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The case of the golden background, a virtual restoration and a physical reconstruction of the medieval Crucifixion of the Lindau Master (c. 1425)

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Abstract

Cleaning and provisional restoration treatments on *The Crucifixion* (1425) revealed that the visible azurite layer obscures an originally golden background. This leads to the question of whether or not the azurite should be removed as it is not original, or should be kept as part of the panel's history. To overcome this dilemma, this paper presents a methodological solution of approaching this problem by combining the knowledge of art historians, restorers and by integrating modern 3D technologies before, during, and after the restoration. By creating a modifiable digital model, a virtual restoration can potentially attribute to analyzing and visualizing optical changes due to restoration treatments. Additionally, multiple 3D-printed facsimiles physicalize these adaptations. A facsimile's value is demonstrated by analyzing the diversity of meanings an artwork can have in terms of authenticity whilst respecting the artwork's material and social integrity. The 3D prints be decisive in the restoration of the panel.

Introduction – Blue or Gold, that's the question.

The Crucifixion of the Master of the Lamentation of Christ in Lindau (which is part of the collection of Museum Catharijneconvent) is an early fifteenth-century panel painting (Figure 1). It shows Christ on the Cross with Mary and St John the evangelist mourning his death. Four angels catch his blood in golden chalices. The painting has a blue background decorated with golden tendrils. The painter has added a layer of plaster on the panel in order to create depth in this panel. In this layer, the space between the tendrils was cut away thus leaving the figures, the cross, and the tendrils in a slightly higher relief that it currently has with the now visible dark blue colored background.

The painting was in a bad condition and has stayed in the museum depot for decades. Its paint was obscured with dirt and yellowed varnish. Furthermore, it contained many discolorations, darkened retouches, and overpaints. When it was taken out of the depot for the *Body Language* exhibition (2020) of the museum the work was cleaned and a provisional restoration was carried out by restorer Caroline van der Elst [Museum Catharijneconvent 2020].^[1] During this process, an interesting discovery was made. The currently visible blue background of the panel originally was golden: golden shining tendrils were placed on a gold field (the gold field was done in "*tremolierung*", small scales, applied with a gouge) (Figure 2.). The blue azurite layer that remains visible today is old. It probably dates from the late sixteenth or early seventeenth century, yet it was not the original intention of the Lindau master.

This leads to an important dilemma in the restoration of the painting. Should the blue layer be removed as it is not part of the original work? This would mean a large and irreversible intervention in the painting, which opposes the ethics of conservation practice. To prevent this, the dark blue layer can also be maintained. It was applied not long after the creation of the work and it is therefore part of the life story of the painting. The owner of the work decided to have it painted over, perhaps because of a change of taste or perhaps a bad condition of the golden *tremolierung*.^[2] To remove it, is to remove this layer of meaning, or to put it differently, to remove this important life event of the painting. Yet, by preserving the blue layer, it is not possible to experience the earliest version of the painting.

Traditionally, the golden background of medieval panel paintings is connected to the divine space. Wölfgang Schöne aptly called it "the echo of Paradise" (Schöne, 1954). Another vein of scholars led by Ernst Gombrich has stressed the importance of the materiality, or, in his words: the "thingness" of gold [Gombrich 1932]. The use of gold turned the average object into a precious material thing. Gold was a costly material, connected with other worlds via trading routes [Dunlop 2009]. The material could be manipulated – using techniques like punch work or the *tremolierung* that was used in the *Lindau Crucifixion* – in ways that wouldn't be possible using tempera. One could argue that panel paintings with a golden background, manipulated to play with the light, are objects that linger between a representation of Paradise and physical reality. As David Young King puts it, the gold ground connects the material and the immaterial, the worldly and otherworldly [Kim 2019]. The current version of the Lindau painting, with the blue obscuring the *tremolierung*, does not do justice to this pivotal role of the painting as the ambassador between the worldly and the divine both in materiality as in its symbolic meaning.

This report will not deliver the final answer to this complex question. However, we aim to propose a methodological solution that potentially can serve both sides of this discussion: a virtual restoration of the painting using a 3D scan and a 3D print of this restoration or the original work. In this project, for the first time, the virtual restoration of the work is presented as an argument that plays a role in the conservation process. Here we would like to share the steps we have taken so far and look into the future of this project.



