conclusions

I. Proposed Project Evaluation

This capstone has explored the topics of collections storage, photogrammetry and 3D modeling, and the relationship between museums and technology. It has revealed the struggles and shortcomings present in both storage planning and in technological applications within the field. It has also demonstrated the largely untouched potential of photogrammetry and 3D modeling beyond gallery interactives. A hypothetical project to ameliorate collections storage problems and technological aversions through the use of these systems was designed. This proposed project has successfully linked together all of the themes explored in this capstone's literature review, and has concretely demonstrated multiple benefits of using these technologies for storage planning.

An organization undertaking this or a similar project would have many ways of evaluating its success and effectiveness. The most obvious indicator of success, of course, is whether the intended goals of the project are adequately met, and if the technologies provide a clear benefit to storage planning. The project as proposed in this capstone also includes a built-in evaluation method of surveying staff perceptions on these technologies, and whether they provided the desired aid. A final report on the project's activities is also required, where it will be evaluated alongside previous moving projects. Through this comparison, concrete data on this project's efficiency will be provided in addition to the subjective survey responses.

Other methods of determining success include recognition within the larger GGNRA organization and its partners. The operations of the GGNRA are complex, as was detailed in the project proposal, and will be further detailed below in the project stakeholders appendix. The Museum Program, though responsible for significant historical and cultural stewardship of park artifacts, is small and often overlooked in the larger GGNRA administration. If this project is notable enough to attract attention, acclaim, or interest for adaptation to other aspects of park management, it can be considered successful. Significant praise could promote the activities and collections of the Museum Program within the GGNRA, potentially attracting more attention from both visitors and park administration.

If the final report on this project is made public, another sign of success will be inquiry from other organizations on implementing similar projects. Offers of partnership from some of the many tech companies in San Francisco for further cultural endeavors is another indicator of success. Use of the models generated during this project or the technology behind them for other purposes will also support this project's relevance and potential beyond being a one-time novelty. As speculated in the project proposal, digital models could also be used to provide virtual tours of Museum Program facilities on the organization's currently simplistic website. Revitalization of unrelated aspects of the Museum Program would concretely showcase the importance of this project. Although a major purpose of this capstone is to extend museums' use of technology beyond patron interactives, the potential to create new forms of interactivity and audience participation through these technologies should also be appreciated, as visitation and use of the collections are some of the main criteria for success in any museum.

Questions related to this project which still remain unclear include the true capabilities of digital modeling software for this purpose. Though 3D modeling software was researched for this capstone, and concrete examples of its capabilities from the archaeology field were demonstrated, no evidence could be found that a project of this exact nature has ever been undertaken. While research provides a good idea of the potential for this project to succeed, it is still difficult to know in theory only if the software will allow for the desired movement of elements within a modeled room, increase users' ability to spatially perceive the proposed room configurations, and other proposed objectives. To answer these questions, the project would have to be fully tested, or, at the very least, more hands-on experience with photogrammetry and 3D modeling software is needed.

Another unanswered question is the willingness of an average organization to undertake a project of this nature. While this proposed project may provide great benefit across multiple areas, a museum may still view it as too frivolous or complicated to implement. Though the costs for training, equipment and software as detailed in the action plan are relatively low, they are still big enough to be seen as a deterrent by some smaller organizations. Many museums do not have large budgets, and despite having the option of applying for grants, may be discouraged from doing so by a lack of grant-writing experience or a perceived inability to compete effectively for funding. Smaller institutions are also likely to operate with older technology, which may not be compatible with certain 3D modeling programs. The cost of upgrading may act as an additional deterrent to undertaking this project. Further research tailored to the priorities, challenges and issues affecting small museums would be needed to accurately determine this project's appeal and benefit to an institution of this size. If necessary, the project's scope, content, and even goals could be altered to better suit these types of museums.

II. Personal Evaluation and Future Applications

At the beginning of this capstone project, my main focus was the digital preservation of historic structures, as a long-term protection against destruction that the physical object could succumb to. I recognized that technologies which could be adapted for this purpose, such as virtual tours, augmented reality, and 3D object models, were already in use by museums in some format. However, these technologies are currently confined to visitor-facing applications, while museum operations are often quite low-tech in comparison. Collections Management in particular is a discipline that often lags behind in technological advancements, with many institutions still using simplistic and antiquated databases to track their collections. After conducting further research, I discovered just how tense the relationship between museums and emerging technologies really is. This project emerged from my original idea of modeling for preservation, and was further shaped by my findings on museums' lack of technological uses beyond influencing their patron experience.

