12-2023

Use of AI to Recreate and Repatriate Lost, Destroyed or Stolen Paintings: The 1785 Parisian Salon Case Study

Charles E. O'Brien

James Hutson

Trent Olsen

Jay Ratican

Use of AI to Recreate and Repatriate Lost, Destroyed or Stolen Paintings: The 1785 Parisian Salon Case Study

C. O'Brien[1], J. Hutson[2*], T. Olsen[3], J. Ratican[4]

[1] Department of Art and Art History, University of Alabama in Huntsville, USA
[2*,3,4] College of Arts and Humanities Lindenwood University, USA

***Email:** JHutson@lindenwood.edu

Received: *30 November 2023;* ***Accepted:*** *9 December 2023;* ***Published:*** *12 December 2023*

Abstract This study investigates the efficacy of artificial intelligence (AI) in the field of artwork restoration, focusing on lost, stolen, or destroyed artworks. Employing a dual approach that combines traditional manual restoration techniques with advanced generative AI tools, the research centers on a case study of the 1785 Parisian Salon. It specifically examines the reconstitution of Antoine François Callet's painting, *Achilles Dragging the Body of Hector*, unveiled alongside Jacques-Louis David's *Oath of the Horatii*. The study utilizes Easy Diffusion and Stable Diffusion 2.1 technologies for inpainting and colorization processes. These AI tools are employed in concert with manual restoration practices to recreate the Callet painting. The methodology also includes the use of secondary visual materials, such as Pietro Martini's 1785 engraving of the Salon Carré, to inform the AI's trained dataset. The application of generative AI in this context significantly accelerates the restoration process. However, the study identifies a critical issue where successive AI-based inpainting iterations lead to a degradation in color fidelity and detail precision. This degradation is evidenced by the emergence of unintended artifacts and a loss of visual coherence in the restored images. While AI significantly expedites the artwork restoration process, its integration with manual techniques is crucial to mitigate the loss of artistic detail and color accuracy. The study's findings emphasize the need for a balanced approach that leverages the strengths of both AI and traditional restoration methods. This integrative strategy is essential for preserving the original artistic essence of artworks, contributing significantly to the fields of art restoration and digital humanities.

Keywords: artwork restoration, digital restoration, conservation, generative AI, stable diffusion

1. Introduction

Developments in digital technologies have fundamentally altered the landscape of cultural heritage preservation, inaugurating novel methods for recreating ancient cities through three-dimensional modeling and digitally reconstructing interior architectural spaces (Tzortzaki, 2001; Gabellone, 2022). Virtual environments and early iterations of digital twins have endowed both scholars and the general populace with unprecedented tools for scrutinizing heritage sites and artifacts (Hutson & Olsen, 2021; Stanco, Battiato, & Gallo, 2011). Particularly commendable is the role played by 3D scanners and photogrammetry technologies in generating meticulous representations of art collections, exemplified by the digitization of the

Uffizi Galleries extensive sculpture repository (Brennan & Christiansen, 2018). These digital reproductions serve not only as assets for scholarly research but also function as invaluable resources for real-time conservation monitoring, thus aiding in the proactive prevention of the artifacts' decay (Lei et al., 2021; Ni et al., 2022).

While the aforementioned technologies constituted early foci in the adoption curve of digital tools for cultural heritage, more recent strides in the development of generative Artificial Intelligence herald a new paradigm. These innovative methodologies exhibit an expansive capability for the rapid reconstitution of damaged or lost works of art (Baduge et al., 2022). Handheld scanning devices, coupled with cutting-edge rendering engines, have made the production of high-fidelity digital assets not only feasible but also remarkably efficient (Kurtha & Balzanb, 2022; Barrile et al., 2022). It is against the backdrop of these technological advancements that the present research seeks to investigate the potentialities and constraints associated with the amalgamation of generative AI tools and traditional restoration techniques. The inquiry aims to broaden existing methodologies while concurrently stimulating critical discourse on the ethical and aesthetic dimensions inherent to these hybrid restoration endeavors.