Figure 1. Master of the Lamentation of Christ in Lindau, *The Crucifixion*, ca. 1425. Tempera on panel, 125 × 89 cm, Museum Catharijneconvent – Courtesy of Museum Catharijneconvent



Figure 2. Digital photo reconstruction where the azurite layer was removed and a golden background was added – Ruben Wiersma

Capturing the current state of *The Crucifixion*

The basis for the digital restoration of the Lindau Crucifixion was a 3D scan of the panel. To record the current state of the panel in terms of color and topography, the Lucida 3D Scanner was used [Factum Foundation 2021c]. This scanner was developed thanks to the collaboration between artist Manuel Franquelo and a team of professionals of different backgrounds (e.g. artists, architects, engineers, and software developers) from the Factum Foundation, a Spanish foundation specialized in digital recording of cultural heritage and in creating three dimensional facsimiles of recorded objects.^[3] The Lucida 3D Scanner is a close-range triangulation laser recording system. It provides a non-invasive method that documents the surface texture data of the artwork. The scanner projects a mechanically moving strip of red light onto the panel's surface. The relief and curvature of the panel's surface distort the light as it moves from left to right, completing scanning sections of about 48 x 48 cm. These deformations of the laser are captured by two cameras that are positioned 45° to the panel's surface *normal*. These cameras take black and white videos of the laser's trail, which are then processed as relief information into a grayscale depth map, using a geometric information system (GIS) and shaded render formats.

The combination of laser scanning and black and white video results in the capture of the panel's topography at a high resolution (up to 100µm).^[4] Furthermore, the scanner makes it possible to capture and unveil the topography of the panel without getting distorted and misled by its color or other material information. By relying upon the combination of laser and video information and the specific algorithms that were developed to interpret the video information, it becomes possible to scan highly reflective and glossy surfaces, such as the golden elements of the panel. This would not be possible when using a technology that solely relies on high-definition photography, such as photogrammetry or systems casting a fringe pattern. Furthermore, scanning the topography this way, it is easier to actually obtain more detailed data in deeper areas of the painting. With photographic methods relying on light sources, this information cannot be captured, meaning that the data of some of the depths relies on calculations rather than actual measurements.

A downside of this technology, in contrast to photographic methods, is the fact that the color information of the panel had to be recorded separately. This was done by using panoramic photography in combination with a two-direction lighting system. In contrast to "regular" parallel photography where each image is taken with its own view point, the panoramic method uses a single point from which the whole surface is recorded in smaller sections, arranged as a mosaic of rows and columns [Factum Foundation 2021d]. This makes recording fast (approximately one hour per 4 square meters, resulting in a file with a resolution of around 600 dpi) and efficient. Reflections are avoided by creating neutral lighting by using two strobe lights and the colors are balanced with the help of an X-rite color checker among other control methods. The separate color photographs (tiles) are automatically aligned and stitched into one full color map with PTGui. We store the geometry of the panel as a heightmap. This representation fits the surface of the panel, is lightweight, and allows users to process the data with image processing software, such as Photoshop. This way, the geometry and shading derived from the geometry can be blended with the color map.

The color information was combined with the heightmap that was recorded by the Lucida Scanner into the final 3D model. The Lucida's capacity of working with 3D information as grayscale depth map images, avoids the need of working with cloud points or polygon meshes. Combining color information with a 3D scan is much more efficient using a GIS map and the final model can be edited easily, making this a user-friendly method of 3D scanning (Figures. 3,4,5.).

Additionally, the digital model will be supplemented with data resulting from other types of material research that will be carried out during the conservation process of the painting (e.g. X-ray, ultraviolet, infra-red analyses) [Factum Foundation 2021a].



Figure 3. Color photograph – Made by Factum Foundation



Figure 4. 3D shaded heightmap – Made by Factum Foundation



Figure 5. Color and height combined Color photograph – Made by Factum Foundation

Processing the virtual reproduction

The 3D model of the painting was the basis of the virtual restoration of the work to its earlier state with the golden background. Not only the appearance (now blue, originally gold leaf) had to be restored, also the geometry (*tremolierung*) had to be adapted. The blue over paint has filled the *tremolierungs* lacunae, and made them less deep than they originally were.