Research into the uses of photogrammetry and modeling technologies also refined this capstone, as I discovered their many unexpected capabilities. The detection of structural defects, in particular, led me to explore how these technologies could be used in Collections Management. The fact that photogrammetry, LiDAR, and 3D modeling are already being used extensively in archaeological projects also demonstrated their potential for museums, not only in preserving a digital version of a space, but in understanding that space as well. My experience at the GGNRA, where I am currently working to redesign a storage area to accommodate large architectural elements, helped me to tie together my research into a concrete idea of using these technologies for storage planning purposes.

Beyond this project, several other possibilities exist for photogrammetry and 3D-modeling in museums. The most obvious application goes back to my original idea of preserving at-risk structures. Since this is currently being done in the archaeological field, this presents an area of opportunity for cross-disciplinary collaboration. A project exploring the use of a 3D model as the catalog record for an historic structure would also be beneficial for the museum field. Many institutions have entered historic buildings into their collections databases, but these structures are difficult to define and fully explain within the confines of collections management software. Through the examples shown in this capstone, a 3D model of an historic building could instead provide full geometric data on the structure, as well as identification of weak spots and other areas of concern.

Another interesting project would be to use a 3D model to create a digital reproduction of a building as it appeared in the past, perhaps with historically accurate paint colors or furniture inside. Where a building may have been altered beyond recognition in reality, a model may aid in visualizing its original appearance and uses. These possibilities are particularly important, as they would work to advance social justice within the museum field by virtually preserving a structure where physical preservation may be impossible. By recreating the past through manipulating a virtual model, we can further understand the cultural heritage of that site.

Further possibilities for recreating lost aspects of our past exist in photogrammetry's reliance on stereo photography. As one of the most popular early photography media, stereo photographs from the 19th and 20th centuries survive in abundance in many historical societies. However, they are not often used in exhibitions or by researchers, due to the need for special viewing equipment to achieve the desired 3D effect, and the perceived redundancy without this equipment of two nearly-identical photographs. By creating digital scans of these photos and importing them into photogrammetric software, truly-3D versions of their images could be achieved, transforming the original media with a new purpose and relevance.

In addition to saving the stereo photographs themselves, this would also help to save sites from our past as well. For example, the Panama-Pacific International Exposition was a world's fair held in San Francisco at the height of stereo photography's popularity, and hundreds of such photos were produced of the fairgrounds. Intended to be temporary, the vast majority of the PPIE site was demolished immediately after the exposition's conclusion. Only a few remnants of the PPIE can be found today, despite it being one of San Francisco's most celebrated historical events. If the many surviving stereo photographs of the exposition were combined to produce a 3D model of the fairgrounds, however, historians would have the most tangible link to the PPIE yet created.

These examples demonstrate the under-explored possibilities of photogrammetry and 3D modeling, and of museums' adaptation of emerging technologies in general. In addition to the practical uses of increasing storage efficiency and the care of related collections, these technologies also have immense potential in forwarding historical research and social justice causes. In this capstone's proposed project and conclusion, concrete examples have been given which demonstrate these technologies' abilities to preserve our at-risk cultural heritage, better understand our past, and recreate lost structures digitally.

This capstone project has successfully explored the relationship between museums and technology, and has demonstrated methods in which this relationship could be improved. It has explained the need for more diverse technological adaptations by museums, and has showcased the potential benefits of doing so through the example of a collections storage project. The proposed project not only demonstrates immediate benefits for the participating organization, but highlights the potential for wider applications and longer-term benefits as well. After conducting this research and designing this project, I highly recommend the widespread adaptation of photogrammetry and digital modeling by the museum field.

Appendices

A. Annotated Bibliography

Abdelhameed, W. A. (2013). Virtual reality use in architectural design studios: A case of studying structure and construction. Procedia Computer Science, 25 (2013 International Conference on Virtual and Augmented Reality in Education), 220-230. doi:10.1016/j.procs.2013.11.027

This paper examines the benefits that virtual reality environments and templates provide the design field. Specifically, it points out the advantages of creating a virtual environment in which to test models. Highlighted in this study is an experiment with design students, which measured how likely the students were to change their initial ideas after testing them out in a virtual environment. This study was integral to my research because it highlighted the benefits virtual reality brings when planning how a space should be designed or used. Since I investigated how technologies within the virtual reality spectrum could benefit collections management, this study greatly supported my argument that it can be used for planning storage configuration.

