Computer-Assisted Restoration

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Digital technology is changing the way we approach heritage preservation. The digitization of paintings, sculptures, architectural forms, early books, manuscripts, and archaeological evidence can provide scholars with new ways of looking at, discussing, and sharing these valuable objects and sites. An important application of digitization is within the field of computer-assisted—"virtual" or "digital"—restoration, a methodology that seeks to question the original appearance of a work of art or site without the need for physical intervention. In digital restoration, diverse forms of high-resolution data can be integrated with conservation records, philological notations, and historical source material using both image-processing and three-dimensional (3D) editing software, thereby addressing the idea of the "original object" by treating originality as a process that changes over time. If conservation is the "management of change," digital restoration allows us to study that change and understand the reasons an object looks as it does. This is leading to a renegotiation of the relationship between originality and authenticity: There are times when the digitally restored object may be the more authentic, more complete, and more easily understood than a heavily restored and transformed original.

An important aspect of digital restoration is that it allows restorers to rethink physical interventions and follow more cautious approaches when considering their course of action. They can test various propositions before a physical intervention is carried out on the original itself. The high-resolution composite photography and 3D data needed for digital restoration helps to inform decisions and actions. Historians and archaeologists can also employ computer-assisted restoration to visualize theories and investigate hypotheses about the original appearance and meaning of a work of art. The role of physical facsimiles in the field of digital restoration is changing the way objects are cared for—from their reinstallation in the original location to the reunification of objects separated for different reasons, the emphasis is moving away from the aesthetic display of discrete objects (and fragments of objects) to the awareness that all objects are embedded "things" with a career that reveals not only their original importance but also how they have been valued, appreciated, and understood at different times and in different places. By revealing the changing nature of originality and the decisions that are made during the restoration process, the general public is able to participate in the protection and preservation of the articulate evidence of the past. This approach is bringing art, science, and technology together in the quest for deeper understanding.

A significant role of high-resolution digital archives is in monitoring the condition of an object over time. They are objective records that document the condition of an object at a specific moment in time. This digital information can facilitate a detailed study of the original in case of accident, theft, natural disaster, or iconoclastic attack, or be used to track its condition through the stresses placed on the object by mass tourism. The "digital passport" provides objective evidence in the case of provenance and ownership disputes, insurance claims, and academic discussions.

Methodology of computer-assisted restoration

The methodology behind digital restoration is unique to the specific requirements of each project, although it is possible to loosely define a number of phases. Two case studies from the work of the Factum Foundation for Digital Technology in Conservation are used to illustrate the methodology of computer-assisted restoration.

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It is first necessary to define the parameters and scope of the digital restoration: What are the objectives? Is the final result virtual or physical? Is it for exhibition display or for the management of vulnerable or remote sites? Is it to reveal the changes an object had undergone? Is it to provide access to the object and reveal its importance? Is it for condition monitoring and to inform restoration decisions? The available materials will in part determine the course of action.

The initial steps involve obtaining color images and a geometrically accurate 3D model, which if possible also captures the subtle surface characteristics that condition our response to a work of art. It is important that the initial color recording is carried out at the highest possible resolution using composite photographic techniques such as panoramic photography, because the work to prepare and merge the image files—elimination of geometric/perspectival distortions and color management operations—reduces the resolution. The result of this step should be an image file that can be significantly enlarged with no loss of quality. All forms of mediation and transformation of the data result in an irretrievable loss and abstraction of information. It is therefore essential to retain both raw and processed files along with a complete history of the actions applied to the digital archive. The "transparency" of the image file will determine the value of a digital restoration, but also enhance the impact it can have as it informs diverse professional decisions.

The recording of 3D information is a relatively new and rapidly developing science. There currently exist a great variety of 3D scanners, each used to document a different aspect of an object or site. Light detection and ranging (LiDAR) scanners can be used to capture geometry quickly and accurately from distances of 1–300 m; white-light scanning technologies record both shape and surface texture from a range of between 0.5 and 1.5 m; and close-range laser scanning technologies can accurately record the surface of objects to submillimeter resolutions. Close- and long-range photogrammetry, a photographic technique to capture color and 3D information simultaneously, is relatively cheap to implement and rapidly replacing more traditional systems in heritage recording. It is currently the case that the resolution of photogrammetric data cannot match other close-range scanning technologies in either 3D or color resolution. However, recent developments in software and capture methods are enabling conservators and digital restorers to start using photogrammetry as a way to capture surface relief, allowing significantly reduced recording times.