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We created a virtual copy of the painting that could be rendered in real-time. The low-frequency geometry, such as the large-scale curvature of the panel, was mapped to a planar mesh with 16x16 quads. High frequency details were applied to the mesh with normal mapping, yielding a convincing virtual object suited for real-time applications [Blinn 1978].

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The panel was rendered using Blender's Eevee renderer for real-time rendering and Cycles for offline, ray-traced rendering.^[5] It can be transported to other programs and into VR and AR applications using a universal scene description file [Elkoura et al. 2019]. The appearance of the materials in the

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painting were modeled with a GGX-based principled BSDF, which allows the user to set material properties such as base color, metallicness, and roughness [Walter et al. 2007].

To virtually restore the object, we assigned both the appearance and geometry masked regions. Mask A is the set of all points that were originally painted with gold leaf and mask $B \subset A$ only contains the regions with *tremolierung*. These masks were created by selecting all pixels with a color within a certain distance to the color of a representative pixel in the *tremolierung* region and corrected manually.

The appearance for mask A was adjusted by setting the base color to an ochre yellow blended with imperfections modeled with Perlin noise [Perlin 2002]. The metallic property was set to 1 and roughness property to 0.6. All other regions were given the base color from the Factum scans, metallic property of 0 and roughness set to 0.4. The appearance was validated by the restorer of the painting Caroline van der Elst.

The geometry in mask B was adjusted to approximate a reconstruction of the *tremolierung* pattern. We opted for a simple intervention: scaling and offsetting the geometry, which is equivalent to increasing the contrast of the height map. This approximates the removal of a layer of paint. In future work, we aim to virtually recreate the *tremolierung* pattern using geometry processing techniques and to investigate the use of the virtual model to situate the piece in its original setting.

The 3D printed facsimile

Based on the previous explanation, it can be stated that 3D scanning the panel's materials will contribute to documenting highly detailed information about the artwork. Moreover, it digitalizes the panel in such a way that we can modify, manipulate and alter it to our own liking without having to alter the original work. This way, it becomes possible to visualize potential outcomes of future conservation treatments. In our case, we were able to reconstruct the original appearance of the painting, with the golden background.

Subsequently, this data can be translated into 3D printable data, which makes it possible to create an exact reproduction of the panel in various stages. In this research two versions will be made: one "as-is" with the blue background and one with the appearance (gold) and the geometry (*tremolierung*) texture restored. The first phase of the creation of an exact 3D replica, is making an elevated print (a technique developed by Canon Production Printing, Venlo).^[6] This technology uses computer data – the grayscale depth map – which is translated into a printable format. This digital information is combined with a 3D printing technique called material jetting, which involves hardening a material of choice (in our case polymer) by exposing it to ultraviolet (UV) light. This way, the panel's relief can be created by printing layer upon layer of plastic until the right height is reached. Elevated printing thus allows for a highly detailed reproduction of textures.

The second phase is the application of color. The polymer that is used in this process has a light gray color. To reconstruct the polychromy of the painting, it is possible to print the last layer in color. Additionally, layers of transparent ink can be added to achieve some glossiness on the surface. Although the developments in improving the quality of these 3D color prints are promising, there still are some limitations to overcome. One major issue is the quality of color. As this technology uses inkjet printing and the curing of photopolymers, the colors achieved are not complex and as a result of the heating process, the color can look grainy. Furthermore, the material is very stiff, which results in an artificial "feel" of the reproduction.

The aim of this project is an exact 3D replica of the painting in its current, and in its restored state. The current quality of the inkjet printing does not yet meet our demands for this project.^[7] To overcome these issues our partner Factum Foundation has found a solution. The elevated printing is used to create the topography of the painting. This is done by using the uncolored elevated print as a positive to create a mold. This mold is then used as a negative, for another positive that consists of a silicon solution, a more flexible material. This monochrome silicon "print" is a basis on which a separately printed two dimensional high quality color image of the artwork is attached. Lastly, to make the material appearance more convincing, paramount features of the artwork's material appearance (e.g. glossiness, varnish) are added manually. In the case of the Lindau *Crucifixion*, the background of the two facsimiles will be gilded manually.