Al-kheder, S., Al-shawabkeh, Y., & Haala, N. (2009). Developing a documentation system for desert palaces in Jordan using 3D laser scanning and digital photogrammetry. Journal Of Archaeological Science, 36, 537-546. doi:10.1016/j.jas.2008.10.009

This study documents the use of two different technologies, photogrammetry and laser scanning (also known as Light Detection and Ranging, or LiDAR), to produce 3D models of ancient palace structures. In addition to describing these technologies, the study also compares and contrasts them, and highlights the results of using them together. For example, while photogrammetry is more cost-effective and allows for a larger degree of user control over the final model, it cannot register differences between large areas that do not have distinct features, like blank walls. Laser scanning is better for these surfaces, and also produces higher-quality models. Photogrammetry and laser scanning are the two primary technologies I researched for this project. This study detailed the benefits and drawbacks of each, and showcased an example of their use within the cultural sector. It proved very useful to understanding these technologies and their many possibilities.

Ascione, F., Ceroni, F., De Masi, R. F., de Rossi, F., & Pecce, M. R. (2015). Historical buildings: Multidisciplinary approach to structural/energy diagnosis and performance assessment. Applied Energy, doi:10.1016/j.apenergy.2015.11.089

While this study does not deal directly with the digital technologies whose uses I showcased in my paper, it provides a good amount of background information on the issues historical buildings face. Problems well-known by collections staff are

detailed, such as environmental fluctuations and structural damage, and approaches to monitoring and correcting these problems are presented. In this capstone, I emphasized the use of photogrammetry for better documentation of historic properties. This writing was a good resource on the challenges which these technologies can potentially correct. By itemizing the issues in this article and analyzing past approaches, I realized new possibilities for the technologies' application, in addition to confirming my previous ideas.

Bayer, A. (2014). Evangelizing the 'Gallery of the Future': A critical analysis of the Google Art Project narrative and its political, cultural and technological stakes (Master's thesis, The University of Western Ontario). Electronic Thesis and Dissertation Repository: http://ir.lib.uwo.ca/cgi/viewcontent.cgi?article=3857&context=etd

This thesis presents a critical analysis of the Google Art Project, one of the most prominent collections digitization projects of recent years. Google's partnership with hundreds of cultural institutions worldwide allows users free access to millions of paintings, sculptures, and other artifacts, as well as virtual gallery tours in the company's well-known "street view" style. While on the surface this open access appears to promote great possibilities of interactivity and access across cultural, generational, and economic borders, the author points out the flaws within the program. She argues that true interactivity and democratization of digital content is impossible when a major commercial corporation is behind a cultural project. This thesis also presents a literature review on the history of access, cultural democratization, and museum digitization narratives in the museum studies and media studies fields. Since my research explored how to move museums' relationship with technology forward into new areas, it was necessary to analyze what had been done in the past and how scholars have felt about it. This thesis was a valuable resource to me for its summary of differing viewpoints, as well as for its highlighting of shortcomings in a major virtual museum initiative.

Cairns, S., & Birchall, D. (2013). Curating the digital world: Past preconceptions, present problems, possible futures. In Proceedings of MW2013: Museums and the Web 2013, Annual conference. Retrieved from http://mw2013.museumsandtheweb.com/paper/curating-the-digital-world-past-preconceptions-present-problems-possible-futures/

This essay highlights the changing definition of "curation" in the digital age, and details the struggles museums face in adapting to new roles with their patrons. It explains that the internet's democratization of information has somewhat undermined the traditional authority of the museum, leading to new interpretations, and to increased exhibition and program input from the audience. Faced with the possibility of competing narratives and "experts," the authors argue that museums must adapt, either by opening up curation to multiple voices, or abandoning it entirely to focus on purposes like education and cultural participation instead. This essay is an interesting look at the growing pains museums face as they adapt to the digital age, and the unintended effects of open-access digital collections. As I explored the main purposes and motivations museums have in digitizing their collections, writings like these which highlight the advantages and disadvantages of the practice were essential.