Fundamental to digital humanities research on historical interiors are key characteristics such as spatial structuring, object placement, acoustical considerations, and the role of musical practices within a specific space. These elements become tangible and analyzable through advanced technologies like photogrammetric scanning and game engine rendering, which offer not only precise measurements but also high-definition visualization and immersive experiential platforms. The project centered on the 1785 Parisian Salon serves as an illustrative example of how these methodologies can be employed. This endeavor aims to digitally resurrect a pivotal pre-revolutionary art exhibition, replete with period-accurate figures and attire. Extensive archival research and precise onsite measurements provide the foundation for this intricate recreation.

Nevertheless, the deployment of 3D modeling in elucidating historical contexts is not devoid of challenges. Such methodologies necessarily encompass assumptions and uncertainties, particularly when historical data are mediated through subjective lenses. Paintings, engravings, and textual accounts—each conveys the idiosyncrasies of individual perspectives and interpretations. Researchers focusing on the 1785 Salon, for instance, had to grapple with incomplete or conflicting blueprints and written descriptions. Assumptions about architectural elements, such as the staircase, had to be made to fill in gaps that were not consistently rendered across available historical materials.

Despite these limitations, the utility of 3D modeling in enriching the understanding of historical interiors remains indubitable. It significantly augments knowledge pertaining to craftsmanship, material culture, and spatial aesthetics. The endeavors to recreate the 1785 Salon not only illuminate the intricacies of one of the most pivotal artistic gatherings of its time but also exemplify the rich potentialities and constraints inherent in the technological tools available to modern scholars. Thus, the context of the 1785 Parisian Salon serves as an ideal locus for examining the complexities and considerations involved in employing generative AI alongside traditional restoration techniques in the realm of cultural heritage preservation.

As such, the study at hand seeks to elucidate a potential new workflow that integrates generative AI technologies into the realm of cultural heritage preservation. Far from merely capturing or replicating extant works of art, the research aspires to a loftier objective: the effective reconstitution of artworks that have either deteriorated or vanished altogether. Employ-

ing a rigorous analytical framework, the study aims to dissect the limitations inherent to prevailing digital restoration methodologies. Such scrutiny is envisioned to offer invaluable insights into the deployment of AI tools for enhanced fidelity and accuracy in restoration efforts. The anticipated result of this integrative approach is multifaceted. On one hand, the merger of AI with traditional restoration techniques holds the promise of expediting the restoration process, thereby providing a timely solution to the enduring challenges plaguing digital historical interior reconstructions and art restorations. On the other hand, this synergistic alignment invites a profound reevaluation of ethical, aesthetic, and hermeneutical considerations that invariably accompany the preservation and representation of cultural heritage.

2. Methodology

The employment of three-dimensional modeling for the explication and analytical examination of cultural heritage artifacts holds considerable promise, particularly in augmenting our comprehension of historical interiors (**Table 1**). The research at hand harnesses Unreal Engine 5 (UE5) by Epic Games to reconstruct the Salon of 1785, an exhibition that showcased an array of over 300 paintings and sculptures. Several pivotal research questions are being investigated, such as: (1) the role of 3D modeling in archiving and preserving the existing and erstwhile states of historical artworks; (2) the scope of assumptions and uncertainties integrated into the modeling process; (3) the insights that 3D modeling could offer concerning the artisanal qualities of historical interiors; and (4) the methodologies for systematically amassing and scientifically evaluating knowledge gleaned from these 3D reconstructions.