Once data have been recorded and processed, they can be made available to a wide range of specialists in easily accessible forms that are independent of expensive specialist software. These data will inform physical restorations and facilitate research into previous states of conservation by comparing these data with conservation reports, historical images, or accounts of the work of art. Other useful supporting materials may include preliminary sketches, prints, and contemporary copies. If the work is fragmented, damaged, or missing parts, the work of digital restoration will also necessitate academic research. This research will involve the identification of different elements of the same object, obtaining recording permissions, and capturing all fragments at high resolution to ultimately create a virtual or physical archive that reintegrates these elements.

The practice of "digital restoration" can work on many levels. Cracks on the surface of a painting can be analyzed, studied, and removed. Such processes can sometimes be automated using algorithms provided by the software or specially written to reveal the specific physical characteristics that are being studied. Areas of information loss can often be refilled either by cloning surrounding data (when the loss is very small) or by relying on secondary sources when the loss is significant. It is possible to use complex computational, and mathematical methods in the reconstruction of 3D objects, for example, to locate the position of broken fragments. Digital restoration can be performed as an end in itself, a way to better understand the object, or it could inform the physical restoration of a fragmented object.

In all cases, the goal is objective clarity and any changes to the original surface or color need to be "marked" in one way or another. This can be by clearly defining layers within an image file or by using different chromatic codes, to signify

that they are not simply restorations of existing information. Most restoration techniques have an equivalent in the digital domain.

Case 1: The Polittico Griffoni: reuniting and studying a fragmented altarpiece

The *Polittico Griffoni* is an important altarpiece of the Bolognese renaissance painted between 1471 and 1472 by Francesco del Cossa and Ercole de' Roberti for the chapel of San Vincenzo Ferrer in the Basilica of San Petronio, Bologna (Polittico Griffoni). Commissioned by the Griffoni family, the altarpiece remained in San Petronio until the early eighteenth century when the chapel came into the possession of the Aldrovardi family. The *Polittico* was then dismembered and the individual paintings sold. The sixteen surviving panels can be found in nine different museums around the world, including the National Gallery (London), the Louvre (Paris), the National Gallery (Washington), and the Pinacoteca Vaticana (Rome).

The project to reunify the panels of the *Polittico* and restore a facsimile to the chapel of San Vincenzo in the Basilica of San Petronio is a digital restoration aimed at nurturing a deeper understanding of the altarpiece and the artists who painted the panels (Factum Foundation 2018a). The first phase of the work involved composite photography to capture color and a high-resolution 3D laser scanner to record the complex surface of each panel. The recording was carried out over a period of three years in seven different countries. In one case, the data were used to assist restorers during physical restoration—where two panels were recorded before and after the intervention to monitor and document the process. In each case, the custodian will own the data for all current and future commercial applications. In return for this clear statement of ownership, each custodian has agreed to share the data for conservation and study with the other institutions which own parts of the whole ensemble. A digital version of all the paintings recorded will be supplied to each museum (or collection).

For each panel, it is now possible to view color and 3D information together or separately, revealing things that cannot easily be identified with the naked eye. While this is leading to a clearer understanding of the reasons behind why each panel looks as it does, the most spectacular part of this "digital" restoration has been the production of a physical facsimile of each painting in its current condition. The individual paintings have been assembled based on new research into how the altarpiece looked when it was first installed in the Griffoni Chapel (Figure 1). The facsimile was installed in the Basilica, thus providing a new context for both the individual panels and the recently restored Griffoni Chapel, itself a historical reinterpretation by Bologna's controversial arts and crafts restorer Alfonso Rubbiani (1848–1913). "On-screen" visualizations may be presented in museums alongside the individual panels, informing discussion about the original design and context of the altarpiece.

Case 2: Wall paintings of the Sala Bologna: digital restoration of lacunae and damaged toponyms

The wall paintings of the Sala Bologna in the Vatican were commissioned by Pope Gregory XIII in 1575 and executed under the supervision of Lorenzo Sabatini. The western wall of the room is almost entirely occupied by a bird's-eye-view map of the province of Bologna. The initial aim of this project was to make a facsimile of this map for the Museo della Citta. However, the facsimile generated interest from the University of Bologna for a virtual reconstruction of the *Map of the province of Bologna*, which would interpret and reintegrate missing areas based on maps and drawings that were discovered in Bologna at the time and other historical research. The digitally restored map gives the viewer a clear and vivid idea of the original appearance of the wall painting. The work was a collaboration between the Factum Foundation and the Alma Mater Studiorum at the University of Bologna, which carried out much of the toponymical research required to "fill in" the missing areas (Factum Foundation 2018b).