Cameron, F., & Kenderdine, S. (2007). Theorizing digital cultural heritage: A critical discourse. Cambridge: MIT Press.

This text is a compilation of essays on the role of new technologies in the cultural heritage sector. Divided into three parts, the writings cover the changing role of museums in the digital age, the struggle of how to best utilize new technologies, and digital projects in the archaeological sector. Many of this book’s essays highlight the issue of technology developing more rapidly than traditional museology can define and conceptualize it. In particular, many of the contributors grapple with the trend of technology for aesthetically-appealing patron interactives. They argue that by focusing mainly on these types of projects, the potential for technology to increase scientific understanding, collections processes, and other elements of museum work is largely overlooked. Since this capstone specifically suggested new applications for technology in museums that would facilitate internal museum functions, this writing was valuable in contextualizing the ideas I had about enhancing the relationship between museums and technology.

Carmo, M., & Claudio, A. (2013). 3D virtual exhibitions. DESIDOC Journal Of Library & Information Technology, 33(3), 222-235.

After a brief history of virtual exhibit presentation on museum websites, this article showcases the more advanced concept of 3D virtual models of museum objects and exhibits. The authors note that in addition to tours from remote locations, museums can use these models to plan out new exhibit spaces, or to virtually showcase objects that are too fragile to display in reality. Different methods of creating a 3D model are also explored. This article was relevant to my capstone because it presents a history of how museums have utilized virtual reality technologies in the past. I drew from this source to summarize these uses, and then suggested new ones that would bring the technology beyond the conventional confines of gallery touchscreens and showcasing current exhibits in a web-friendly format. This article also details the concepts behind why museums use these technologies, which strongly supports arguments for their relevance.

Drap, P., Merad, D., Hijazi, B., Gaoua, L., Nawaf, M. M., Saccone, M., ... Castro, F. (2015). Underwater photogrammetry and object modeling: A case study of XlendiWreck in Malta. Sensors (14248220), *15*(12), 30351-30384. doi:10.3390/s151229802

This report showcases some of the greatest extents of photogrammetry for 3D modeling. It details a project in which a high-quality virtual map of an underwater shipwreck was created, simply through taking large quantities of pictures of the wreck from every angle. The authors also contrast the photogrammetric method against that of laser scanning, and explain some benefits of both processes for archaeological projects. These benefits include mapping a site without touching it and risking damage, and creating a model which can be sent to off-site experts who can then consult remotely. All of these benefits and potential uses were valuable considerations for my research. This case study was extremely useful in detailing how these technologies can be used for cultural purposes, and in showing their incredible accuracy even in modeling a nontraditional site with environmental deterrents.

Droitcour, B., & Smith, W. S. (2016). The digitized museum. Art In America, 104(9), 77-81.

This very recent article, published in October 2016, asks thought-provoking questions on the role of technology in museums. The authors manage to explore a full range of opinions in a short space, praising the ability of Google Cultural Institute to make far-away galleries accessible to people from all over the world, while at the same time questioning the true necessity and significance of gallery kiosks and similar features. The authors argue that by placing emphasis on technological additions to a gallery, museums are stating that the objects themselves are not as important. They also point out the tendency for these technological features to be viewed as merely superficial “fancy new things,” similar to the increase in building new wings and other extravagant but largely unnecessary additions to many museums. This article also discusses patrons’ growing desire to personalize their museum experience through the use of social media, selfies, and other similar methods, and highlights the lack of proper response museums have so far given this phenomena. For its thought-provoking musings on many different technology-centric issues in museums, this article has been extremely valuable in formulating my ideas for this project.

Fujii, Y., Fodde, E., Watanabe, K., & Murakami, K. (2009). Digital photogrammetry for the documentation of structural damage in earthen archaeological sites: The case of Ajina Tepa, Tajikistan. Engineering Geology, *105*, 124-133. doi:10.1016/j.enggeo.2008.11.012

This case study gives comprehensive information on how photogrammetry works, how it differs from laser scanning, and how the system can record structural defects that may be invisible to the naked eye. It also includes a brief history of photogrammetry and its uses in the past, revealing a much older practice than one would expect given its current digital associations. In actuality, photogrammetry has been a practice for over a century, originally used for creating stereo photos and topographical maps. This information provided useful background context for my paper. In addition, this source was also an additional example of an archaeological study using photogrammetry. The reports of how the technology can highlight structural defects was extremely useful for my research purposes.