Table 1. Flow Chart for Digital Restoration

No	Step	Description
1	Selection of Artworks	Identification and selection of the case study: Antoine François Callet's painting, Achilles Dragging the Body of Hector, from the 1785 Parisian Salon.
2	Review of Traditional Techniques	Analysis of traditional manual restoration techniques relevant to the selected artwork.
3	Integration of AI Tools	Incorporation of AI technologies (Easy Diffusion and Stable Diffusion 2.1) for digital inpainting and colorization.
4	Secondary Material Analysis	Examination of secondary materials, such as Pietro Martini's 1785 engraving, to inform the AI's training dataset.
5	AI-Assisted Restoration Process	Application of AI tools in restoring the painting, alongside manual techniques.
6	Quality Assessment	Evaluation of restored image quality, focusing on color fidelity and detail precision.
7	Identification of Limitations	Identification of limitations in the AI restoration process, particularly in 'inpainting' iterations leading to image degradation.
8	Comparative Analysis	Comparison with existing research and methodologies, such as those out-lined by Xiaoli Yu et al. (2021).
9	Proposal for Future Research	Proposing new research avenues, such as the "Reconstituting Period Materialities for the Period Eye" subfield.
10	Final Conclusions	Drawing final conclusions about the efficacy of integrating AI with manual restoration, and its implications for the field of art conservation and digital humanities.

UE5, an engine increasingly adopted for game development and simulation, presents several advantages pertinent to the research project, including user-friendliness, accessibility, and an expansive online community of users and developers. Of note is the engine's visual scripting language, known as Blueprints, which has garnered praise for its ease of use. The release of UE5's Version 5.0 in April 2022 introduced innovative functionalities, such as Nanite technology for efficient object resource management and Lumin for enhanced natural lighting, thus augmenting its performance in virtual reality contexts. Furthermore, through a collaboration with Quixel, Epic Games has facilitated the availability of high-resolution (8K) textural materials, which serve as invaluable assets for rendering the Salon's interior. The subsequent discourse shall delve into the methodological intricacies involved in employing UE5 for the 3D modeling of the Salon of 1785, concurrently addressing the research questions posited earlier.

A pivotal initial endeavor in the construction of a virtual Salon consisted in ascertaining the appropriate spatial scale for the virtual reality environment (**Figure 1**). For this purpose, a physical measurement of 172 cm (approximately 5.64 feet) was obtained between Oculus controllers, which was then transposed onto the virtual canvas by situating two objects at corresponding locations while utilizing the VR headset. Following this, a ruler of equivalent dimensions was crafted for use as a reference in virtual space. To replicate the dimensions of the Salon Carré with precision, historical architectural plans of the Louvre were consulted. According to these blueprints, the Salon encompassed a length of 22.86 meters, a width of 12.8 meters, and a height of 14 meters from the center of the room to the ceiling. Notably, engravings illustrate ceilings of a curved nature, subsequently embellished with elaborate sculptures and a central skylight—a hallmark of the extant Salon Carré. Such data served as an empirical bedrock for the development of a historically accurate and realistic three-dimensional portrayal of the Salon's spatial configuration.

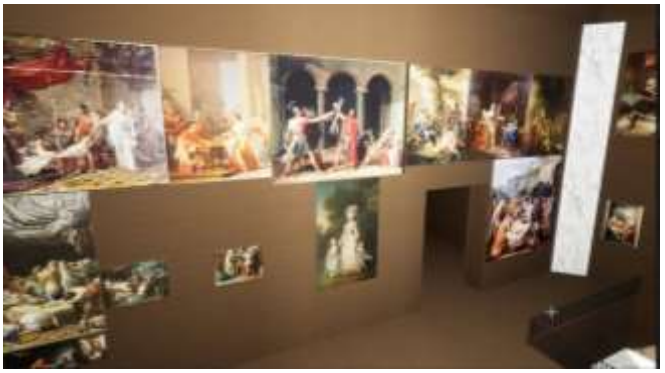

Figure 1. Charles O'Brien, Salon Carré with Reconstructed Staircase and Repatriated Paintings, Salon 1785 Project, Unreal Engine 5, 2022, The College of Arts and Humanities, Lindenwood University, Saint Charles, MO, USA

The foundational framework and proportional schematics of the simulated environment were configured utilizing Unreal Engine 5's geometry builder. In contrast to more intricate modeling apparatuses such as Maya or Blender, this approach afforded greater simplicity. Calibration was achieved by adjusting the geometry builder in accordance with a pre-established 172 cm ruler. Consequently, objects could be rendered at 92% scale, facilitating brush settings that directly converted to centimeters. As an exemplification, Louis-Jean-François Lagrenée's painting, Mort de la femme de Darius, was accurately resized within the virtual confines by stipulating specific x and y values corresponding to its original dimensions.