The frescoes were initially photographed using a panoramic recording system. This provided the high-resolution color information required

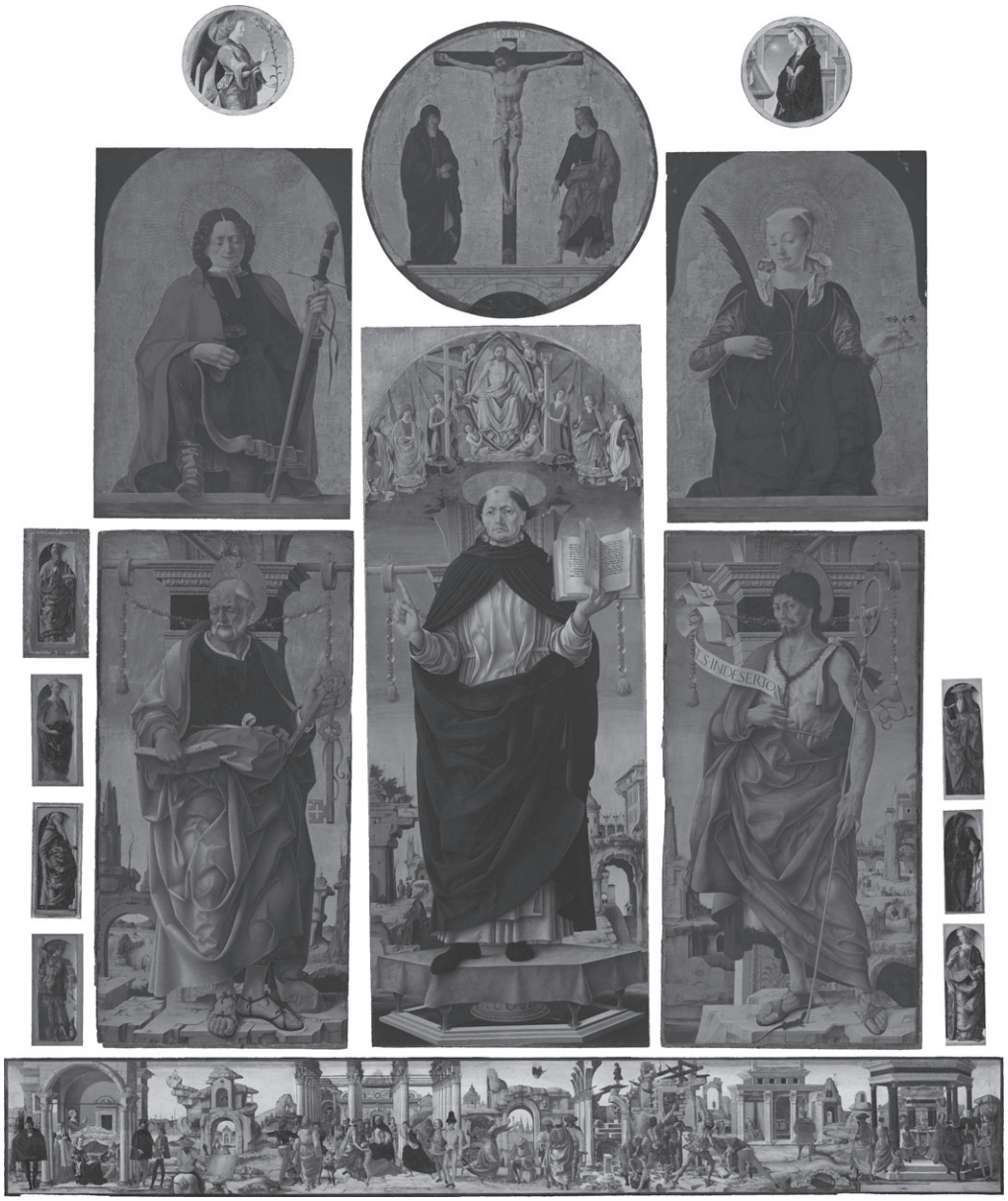

Figure 1 High-resolution color data for the sixteen surviving panels of the Polittico Griffoni as they might have been assembled in their original configuration.
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to produce the image files used in the digital restoration process. The next step involved removing or softening the damage and cracks in the paint—a process that was performed either manually or automatically depending on the type of crack and its location. This was followed by the reintegration of small losses in the landscape. Areas of the *Map* that retained abrasions and rubbings resulting in loss of information were digitally restored by employing both old and new