Johnson, K. M., & Ouimet, W. B. (2014). Rediscovering the lost archaeological landscape of southern New England using airborne light detection and ranging (LiDAR). Journal Of Archaeological Science, 43, 9-20. doi:10.1016/j.jas.2013.12.004

This report focuses on light detection and ranging (LiDAR), also known as laser scanning, in contrast to several of the other reports listed here which focus on photogrammetry. The study highlights aerial terrain mapping, an activity where LiDAR can be argued as more effective than photogrammetry. This report explains that aerial LiDAR technology can reach through tree cover to pick up subtle differences in ground terrain, allowing surveyors to detect previously unexplored ruins of colonial-era and Native American civilizations. Though other research conducted for this capstone contradicts this study's claims that LiDAR is powerful enough to reach through forestry cover, the study is still useful in showing how this technology can be used to uncover hidden aspects of our past. A comparson of LiDAR-generated terrain photos to circa 17th-century maps is particularly interesting. This study, and my associated research into other opinions on LiDAR's capabilities, was a valuable resource in determining whether photogrammetry or LiDAR was the best method of generating digital models.

Johnson, R. A., & Solis, A. (2016). Using photogrammetry to interpret human action on Neolithic monument boulders in Ireland's Cavan Burren. Journal Of Archaeological Science: Reports, 8, 90-101. doi:10.1016/j.jasrep.2016.05.055

Another report which showcases photogrammetric applications in archaeological studies, this essay takes the technology's ability one step further by demonstrating how it can be used not only to model a site, but to manipulate it as well. This project involved the modeling of two separate boulders which both contained evidence of human tools and Neolithic drawings. The team members working on this project hypothesized that these boulders had at one point been one larger stone that was separated. By using the generated 3D models, the team simulated the movement of these boulders to test whether they would fit together. This case study shows that photogrammetry and 3D modeling can be particularly useful for situations where the movement or manipulation of an object would be unrealistic or could cause damage. Virtual manipulation is a zero-impact method of moving objects, and it could in theory have broader applications, such as simulating original appearances and uses of historic buildings. This report served as an important case study for my research.

Johnson, T. T. (2016). Let's get virtual: Examination of best practices to provide public access to digital versions of three-dimensional objects. Information Technology & Libraries, 35(2), 39-55.

This article examines five different museums' digital collections and evaluates how they are presented to the public on the institutions' websites. Through this evaluation, the report highlights how patrons interact with digital content, and gives guidelines on museum focus when providing digital access to patrons. It also examines and compares 3D scanning methods. Unlike other sources which vaguely hint at the costs of these different systems, however, this report includes a useful chart which clearly lists the average prices of laser scanning, photogrammetric, white light, and volumetric scanning equipment. This report was beneficial in augmenting the information about 3D scanning technologies I had acquired from other sources. It was also valuable as a theoretical study of the goals museums have in allowing patrons to view their collections online.

Kang, J., & Lee, I. (2016). 3D modeling of an indoor space using a rotating stereo frame camera system. International Archives Of The Photogrammetry, Remote Sensing And Spatial Information Sciences - ISPRS Archives, 41(23rd ISPRS Congress, Commission IV), 303-308. doi:10.5194/isprsarchives-XLI-B4-303-2016

This paper presents an interesting study in attempting to make photogrammetry more cost-effective for small projects and institutions. Most digital photogrammetry projects involve taking hundreds of pictures of a space from every possible angle, from which computer software locates "stereo pairs" of different parts of the structure and extrapolates geometrical data from them. The project showcased in this paper, however, involves placing one stereo camera onto a rotating frame. Since the use of a stereo camera ensures the presence of the stereo pairs that photogrammetric software needs, this system requires far less photographs than other methods, and is much more automated. However, with lower cost comes lower-quality results, and this study honestly accounts the multiple errors that resulted from this experiment. This study was a good resource in highlighting the limits of photogrammetry, as well as detailing low-cost options for projects where high-quality models and accurate dimensions are not imperative. Since the target audience for this capstone is cultural heritage institutions, many of them operating on small budgets, it was important to explore the benefits, drawbacks, and possibilities of these low-cost, "do-it-yourself" style photogrammetric projects.