To supplement the structural data gleaned from historical blueprints, 18th-century engravings and paintings served as invaluable repositories of spatial information. The research considered fluctuating portrayals of architectural elements such as staircases and windows. For instance, historical narratives from the 1800s specify that the Salon Carré was an adjunct to the Galerie d'Apollon, with its windows overlooking the Seine River. Based on this understanding, the research posits Chereau's engraving as the most reliable representation of the staircase's location, thereby inferring the orientation and placement of doors and windows. The livret, an exhibition brochure, furnishes a meticulous inventory of paintings along with their respective dimensions (Guiffrey, 1870). In conjunction with Pietro Martini's engraving, 24 works of art were precisely identified and positioned within the virtual space. Textural images for these artworks were procured online and employed as foundational files. Subsequent adjustments were executed to harmonize the scale of these virtual paintings with their historical dimensions.

VR technology, although nascent, has witnessed a burgeoning corpus of literature concerning texture optimization (Tricart, 2017). The study implemented 8K resolution images, secured via the Quixel Megascans Bridge Plugin, to texture expansive objects within the virtual milieu. Examples include the rendition of an "Old Wooden Floor," Magny limestone, and 18th-century arabescato marble. Following the formulation and integration of base textures, a spectrum of best practices was deployed to optimize these materials for VR application. Illumination within the simulated environment adhered to methodologies delineated by Scorpio et al. (2022), albeit with nuanced adjustments. Specifically, Unreal Engine 5's Lumen was utilized as the engine's dynamic global illumination method. A comparison was also conducted between Lumen and the beta version of screen space methods for post-process illumination. Additionally, specific lens flare effects were subtly incorporated to emulate authentic sun glare through windows. Overall, the meticulous efforts in calibration, texture optimization, and lighting not only contribute to the verisimilitude of the simulated Salon of 1785 but also advance the larger academic discourse on the applications and limitations of 3D modeling in the study of historical interiors. This endeavor serves as a compelling case study for how emerging technologies can complement traditional methodologies in the pursuit of historical understanding.

For the objectives of the current inquiry, a painting entitled Achilles Dragging Hector's Body past the Walls of Troy, created during 1784-1785 by Antoine François Callet (1741–1823), was selected as the focus of the restoration endeavor (**Figure 2**). The painting's original form is corroborated by a panoramic engraving executed by Pietro Antonio Martini (1738–1797) for the 1785 Salon (Figure 5). The portion of the painting earmarked for experimental restoration centers around a celestial or infernal female figure situated in the top right corner. This figure is depicted with outstretched wings and is brandishing either a dagger or an athame. The rationale for choosing this specific segment lies in the juxtaposition of its predominantly preserved state against a background of significant degradation.

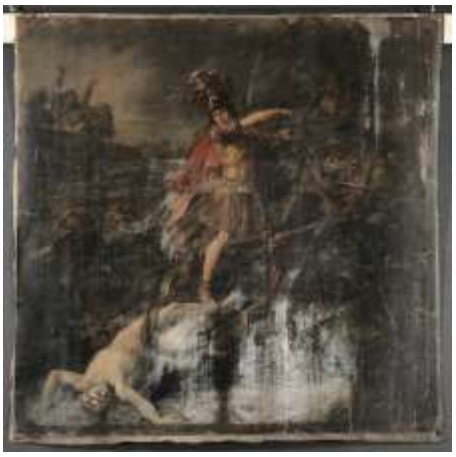

Figure 2. Antoine François Callet, Achilles Dragging Hector's Body past the Walls of Troy (1784-1785), Louvre, Paris

The focused preservation of this singular figure within the larger canvas offers a compelling case study for the application of artificial intelligence in the restoration of historical artworks. Such a focused approach enables a rigorous examination of the AI's capability in handling complexities in color, texture, and form within a constrained spatial domain. Furthermore, it invites nuanced discussion around the interpretative choices made by the algorithm—choices that bear ramifications for the understanding of not only the artwork itself but also the historical and cultural contexts in which it is situated. Therefore, this selection serves not just as an exercise in technological capability, but also as a touchstone for ethical and epistemological debates in the field of art restoration and historical interpretation.

