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Building an Immersive Simulation of the 1785 Parisian Salon in VR: A Guide to Recreating Historical Interiors and Digital Twins

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BUILDING AN IMMERSIVE SIMULATION OF THE 1785 PARISIAN SALON IN VR: A GUIDE TO RECREATING HISTORICAL INTERIORS AND DIGITAL TWINS

A Project Report Submitted to the Faculty of the College of Arts and Humanities
in Partial Fulfillment of the Requirements for the
Degree of Master of Arts in Game Design
at
Lindenwood University

By

Charles E. O'Brien

Saint Charles, Missouri

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DEDICATION

To my beloved wife, Bethany, and our wonderful daughter, Frankie:

You have been my guiding lights throughout this journey, providing me with endless love, support, and encouragement. Your unwavering belief in me has been the fuel that kept me going, even during the most challenging times.

Bethany, thank you for always being my rock and my biggest cheerleader. Your patience, understanding, and kindness have been the pillars of our family, and I am so grateful for your unwavering support. We finally have our Sunday nights back together.

Frankie, my little angel, you have brought so much joy and laughter into our lives. Your infectious energy and boundless curiosity inspire me every day, and I am so proud to be your dad. Always continue being silly and lighting up the room whenever you enter.

This thesis is dedicated to the both of you, with all my heart. I hope that it serves as a small token of my gratitude for everything you have done for me. I love you more than words can express.

And finally, to Char. I can't wait to meet you someday. I'm sure you will be just as silly and joyful as your sister.

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I am also grateful to Dr. James Hutson and Dr. Trent Olsen for their mentorship throughout this project. Their expertise, enthusiasm, and encouragement kept me motivated and focused. Their guidance was crucial in shaping my research direction. Thank you both for bringing me into the world of historical reconstruction and digital twins. I cannot think of a better project to have worked on.

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ABSTRACT

Title of Thesis: Building an Immersive Simulation of the 1785 Parisian Salon in VR: A Guide to Recreating Historical Interiors and Digital Twins

Charles E. O'Brien, Master of Arts in Game Design, 2023

Thesis Directed by: Prof. Jeremiah Ratican

This project aims to identify a workflow for creating digital twins without access to specialized 3D imaging equipment, such as photogrammetry. The process of creating a digital twin without specialized equipment is focused more on research than data analysis. Readily available resources, such as literature, paintings, drawings, and any other historical accounts, need to be considered. The case study for this workflow was reconstructing the Parisian Salon from 1785. The Salons were a haven for men and women to have intellectual discourse. The essence of scholarly thought that was produced through these Salon exhibits makes them perfect historical event candidates for producing a digital twin. The *Livret*, a brochure of the artists and works represented in the Salon, was the main historical account, while Pietro Martini's *Vue du Salon de 1785* engraving was used as the principal visual reference. Both sources were invaluable in finding many pieces of artwork present during the Salon. To further enhance the simulation, virtual textures were created for the paintings, lighting and environment effects were developed for the scene, AI art generators were used to produce unknown or lost artwork, and digital restoration techniques were employed to improve the conditions of damaged paintings. The impact of this workflow reaches beyond the digital humanities and is applicable to all fields where an immersive VR experience will help users connect with the material.

Keywords: Digital Humanities, Historical Interiors, Extended Reality, Digital Twin

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INTRODUCTION

The creation of digital twins is a rapidly evolving field that is transforming the way people interact with and understand the physical world (Jones, 2020). A digital twin is a virtual replica of a physical object, process, or system that allows for a range of activities (El Saddik, 2018). The more common uses include real-time monitoring, analysis, and simulation (Tao, 2022). While the technology has been used primarily in engineering and manufacturing, it has the potential to revolutionize the way we approach cultural heritage and history. Digital twins are quickly becoming an important tool in the fields of digital humanities and cultural heritage preservation (Hutson, 2023; Luther, 2023). While the digital humanities have opened up new opportunities for research and education, there is still a need to make this work accessible and engaging to wider audiences (Dalbello, 2011). Digital twins offer a solution to this problem by creating virtual replicas that can be accessed and explored by people around the world.

Historical interiors are complex spaces that are rich with cultural and historical significance (Grau-Bové, 2018; Turgeon, 2009). However, they are often inaccessible to the public due to their fragile nature, restricted access, location, or simply being anachronistic - especially in the case of an interior space that hosted a historical event (Shabani, 2022). The recreation of historical events and interiors is a process that involves a range of stakeholders, from art historians and conservators to museum curators and public audiences. By creating virtual copies of these environments, new forms of analysis, interpretation, and engagement are formed (Hutson, 2023). This includes creating new forms of museum exhibits and engaging students in art history classrooms.