Figure 2 The castle of San Martino Manzuoli in the *Map of Bologna* before and after digital restoration. Source: Copyright Factum Foundation, published with permission.

maps to define the locations of buildings and different features within the various townscapes. It was possible to reconstruct a number of larger lacunae (up to 0.5 m^2) thanks to the existence of preliminary painted sketches. The castle of San Martino Manzuoli in Soverzano was reconstructed based on a drawing by Egnazio Danti, which contained sufficient detail to produce an accurate rendition of the missing section of fresco (Figure 2). The drawing was also used to recreate the castle grounds, although specific features were added based on written descriptions of gardens of the period. An interesting reintegration was carried out for a lacuna in the city of Bologna itself: By superimposing a contemporary map of the city over the image of the fresco, it was found that the missing area exactly corresponded with the Basilica di San Petronio. Adapting the design of the Basilica to the style of the map, the building was reconstructed and reintegrated into the representation of Bologna. Several areas that were found to have undergone previous physical restoration were digitally enhanced to "bring back" the appearance of the original. In the end, two versions of the *Map* were produced: one retaining the appearance of the restored areas, the other showing the *Map of Bologna* as it may have looked without historical restorations.

This project is an excellent example of the virtual integration of a number of different historical materials to produce a plausible non-contact reconstruction of the original appearance of a work of art. In the process of the virtual restoration, original research was carried out, leading to a deeper understanding of the *Map of Bologna* and the biography of its creation.

Conclusion

A new key concept in the digital age is "non-contact," and although the mantra of the conservation community used to be reversibility, this has recently come under pressure as both practitioners and the general public realize that it can be a relative concept at best and misleading at worst. Digital restoration can ensure that subjective and temporally located decisions are not imposed on original works of art. Moreover, it creates the space for detailed study to be carried out in tandem with restoration and conservation initiatives. Increasingly, digital recording technologies are also facilitating objective records that can be used to monitor change and ensure preservation is both collectively agreed and forensically sound. As exemplified by the case studies discussed above, digital restoration is emerging as a field that can lead to a deeper understanding of heritage and to the objective monitoring of physical interventions. It separates the necessity for subjective projections onto the original object from the desire to understand the original object more deeply. The relationships between originality and authenticity, facsimile, and the need to preserve works of art for future generations are very relevant topics in heritage management, particularly as the world's population rises above seven billion and more and more people have the means and desire to travel. Pressure is mounting

on heritage sites for a variety of reasons and visitors will need to understand that there is a delicate contract between providing access and the destruction of the articulate evidence of the past.

SEE ALSO: Adobe; Computer Applications in Archaeology; Digital Heritage; Digital Photogrammetry; Laser Scanning

REFERENCES

Factum Foundation. 2018a. Digital Restoration of the Map of Bologna. *Sala Bologna, Vatican's Apostolic Palace Private Quarters, 2012*, accessed February 7, 2018. http://www.factumfoundation.org/pag/217/-p-Digital-restoration-of-Sala-Bologna-39-s-map-p-.

Factum Foundation. 2018b. *Recording and Re-materializing the Griffoni Polyptych*. Digital Technology Applied to the Re-unification of a Scattered Altarpiece, accessed February 7, 2018. http://www.factumfoundation.org/pag/231/Griffoni-Polyptych.

FURTHER READINGS

Latour, Bruno, and Adam Lowe. 2011. "The Migration of the Aura, or How to Explore the Original through its Facsimile." In *The Miracle of Cana. The Originality of the Re-Production*, edited by Pasquale Gagliardi, 117–28. Venice: Fondazione Giorgio Cini onlos.

Lowe, Adam. 2016. "Tomb Recording: Epigraphy, Photography, Digital Imaging and 3D Surveys." In *The Oxford Handbook of the Valley of the Kings*, edited by Richard H. Wilkinson and Kent R. Weeks, 528–43. New York: Oxford University Press.