The restoration experiment utilized Easy Diffusion, a generative imaging software, which operates on the algorithmic foundation of Stable Diffusion 2.1 (Easy Diffusion README, n.d.; Stable Diffusion 2.1, 2022) Chosen for its cost-effectiveness and adherence to the General Public License, the software possesses dual operational modes—text-to-image and image-to-image—providing a versatile toolbox for restoration endeavors. Of particular significance is the 'inpainting' functionality, wherein users have the discretion to mask specific areas for the purpose of defect correction or detail augmentation.

The restoration commenced with an initial round of recolorization, grounded in the methodologies articulated by Oncu et al. (2012). Specific attention was given to the painting's background features, while nuanced treatments were executed on the female figure, brown fabric, Achilles' appendages, and equine elements via the employment of semi-transparent color masks. These masks were rigorously matched to adjacent chromatic regions to mitigate the presence of visual discrepancies. Additional strata of color masks were applied to background sectors to achieve a seamless chromatic transition, especially in areas proximate to the female figure and arm portions.

The terminology deployed within the Stable Diffusion framework demarcates the various phases of the restoration process. For instance, 'inference steps' denote incremental image refinements, 'diffusion' signifies the stabilization procedure, and 'guidance' pertains to the incorporation of reference images for enhanced accuracy. Furthermore, 'prompt strength' modulates the primary input, while 'image quality' is indicative of the resultant fidelity. The term 'inpainting' is of particular salience to the experiment as it delineates the practice of masking designated areas for subsequent modification or detailed introduction.

For the restoration endeavor, Stable Diffusion was initialized with a stochastic seed and

configured for an image dimension of 768x768 pixels. The image was subjected to an initial 25 inference steps, each successive set of 25 steps undergoing critical evaluation for visual integrity and quality. The guidance scale remained at 7.5, while prompt strength oscillated between 0.25 and 0.5, thereby ensuring a judicious and nuanced restoration outcome. Image quality was set at a value of 75 to approximate the original artwork with high fidelity. Moreover, the inpainting procedures were performed at an augmented prompt strength of 0.7, enabling a more expansive spectrum of restoration possibilities.

2. Result and Discussion

The initial phase of the restoration concentrated on a manually cropped segment of the original painting (**Figure 3**). Employing heavy color masking, along with layers of noise and caustic effects, served to moderately rejuvenate the painting's degraded elements. Yet, the endeavor exposed the confines of human interpretation and craftsmanship in achieving a comprehensive restoration.

Figure 3. Manual Painting and Recolorization

Transitioning to computational methodologies, Stable Diffusion was employed with defined parameters: a prompt strength of 50%, a guidance scale of 7.5, and an initial set of 25 inference steps (**Figure 4**). A notable curiosity emerged: the algorithm interpreted damaged areas as distinct celestial entities rather than executing the intended restoration. These findings underscore Xiaoli Yu et al.'s (2021) assertion that AI systems lack an intrinsic understanding of artistic intentionality, thus necessitating human oversight.

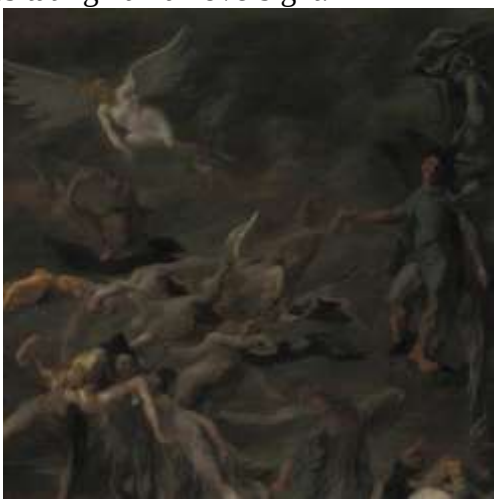

Figure 4. Artificial Intelligence-based Restoration

Subsequent to these initial phases, a hybrid strategy integrating manual restoration with

AI techniques was adopted (**Figure 5**). Detailed prompts describing the painting's elements, alongside specific technical parameters, were issued to the AI model. The 'inpainting' feature was subsequently deployed to address superficial defects. This melding of human expertise and machine capabilities produced the most harmonious results—closely approximating the original artwork, albeit with minor color and texture aberrations.