The meaning of material

The creation of exact reproductions using elevated printing generates the opportunity of visualizing and physicalizing the potential effects of decisions made and treatments done during the restoration process. It allows us to think about the way this 3D print could provide a solution to the important dilemma in the restoration of the painting and whether or not the blue layer be removed as it is not part of the original work. Could the 3D print help in understanding and discussing the complexities of this discussion within the field of art restoration. Additional questions that automatically come to mind are: What this type of reproduction means to the original panel? In what way does this second physical manifestation of the panel (in its current blue and its earlier golden state) contribute to the understanding of the original artwork? How does 3D printing a panel affect the value of the original? Could the 3D print potentially have its own value at some point?

The authenticity of art and the role of facsimiles – which are everything but original, and are often considered as anti-authentic – has been a heated topic of debate ever since German sociologist Walter Benjamin [Benjamin 1936] described how reproduction (in his case photography) changes artworks' historic value – in Benjamin's words: "aura" – into one of exhibition value [Benjamin 1936]. It has lost its artistic relevance and connections to the past. Contemporary Western society has been highly fixated on the "magical" encounter with the physical original artwork. Nowadays, art reproductions are omnipresent (e.g. on mobile devices and posters). The discussion that Benjamin started has gained momentum and still continues to grow ([Jones 2010]; [Latour and Lowe 2011]; [Tissen 2020]; [Malik, Tissen, and Vermeeren 2021]; [Di Giuseppantonio Di Franco, Galeazzi, and Vassallo 2018]). There has been an increase in theorists specifically examining the moral and ethical implications of art reproduction. A reason for this might be the rapid development of advanced reproduction technologies such as 3D printing. In today's world of "fake news", not knowing what to believe and where to find the truth when information is at our disposal at any time and any place, the material qualities of original artworks, carefully guarded in the museum seem to be the one of the only sources that can validate an artwork – the survivor of the passage of time – as genuine. Consequently, in conservation practice this has resulted in the prevalent goal to keep and conserve as much of the artworks' material features as possible in their current state – thus including *patina*, cracks, losses and other material traces of time – for generations to come. This means that any form of treatment should be done in favor of its original materials and implies that treatment should be reversible, in the case that better conservation methods are discovered and can be applied.

With this information in mind, how can a 3D print, a visually indistinguishable copy yet one without the material features of the artwork itself, mean something to the original artwork? In the case of the Lindau *Crucifixion*, it is precisely the materiality of the artwork that poses the dilemma. As previously described, the biggest issue we are currently facing during the restoration of the panel is the decision regarding the appearance of its background. During a seminar *The digital reconstruction of the crucifixion of the Lindau master (ca. 1425)* (held on the 9th of June 2021 at Museum

Catharijneconvent (Utrecht)) we presented this dilemma to a group of professionals from different backgrounds (curators, restorers, (technical) art historians, and art scholars) and the online participants [Tissen 2021].

3D scanning the panel's materials and the possibility to 3D print exact reproductions generate the opportunity of visualizing and physicalizing the potential effects of decisions made and treatments done during the restoration process in two ways. Firstly, by using the 3D print, the blue background can be documented and physicalized before it would be lost, due to an irreversible restoration of the painting's background to the earlier version. Secondly, when the decision would be made to maintain the blue azurite layer, the 3D print could be used to show a reconstruction of the painting to the primary version without the azurite blue layer that is currently covering the golden background. We asked the participants whether or not the azurite blue should be removed and what role a 3D print of the panel could function as a solution for this issue. Here, when proposing these options, in the discussion it soon became evident that the panel's value cannot be solely attributed to its material qualities. In this report we would like to reflect on two arguments considering the "authenticity" of the 3D print that came up during the discussion.

The first important aspect of authenticity mentioned was the intention of the artist, which is oftentimes a highly valued quality [Martens 2010]. In the case of the panel, the Master of Lindau himself initially decided to fully gild the panel's background. When this intention is considered of utmost importance, this would imply that the 3D print with the reconstruction of this "original" background with the gold leaf in itself could be considered more valuable than the panel in its current state, with the blue. The latter does not visually simulate what the Master would have intended, and thus one could argue that the 3D printed reconstruction of the golden background is closer to the artist's original intentions than the panel in its current state, thus more significant in terms of authenticity.