The creation of digital twins has numerous benefits for cultural heritage preservation and research. First, it allows for the creation of virtual museums and archives for remote visitation

(Luther, 2023; Gabellone, 2022). This increases access to cultural heritage and allows for new forms of engagement and interpretation (Perry, 2017). Second, a digital twin can provide new insights into the physical and cultural contexts of artifacts. By creating high-resolution 3D models, the physical properties of artifacts can be analyzed and compared in new ways. This allows for a deeper understanding of their materials and production (Kalidindi, 2022; Tao, 2022). Finally, the creation of digital artifacts and interiors can contribute to the preservation and restoration of cultural heritage. By creating the virtual replicas, potential alteration, restoration, or decay scenarios can be documented and simulated.

The current trends in digital simulation production rely heavily on advanced imaging technologies, such as photogrammetry and 3D scanning (Shabani, 2022). These techniques are considered essential for creating digital twins and replicas of artifacts that are too fragile to be handled. The process of creating a replica involves multiple steps, including data and image collection, data processing, and computational algorithms for creating the virtual replica (Luther, 2023). Each step requires careful attention to detail, as small errors or inaccuracies in the data can lead to significant discrepancies in the final model. Common deviations in models include mis-extruded faces, where one or many edges of the model become distorted and jagged, or a mismatch in the texture being wrapped around the model. In any case, these types of flaws result in a loss of immersion for the user. Because of the reliance on advanced equipment, digital twin creation requires collaboration between multiple experts, including imaging specialists, data analysts, and software developers. This can be a daunting task, especially if access to 3D imaging scanning technology, for capturing high-resolution and accurate data is limited. The difficulty is compounded when researching cultural heritage sites or events from before the invention of photography.

Creating a digital twin without access to 3D scanning or photogrammetry requires a different approach to the process. Instead of relying on computational data analysis, it involves more of a thought experiment, using reference materials to build an understanding of the artifact, interior, or event being replicated. The process requires research into the literature, contemporary artwork, drawings, diagrams, or any other reference materials from the time period. The goal, as with any digital twin, is to match the historical context, physical environment, and cultural significance.

Examining the various methods and challenges associated with cultural heritage digital twins contributes to the development of best practices for their creation. The workflow presented in this thesis has been developed and refined through the production of a digital twin for the 1785 Parisian Salon exhibit. This case study and analysis - for a historical interior replica - explores the potential to transform the digital twin creation process. Through the presentation of this workflow, this thesis aims to contribute to the democratization of digital twin creation, making it more accessible and less intimidating for a wider range of users and researchers. This can lead to a more diverse and inclusive representation of historical events, interiors, and artifacts, regardless of technical expertise or access to specialized equipment.

LITERATURE REVIEW

The Vanishing of Ethan Carter was originally released in 2014. It took a few years to create the game because the developers, Adrian Chmielarz, Michał Kosieradzki, and Andrzej Poznańsk, employed a powerful new technique for creating art assets. That technique was called photogrammetry. Photogrammetry is not a new technique on its own. In fact, it dates to the 1800s, after photography was first invented. Photogrammetry is the use of photos or recordings to interpolate a three-dimensional structure. Cartographers were the original photogrammetry artists. Current photogrammetry methods, involving digital photographs, employ computational algorithms.

With the onset of 3D graphics in video games, photogrammetry has always been considered too time consuming and resource heavy for practical use (Statham, 2018). *The Vanishing of Ethan Carter* marked the first-time photogrammetry had been one of the core design elements of a development pipeline. Since 2014, the use of photogrammetry has expanded dramatically (Statham, 2018). It is now a common thing to do when making video games, especially games with realistic environments and assets. The field of photogrammetry has expanded to the point where it is now an entire career path. Photogrammetrists, or “photogrammetry artists," are in such high demand that they can make six-figure salaries depending on the company and their skill level.

Digital Photogrammetry (DP) involves creating a library of high-resolution photographs. These images can be fed into a computer algorithm designed to sew them together. The result is both a 3D model of the object and a texture file using the object’s own colors and topology (Ashikhmin, 2001). When the texture is applied in 3D space, the object will mimic exactly what the original object looks like in a computer program. Many 3D models and associated texture files produced from photogrammetry can be used to populate an entire scene - what the user sees when running an application - inside a game or simulation. The result is a realistic looking object on the screen, or in many cases, the scenes are viewed within the three-dimensional space of Virtual Reality (VR).