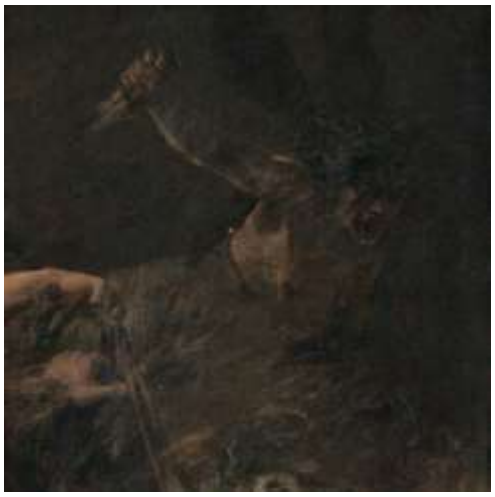

Figure 5. Confluence of Manual and AI Techniques

A granular examination of the 'inpainting' effect was conducted through a sequence of iterative rounds (**Figure 6**). Although the initial rounds successfully ameliorated surface blemishes, these enhancements compromised the painting's chromatic fidelity and nuanced details, particularly evident in the depiction of Achilles. Multiple rounds led to nearly complete effacement of scratches but precipitated an undesirable shift in the color profile and a loss of fine details. Such observations echo the broader academic consensus that AI techniques, though powerful, require cautious application to prevent inadvertent degradation (Xiaoli Yu et al., 2021).

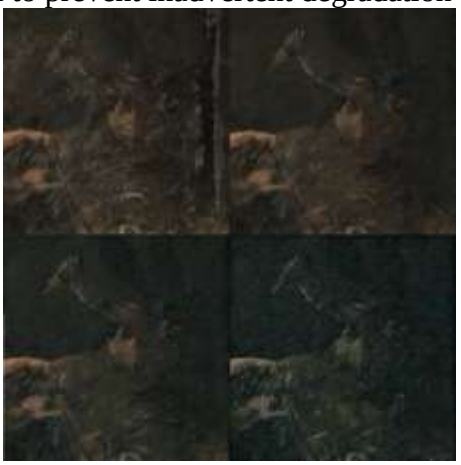

Figure 6. Effects of Inpainting

Synthesizing the outcomes from both Figures 5 and 6, the data substantiate the crucial role of human expertise in calibrating machine learning algorithms. Such findings resonate with the burgeoning academic discourse advocating for an interdisciplinary approach that synergizes the robust capabilities of both manual restoration and advanced computational methodologies.

Evidently, both manual and computational methodologies validate the imperative for a composite strategy in the conservation of cultural heritage artifacts. While machine learning algorithms offer unparalleled capabilities for detail and nuance, their limitations—primarily concerning color fidelity and the risk of overprocessing—are manifest. Conversely, manual

techniques remain invaluable, particularly for tasks necessitating nuanced, subjective judgment—a skill exclusive to human conservators. Collectively, these results reaffirm the academic position that advocates for a judicious equilibrium between traditional art conservation and computational techniques (Xiaoli Yu et al., 2021). The forthcoming section will elucidate a nuanced discussion and critical evaluation of these empirical findings.

3. Conclusions

This investigation has made a significant contribution to the intersection of art conservation and artificial intelligence, focusing on the restoration of Antoine François Callet's painting. It confirms that a synergistic approach, blending manual and AI techniques, is most effective for art restoration, echoing Xiaoli Yu et al.'s (2021) observations. However, the study acknowledges limitations, notably the AI-induced degradation in image quality during 'inpainting,' highlighting the need for advanced algorithmic development to more accurately emulate human artistry. Future research is directed towards a new subfield, Reconstituting Period Materialities for the Period Eye, exploring the use of generative AI to reconstruct and reconstitute artistic materialities. This approach could extend to various forms of cultural heritage, requiring innovative conservation methods. Additionally, refining 'inpainting' techniques to balance detail with overall image quality remains a crucial area for subsequent research. This study marks a foundational step in merging manual craftsmanship with AI, offering a blueprint for future interdisciplinary research in cultural heritage preservation and revitalization.