Furthermore, another participant mentioned, what should be remembered when looking at original artworks (or at their facsimiles), is that the artwork's current state is just a snapshot of a single moment in time. Artworks have their own lifecycle which spans over decades if not centuries, not only in their material composition but also in their function, communal and social value. Their conceptual value is not set in stone, it changes over time. This way, an artwork knows many "faces" or "identities". With the help of conservation methods, it can be decided to freeze the panel's material appearance. But this does not do justice to the lifecycle of the artwork. An example of how reconstructions can help to demonstrate this lifecycle is the recently revealed reconstruction of missing parts of Rembrandt van Rijn's *The Night Watch* at the Rijksmuseum (Amsterdam) [Rijksmuseum 2021]. For centuries the public has looked at a mutilated version of this painting. In the case of the Night Watch, the reconstruction has revealed an earlier, lost identity of the art work.

Both arguments show that reproductions of artworks and especially the high-quality 3D printed facsimiles can contribute to visualizing and physicalizing the elements that contribute to the diversity of identities one artwork can have. The authenticity of *The Crucifixion* is not static and solely based on the original panel's unique materials alone. In contrast, the discussions during the symposium showed that the panel's authenticity is considered diverse, it changes over time and it can be attributed to many different elements (e.g. the intention of the artist and changes in materiality). Reproductions of artworks and especially the high-quality 3D printed facsimiles can contribute to visualizing and physicalizing the elements that contribute to the diversity of values, "authenticities", and identities one artwork can have, such as its artistic and conceptual value to name a few [Latour and Lowe 2011]. As the original artwork can only represent one specific moment in time due to its unique material, 3D printed reproductions can be used in addition to the original artwork to express its life cycle and multiplicity of values.

The question that arises in this case and which we hope to solve using the 3D prints, is which version will be considered to be more genuine or "authentic": would this be to present the painting in its current state, conserving its materials the way it looks today and by considering the blue layer as a part of its history? Or to irreversibly remove the azurite layer, but coming closer to the way the Master would have wanted the panel to look and in a way more similar to the way the artwork was experienced during the Middle Ages? This relates to the question if the availability of a high quality facsimile of one over these versions will play a role in the conservation process? How will the restoration committee weigh the availability of both versions in their decision on what conservation treatment will be applied to the panel?

Discussion

Within this research, we want to use a 3D facsimile to see whether visualizing a past state of an artwork can help to get a better understanding of the material changes an artwork goes through, which might aid the final restoration of the original. Although it is a high-quality reproduction based on detailed 3D data and extensive material research opting to be as scientifically close to the original painting as possible, it is important to realize that a facsimile will and can never be identical to a previous state of the artwork. For this reason, it is essential to pinpoint where the differences lie. First and foremost, a synthetic 3D print is different in terms of materials and could therefore never provide an exact and accurate model of the panel in a previous state.

Furthermore, although the way the facsimile looks is partly based on accurate measurements, it will always be a "best guess". However, the same can be said in the case of the actual restoration of the original for the interpretation of the past is always subjective and place and time dependent [Stols-Witlox 2021]. Consequently, both the 3D prints as well as the original represent the object in a specific moment in time: one 3D print will show the artwork before the restoration; one 3D print will show a reconstructed version of what we think the artwork must have looked like in 1425; the painting itself will show a restored version of the panel. Although the facsimiles make it possible to visualize multiple stages of the artwork's lifecycle, it simultaneously "freezes" them in time. Subsequently, all three "time-freezes" will impact the way the artwork will be perceived and interpreted for the years to come. For this reason, similarly to the actual restoration, the way the 3D reconstructed version looks must be carefully discussed. For instance, one could question that if the background would be reconstructed to a "pristine" state, should the figurines and the tendrils be reconstructed as well? Or since the figurines and the tendrils are weathered, to what extent should the golden background be adjusted? Simultaneously, the same kinds of questions can be asked in terms of storytelling and explaining the context in which this artwork was made. Do we know how the artwork was used and how it was displayed?