Close ranged DP is still used for texturing scenes to this day, such as in Slater (2016) and Martin (2018). However, the current uses of the technique have evolved well beyond creating objects and textures for video games. For instance, many research groups are using drones for long-range DP (Anifantis et al., 2019; Guerra et al., 2019; Huo et al., 2021; Mielcarek et al., 2020). These studies do not result in high-fidelity texture images like those described above but can give calculations for forestry and city planning. Many different fields are now using DP and VR, as well. Tricart (2018) describes its use in filmmaking; Wesencraft (2020) is using it in anatomy education; and Guerra et al. (2019) employ DP and VR for training drone pilots in the robotics sector. Of particular interest, research groups are now using DP and VR to preserve and share heritage sites. In Dhanda et al. (2019), they describe recreating a virtual model of a Myanmar temple. The Church of Saint Nicholas in Serbia has also been documented and preserved (Obradović et al., 2020). Ch'ng et al. (2019) requested photos from around the globe to create 3D models of lost or hidden artifacts and sites in Eastern Asia. After the Islamic State destroyed museums, archaeologists decided to recreate the lost relics in VR (Curry, 2019).

Having the ability to view a remote museum or interact with lost heritage sites has a wide range of implications, especially for education. As the world has found from the recent COVID-19 pandemic, the way students learn is constantly evolving. Hybrid instruction methods, online courses, and distance learning are now essential aspects of most programs. The application of VR in educational settings has grown a great deal over the past few years.

Educational simulations and training modules are still focused on applied fields, such as the natural sciences, health care, and the military (as seen in Wesencraft, 2020; Guerra, 2019). However, advancements are also being made in the digital humanities, pushing those fields into a new era. Computational techniques in the digital humanities, such as VR and DP, are not only applicable to remote or destroyed museums. Currently, there are over 2,000 museums with VR exhibits. One such museum in St. Petersburg, Florida, created a surreal virtual experience for users based on the works of Salvador Dali (Antunes, 2021; Dreams of Dali, 2022).

The usage of these virtual scenes is also stretching beyond the museum space (Johnson, 2018; ISSEC, 2018). They have become an amazing tool for education (Gerasimova, 2019; Nebel et al., 2020). The main consideration when developing such a tool is having an immersive experience for the users to feel connected to the events (Loureiro et al., 2021; Gilbert, 2019). Communicating with the user about what should be experienced, guiding the user with signs and cues, interacting with the user's headset, and creating a virtual guide within the program are all methods that can be implemented into the final application (Hammady & Ma, 2021). The designers must form clear learning outcomes for the simulation to hone their designs based on which parts are most important (Hutson & Olsen, 2021; Times, 2019). The final goal of such a project is to produce enough interactions for the user to feel like they influence the events instead of just playing a game or watching a scene unfold (Carrozzino & Bergamasco, 2010; Gilbert, 2019; Robinson, 2009). Virtual experiences, in general, need to focus on certain characteristics to be more successful, such as presence, a sense of control, pleasantness, exploration, and immersion (Kauhanen, 2017). This is where photogrammetry comes into play. Techniques, such as photogrammetry, further increase immersion, and subsequently enhance the learning outcomes. Tapping into the visual sensory cues gives the user a better frame of reference for the events.

Photogrammetry and VR have been shown to replicate existing heritage sites, recreate destroyed museums, and enhance current museum exhibits (Dhanda et al., 2019; Curry, 2019; Antunes, 2021). A currently untapped direction for the technology is recreating historical events. Digital versions of past events have been programmed into video games, with the writers taking some liberties to make the events fit into the gameplay scenario (Rollinger, 2020; Rollinger, 2021; Gilbert, 2019). However, historical events are not well represented in a non-game setting. Techniques such as digital photogrammetry and virtual reality are normally used to generate content related to historical buildings or video games. This work will employ photogrammetrically generated materials based on those that would have been used in 18th century French architecture to construct an entire Salon scene from over 200 years ago in VR.

The Royal Academy of Painters and Sculptures in Paris began exhibiting works of art to the public in 1663 (Hallam, n.d.). A few years later, in 1667, they started a tradition of holding a yearly showcase called the Salon. Following the Salon's inception, members of the Academy would choose pieces of work to display (Cornette, 2014). These events grew in frequency and complexity over the years. The Parisian Salons had profound influence on art, culture, and society (Whyte, 2013). This art exhibit became a place for both men and women to have intellectual discourse. It gave birth to royal awards, grants, and critiques. The only remnants from these events are engravings or paintings of the Salon displaying the artwork and the *livret*, or catalog, of artists attending (Liepmannssohn, 1870; Martini, 1987). The Salon's influence on culture and Art History makes it the perfect case study for recreating historical events in VR.