Conflicts of Interest

The authors declares that there is no conflict of interest regarding the publication of this paper.

References

Baduge, S. K., Thilakarathna, S., Perera, J. S., Arashpour, M., Sharafi, P., Teodosio, B., ... & Mendis, P. (2022). Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications. Automation in Construction, 141, 104440.

Barrile, V., Bernardo, E., Fotia, A., & Bilotta, G. (2022). A Combined Study of Cultural Heritage in Archaeological Museums: 3D Survey and Mixed Reality. Heritage, 5(3), 1330-1349.

Bevilacqua, M. G., Russo, M., Giordano, A., & Spallone, R. (2022, March). 3D Reconstruction, Digital Twinning, and Virtual Reality: Architectural Heritage Applications. In 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) (pp. 92-96). IEEE.

Boel, C., Rotsaert, T., Schellens, T., & Valcke, M. (2021). Six years after google cardboard: what has happened in the classroom? A scoping review of empirical research on the

use of immersive virtual reality in secondary education. In 13th International Conference on Education and New Learning Technologies (pp. 7504-7513). IATED.

Bordoni, L., Ardissono, L., Barceló, J. A., Chella, A., de Gemmis, M., Gena, C., ... & Sorgente, A. (2013). The contribution of AI to enhance understanding of Cultural Heritage. Intelligenza Artificiale, 7(2), 101-112.

Brennan, M., & Christiansen, L. (2018). Virtual Materiality: A Virtual Reality Framework for the Analysis and Visualization of Cultural Heritage 3D Models. Digital Heritage.

Carrozzino, M., & Bergamasco, M. (2010). Beyond virtual museums: Experiencing immersive virtual reality in real museums. Journal of cultural heritage, 11(4), 452-458.

Christou, Chris. (2010). Virtual Reality in Education. In: Aimilia Tzanavari & Nicolas Tsapatsoulis, Affective, interactive and cognitive methods for e-learning design: creating an optimal educational experience: 228-243.

Clini, P. Ruggieri, L., Angeloni, R., & Sassob, M. (2018). Interactive immersive virtual museum: digital documentation for interaction. In: ISPRS TC II Mid-term Symposium Towards Photogrammetry: 251-257.

D'Orazio, M., Bernardini, G., & Di Giuseppe, E. (2023). Predict the priority of end-users' maintenance requests and the required technical staff through LSTM and Bi-LSTM recurrent neural networks. Facilities, 41(15/16), 38-51.

Favro, D. (2006). In the Eye of the Beholder: VR Models and Academia, in Imaging Ancient Rome: Documentation, Visualization, Imagination: Proceedings of the Third Williams Symposium on Classical Architecture, ed. Lothar Haselberger and Jon Humphrey. Portsmouth, RI: Journal of Roman Archaeology: 321–34.

Gabellone, F. (2022). Digital Twin: a new perspective for cultural heritage management and fruition. Acta IMEKO, 11(1), 7-pp.

Guiffrey, J. (1870). Collection des Livrets des Anciennes Expositions: Salon de 1791. Liepmannssohn, Paris.

Hutson, J. & Olsen, T. (2021). Digital humanities and virtual reality: A review of theories and best practices for art history. International Journal of Technology in Education (IJTE), 4(3), 491-500. https://doi.org/10.46328/ijte.150

Hutson, J. & Olsen, T. (2022a). Virtual Reality and Learning: A Case Study of Experiential Pedagogy in Art History," Journal of Intelligent Learning Systems and Applications, November, vol. 14, no.4: https://www.scirp.org/journal/paperinformation.aspx?paperid=120925

Hutson, J. & Olsen, T. (2022b). Virtual Reality and Art History: A Case Study of Digital Humanities and Immersive Learning Environments. Journal of Higher Education Theory and Practice. vol 22 (2), 49-64. DOI: https://doi.org/10.33423/jhetp.v22i2

Johnson, D. (1989). Corporality and communication: the gestural revolution of Diderot, David, and The Oath of the Horatii. The Art Bulletin, 71(1), 92-113.