Linder, W. (2009). Digital photogrammetry: A practical course. Berlin: Springer Berlin Heidelberg.

This textbook provides a step-by-step guide to photogrammetry, from its uses in the analog age to sophisticated software programs for 3D modeling. It explains photogrammetry, a complex scientific and mathematical practice, in very simple terms, greatly demystifying the process. It also gives useful information on the mathematical equations that go into measuring depth through stereo photography (though thankfully the use of digital modeling software removes most of the need to do these complex calculations). While the basic gist of the photogrammetric process can be derived from the other sources on this list, this textbook is essential as a detailed and easy-to-read guide to it. I relied on this text as a guide whenever I encountered a vague or confusing reference to a photogrammetric technique in the case studies I researched.

Shin, D. H., Park, J., Woo, S., & Jang, W. (2013). Representations for imagining the scene of non-existing buildings in an existing environment. Automation In Construction, 33(Augmented Reality in Architecture, Engineering, and Construction), 86-94. doi:10.1016/j.autcon.2012.09.013

This study is on mixed reality, wherein virtual elements are added into a digital representation of a landscape or building. Included in this report are the interesting results of an experiment conducted with design students, where one group was shown a mixed reality model of a real space with a digital object inserted into the scene, while the other was shown an entirely virtual representation of the same scene and object. Each group was then asked to determine the correct size and placement of the virtual object in the real room. The experiment showed that mixed reality was easier than virtual reality for visualizing objects and spatial layouts. As I researched the possibilities of virtual storage configuration, this study was an effective resource for arguing which technology would be most effective for this purpose. The report's descriptions of how digital environments and computer screens affect spatial perception were particularly helpful.

Wilsted, T. P. (2012). Renovating special collections facilities. Journal Of Library Administration, 52(3-4), 321-331. doi:10.1080/01930826.2012.684530

This article primarily discusses the renovation of special collections spaces in library settings. It goes into great detail on the considerations that an institution must take in renovating, including environmental and structural concerns. While it does not talk about the 3D modeling or virtual reality technologies I highlighted in this capstone, this report served as a valuable source of information on collections storage and related concerns. The issues that the article highlights in turn raised questions about how the technologies I explored could be used to solve them. For example, the report notes that floor loading weight is often a concern for library special collections, as the areas they occupy were often not originally intended for that type of storage. After reading this, I made sure to research the capabilities of photogrammetry to reveal structural defects. This report also notes the importance of working with special consultants when renovating a space, which made me realize the advantage that 3D modeling would have in such a scenario. This text was extremely helpful in connecting the technological concepts I was researching back to the core challenges of collections management that I have seen in my career.

B. Project Stakeholders

The key stakeholder in this project will be the Golden Gate National Recreation Area (GGNRA), a unit of the National Park Service. Specifically, this project aims to optimize an upcoming collections move for the Museum Program division of the GGNRA. The Museum Program and its staff are the primary stakeholders in this project. Also included in this group will be the contracted employee who is hired to work on the project. The Museum Program itself has a small staff of five permanent employees, though its operations effect the much larger GGNRA organization as well. The Museum Program receives an annual operating budget from the National Park Service, though this amount only covers the salaries for permanent staffmembers, supplies, and certain incidentals. Other funding, such as for specific projects like this one, must be obtained through grants. The grants process opens up this project to other stakeholders as well, which will be detailed in the next paragraph. The GGNRA is adherent to the mission statement of the National Park Service: to "[preserve] unimpaired the natural and cultural resources and values of the National Park System for the enjoyment, education, and inspiration of this and future generations" (National Park Service, 2016).

In order to secure funding for various projects throughout the GGNRA when government funding may not be available, the park has partnered with two other organizations, the Presidio Trust and the Golden Gate National Parks Conservancy. Both of these organizations are stakeholders in this project as well. The Presidio Trust was created by an act of the Federal Government in 1996 in order to lessen the burdens of the GGNRA in managing, caring for, and securing funding for its vast holdings. The Trust manages about eighty percent of the lands, activities and administration of the Presidio, the section of the GGNRA where the Museum Program is located. The project to relocate the Museum Program into another building within the Presidio has been a joint operation between the Presidio Trust and the National Park Service.