Yet, we want to emphasize that although the 3D print might not be exactly accurate to the original's current or past state, it meets the inquiry central to this research project [Fors, Principe, and Sibum 2016]. Furthermore, we believe that using reproduction and visual reconstructions could be greatly beneficial to get a better and more life-like idea of how the artist and his contemporaries must have experienced the artwork. This way, not only researchers and conservators can understand the inquiries central to the conservation of art, but also the public can get an insight in the difficulties of restoring this panel.

Future works

Currently, after recording the panel's colors and topography, we are aiming to continue this research by processing the data. By researching the artwork's materials (e.g. using dendrological research, IRR, MA-XRF scanning), damages, art historical past, and by relying on the knowledge of the

restorer, we will analyze the digital model on its accuracy. This way, we can combine the digital data gathered by Factum Foundation with the knowledge of the professionals involved in the conservation to come to a digital model which most accurately presents the current and past state of the panel. We aim to explore how we can combine different modalities to learn more about the materials and stratigraphy of the panel. This could be used to study the effect of changes in material composition.

Consequently, multiple printed facsimiles of the artwork will be made to see the physical effects of digital changes made to the materials. Two 3D prints will be made by Factum Foundation in collaboration with the restorer of the painting, Caroline van der Elst. She will be involved with the digital restoration and will check the facsimiles to make the final material appearance correspond to what the panel originally must have looked like. Additionally, in collaboration with Canon Production Printing, we will try to create a third 3D printed facsimile without the post-printed craftsmanship (the retouchings of the restorer). This way, we aim to analyze both the digital model as well as the 3D printing technology's ability to correctly reconstruct the material appearance of the panel. The 3D prints will be useful in communicating the dilemma to a larger audience (of both professionals and non-professionals) and will help in making the multifaceted authenticity of the artwork more clear during a potential exhibition about this project. Additionally, perception research done during this event and using the 3D prints will provide insight into the perception of the artwork and the potential effects of removing the background.

The two accurate 3D prints of Factum Foundation of both versions of the painting also allow the investigation of the perception of the artwork. An eye tracking experiment will be conducted to analyze the viewing experience of the visitor, regarding the two versions of the artwork. The eye tracking research will be combined with the think aloud-method, in which raw eye-tracking data is supported with qualitative data based on the conversations of the participants. We will focus on the effect of the light source (stable / unstable) on the perception of both versions of the painting. A hypothetical difference in perception is the appearance of the blood of Christ in the painting. Using an unstable light source (e.g. flickering candle-light), the contrast between the shine of the full golden background and the matte red tempera used for the blood could mean a better visibility and thus a stronger symbolic presence, in comparison to the current blue background. The perception research using the 3D prints will provide insight in the perception of the artwork and the potential effects of removing the background. This, together with the high quality of the reproductions, will be highly important for the final restoration of *The Crucifixion*.

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Notes

[1] The authors would like to thank Dr. Micha Leeftang, Caroline van der Eyck and Carlos Bayod for their valuable input in this research project.

[2] The question why the painting was overpainted is part of the ongoing conservation process.

[3] Since 2011, the Factum Foundation has been using this scanner to record the surface topography of 200+ paintings and cultural heritage objects with low relief surfaces all over the world (e.g. the tombs of the Valley of the Kings in Luxor and Michelangelo's Epiphany at the British Museum) [Factum Foundation 2021e].

[4] Factum Foundation, 2021. *Lucida 3D scanner*, https://www.factumfoundation.org/pag_fa/1478/lucida-3d-scanner. Accessed 09 September 2021.

[5] Blender Community. 2018. *Blender – a 3D modeling and rendering package*. Stichting Blender Foundation, Amsterdam. (Retrieved from <http://www.blender.org> 20 March 2022)

[6] 3D printing (or additive manufacturing (AM)) is a technique that uses digital computer information to rapidly create a physical three-dimensional object. This digital design can either be acquired by scanning an existing object or by constructing a shape from scratch. The physicalization of the digital model can be done using various methods, but this process is either additive (printing layers upon layers of photosensitive filament) or subtractive (by gradually removing materials until the desired design has been achieved).

[7] Although currently, 3D printing is not yet up to par with the requirements of art historians and restorers working with these reproductions, the developments of the technology are promising. Thanks to the work of Clemens Weijkamp, it will be a matter of time before the creation of high quality reproductions of artworks with mixed materials are possible without any manual labor.

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