Kim, J., & Lee, B. K. (2021). Research on the possibility of restoring cultural assets of artificial intelligence through the application of artificial neural networks to roof tile (Wadang). Journal of The Korea Society of Computer and Information, 26(1), 19-26.

Kurtha, H., & Balzanb, L. (2022, May). Process analytical technologies for precise, timely and representative elemental and moisture measurement for conveyed flows. In TOS forum (No. 1). IM Publications Open.

Lei, Z., Zhou, H., Hu, W., Liu, G. P., Guan, S., & Feng, X. (2021). Toward a web-based digital twin thermal power plant. IEEE Transactions on Industrial Informatics, 18(3), 1716-1725.

Li, J. (2021, April). Application of artificial intelligence in cultural heritage protection. In Journal of Physics: Conference Series (Vol. 1881, No. 3, p. 032007). IOP Publishing.

Loscos, C., Tecchia, F., Frisoli, A., Carrozzino, M., Widenfeld, H. R., Swapp, D., & Bergamasco, M. (2004, December). The Museum of Pure Form: touching real statues in an immersive virtual museum. In VAST (pp. 271-279).

Moreno, M., Prieto, A. J., Ortiz, R., Cagigas-Muñiz, D., Becerra, J., Garrido-Vizuete, M. D. L. A., ... & Ortiz, P. (2023). Preventive conservation and restoration monitoring of heritage buildings based on fuzzy logic. International Journal of Architectural Heritage, 17(7), 1153-1170.

Ni, Z., Liu, Y., Karlsson, M., & Gong, S. (2022). Enabling Preventive Conservation of Historic Buildings Through Cloud-Based Digital Twins: A Case Study in the City Theatre, Norrköping. IEEE Access, 10, 90924-90939.

Oncu, A. I., Deger, F., & Hardeberg, J. Y. (2012). Evaluation of digital inpainting quality in the context of artwork restoration. In Computer Vision–ECCV 2012. Workshops and Demonstrations: Florence, Italy, October 7-13, 2012, Proceedings, Part I 12 (pp. 561-570). Springer Berlin Heidelberg.

Ranaldi, L., & Zanzotto, F. M. (2021). Discover AI knowledge to preserve Cultural Heritage.

Roussou, M. (2001). Immersive Interactive Virtual Reality in the Museum. Foundation of the Hellenic World. 254.

Scorpio, M., Laffi, R., Teimoorzadeh, A., Ciampi, G., Masullo, M., & Sibilio, S. (2022). A calibration methodology for light sources aimed at using immersive virtual reality game engine as a tool for lighting design in buildings. Journal of Building Engineering, 48, 103998.

Stanco, F., Battiato, S., & Gallo, G. (2011). Digital imaging for cultural heritage preservation. Analysis, Restoration, and Reconstruction of Ancient Artworks.

Tan, J., Leng, J., Zeng, X., Feng, D., & Yu, P. (2022). Digital Twin for Xiegong's Architectural Archaeological Research: A Case Study of Xuanluo Hall, Sichuan, China. Buildings, 12(7), 1053.

Tricart, C. (2017). Virtual reality filmmaking: Techniques & best practices for VR filmmakers. Taylor & Francis.

Tzortzaki, D. (2001). Museums and virtual reality: using the CAVE to simulate the past. Digital Creativity, 12(4), 247-251.

Yu, X., Shan, W., Ding, H., & Li, B. (2021, October). Research on Intangible Cultural Heritage Amusement Space Design from the Perspective of Artificial Intelligence. In 2021 2nd International Conference on Intelligent Design (ICID) (pp. 203-207). IEEE.