The Golden Gate National Parks Conservancy is a nonprofit organization created in 1981 to provide support and generate funding for the GGNRA. The Conservancy's mission is "to preserve the Golden Gate National Parks, enhance the park visitor experience, and build a community dedicated to conserving the parks for the future" (Golden Gate National Parks Conservancy, 2014) In addition to fundraising endeavors, the Conservancy is also greatly involved in restoration projects. The organization has been responsible for the rehabilitation of several trails and landscapes within the GGNRA, as well as the construction and renovation of visitor centers. Funding for Museum Program projects is secured through grants from the Parks Conservancy. All projects must be approved by the Conservancy and must meet certain goals before funding can be awarded.

C. Gantt Charts

The following Gantt Charts detail each phase of the proposed Collections Move Modeling Project, showing when tasks will be completed and how they will overlap to ensure that the project remains on schedule. GGNRA Museum Program staffmembers are assigned to various tasks, and are identified here either by their position titles, or by the initials for those titles (i.e. “RA” for Reference Archivist), or by “All Staff” when the entire Museum Program is involved. Tasks are color-coded for ease of reading.

Phase One

<table>
<tr><th>Task</th><th>Week 1</th><th>Week 2</th><th>Week 3</th><th>Week 4</th><th>Week 5</th><th>Week 6</th><th>Week 7</th><th>Week 8</th></tr>
<tr><td>Job Announcement for Project Contractor</td><td colspan="4">Supervisory Curator/Reference Archivist</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Contractor Selection & Interview Process</td><td></td><td colspan="3">Supervisory Curator/Reference Archivist</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Inventory of Objects to Move</td><td colspan="8">Reference Archivist/Museum Specialist</td></tr>
<tr><td>Correction of Errors in Object Records</td><td colspan="8">Reference Archivist/Museum Specialist</td></tr>
<tr><td>Contractor Orientation & Training On-Site</td><td></td><td></td><td></td><td></td><td colspan="2">All Staff</td><td></td><td></td></tr>
<tr><td>Training of Contractor in Photogrammetry</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="2">Contractor</td></tr>
<tr><td>Cleaning of New Building Rooms</td><td colspan="8">All Staff</td></tr>
<tr><td>Purchase of Necessary Equipment</td><td></td><td></td><td></td><td></td><td colspan="4">Supervisory Curator/Reference Archivist/Contractor</td></tr>
<tr><td>Purchase, Install & Test of Software</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Supervisory Curator/Reference Archivist/Contractor</td></tr>
<tr><td>Finalization of List of Objects to Move</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>MS/RA/Cont.</td></tr>
</table>

Phase Two

Task	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16
Test of Photogrammetry with One Room	Contractor							
Test Input of Photos into Software	Contractor							
Correction of Any Errors in Photos	Contractor							
Test Model of Room with Software		Contractor						
Check In/Progress Report		SC/RA/Contractor						
Photogrammetry of Remaining Rooms			Contractor					
Input of Remaining Room Photos			Contractor					
Correction of Any Errors in Photos			Contractor					
Modeling of All Remaining Rooms			Contractor					
Identifcation of Problem Areas in Building						Contractor/RA		
On-Spot Correction of Problems or Purchase of Equipment to Correct						All Staff		

Phase Three

Task	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25
Testing of Various Space Configurations with Models	All Staff								
Check-In/Progress Report	SC/RA/Contractor								
Survey of Staff Perceptions on Model Interaction		All Staff							
Selection of Most Efficient Space Configurations				Contractor					
Interaction with Most Efficient Configuration Models				All Staff					
Survey #2 on Staff Perceptions					All Staff				
Report on Storage Recommendations						Contractor			
Test Setup of One Room in Recommended Configuration							All Staff		
Final Report on Effectiveness of Model Use/Survey Findings									Contractor
Final Check-In and Future Recommendations									SC/RA/Contractor

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Abdelhameed, W. A. (2013). Virtual reality use in architectural design studios: A case of studying structure and construction. Procedia Computer Science, 25(2013 International Conference on Virtual and Augmented Reality in Education), 220-230. doi:10.1016/j.procs.2013.11.027

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Al-kheder, S., Al-shawabkeh, Y., & Haala, N. (2009). Developing a documentation system for desert palaces in Jordan using 3D laser scanning and digital photogrammetry. Journal Of Archaeological Science, 36, 537-546. doi:10.1016/j.jas.2008.10.009

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