METHODOLOGY

Key Terminology

- VR – Virtual Reality, an experience where the real world is hidden from the user
- AR – Augmented Reality, an experience where computer generated objects are overlaid on the real world without the user being able to interact with them
- MR – Mixed Reality, an experience combining both AR and VR where physical and digital objects can interact with each other
- XR – Extended Reality, an experience where visual, audio, and haptic (touch) cues are used to make a more immersive experience for the user
- UX – User Experience, the overall experience of a person using a computer application, focused especially on whether it is pleasing or easy to use
- Interactive VR/XR – content that enhances the user experience in a virtual environment
- Immersion – user presence and interaction within a computer application, specifically important for learning outcomes in VR/XR simulations (Gilbert, 2019; Hutson & Olsen, 2021)
- HMD - Head Mounted Display; the Oculus Quest 2 HMD was used in this study
- Degrees of freedom – four degrees is sitting in one place, while six degrees allow the user to completely move around the space
- Latency – one of the major concerns in VR/XR, where the framerate of the simulation drops due to how many resources are being simultaneously used to run the program

Development Tools Selection

For this work, Epic Games' Unreal Engine 5 was used. Unreal Engine is one of the most popular tools for developing games and simulations. It has a large online community and online documentation. The engine was selected mainly because of the ease of use and accessibility of the visual scripting language, called blueprints. It is also free to use and customize. Version 5.0 launched in April of 2022 with many upgraded features to assist with object resource impact through recent technology, called Nanite, and provide more natural lighting using Lumin. The Salon of 1785 has over 300 paintings and sculptures, which would normally hinder the latency of a VR application. Plugins for creating VR simulations already existed and were easily adapted to the latest version 5.0. Epic Games is sponsoring a lot of free content to bolster their community. For instance, Quixel recently partnered with Epic Games to release 8K resolution materials to be used in the Unreal Engine. These materials were used as a primary resource when texturing the interior of the Salon.

Case Study

In 1667, the Royal Academy of Painters and Sculptures in Paris began exhibiting artwork in a yearly showcase called the Salon. This art exhibit became a place for both men and women to have intellectual discourse. It gave birth to royal awards, grants, and critiques. Artists began capturing the Salon in paintings and engravings (Figures 1 and 2). The Salon of 1785 was chosen as a case study for a few reasons. The primary reason was Pietro Martini's engraving of the exhibit on display in the Salon Carré in 1785 (Figure 1). Martini's engraving was masterfully done and allowed for the clear identification of many pieces that were on display. The second reason is that construction was carried out on the Salon Carré in the following years. This means that the basic shape of the room changed each year afterwards. Some of the notable alterations were connecting the Salon Carré to the main buildings of the Louvre, introducing ornate carvings into the ceiling, and the addition of a skylight (all seen in Figure 2, bottom right). Recreating the Salon of 1785 gives a strong proof of concept for developing this type of simulation in the future.

Boxing out the Salon in VR

The initial step before creating any assets was to create a scale for use in the VR scene. A measurement of 172 cm (about 5.64 ft) between Oculus controllers was taken. This span was translated into the scene by placing two objects at the positions of the controllers while wearing the headset. A 172 cm ruler was created within the scene and continues to be used as a standard length when measuring paintings. The initial dimensions of the room were taken from blueprints of the Louvre palace (Figure 3). According to the scale, measured in fathoms, the dimensions of the Salon Carré were 22.86 m in length, 12.8 m in width, and 14 m tall, - from the center of the room to the ceiling. As depicted in many of the paintings and engravings, the ceilings were curved (Figures 1 and 2). The exact dimensions for the initial curve during that time period are unknown.

Interior Space and Models

The Unreal Engine 5 geometry builder was used for creating and gray-boxing the scene for initial setup and proportions (Figure 4). This was a preferred method over using more advanced modeling tools, such as Maya or Blender. The geometry builder was quickly adapted to the 172 cm ruler. When objects created with the geometry builder are reduced to 92% scale, the brush settings directly correlate to centimeters. For instance, *Mort de la femme de Darius*, by Louis-Jean-François Lagrenée, is reported to be 10 ft by 13 ft (304.8 cm by 396.2 cm; Liepmannssohn, 1870). With a brush box cube scaled to 92%, the brush settings can be set to an x of 396.2 and a z of 304.8. This gives the painting a realistic scale within the scene. Using the exact scale for each painting also allows for correlation to Martini's engraving for precise painting placement. Other factors, such as the tilt of higher placed paintings and scaffolding in the scene, will become apparent as the scene is populated with more paintings.

Other than the dimensions taken from the blueprints, the rest of the details for the space itself had to be deduced from the 18th century paintings and engravings. With each representation of the Salon shown from different perspectives (Figures 1 and 2; Hallam, n.d.), a general sense for the space was deduced. The finer details, such as window and door placement, utilized the original blueprints of the Louvre (Figure 3) in correlation with artists' portrayals. Placement of the staircase and scaffolding for paintings required assumptions to be made about what the space looked like in 1785. The depictions of the Salon Carré interior from Martini and other artists formed a general consensus for gray-boxing the room (Figure 4). Martini's engraving was the sole source for painting placement on the walls.

Populating the Scene with Paintings

A comprehensive list of the paintings and their sizes can be found in the *Livret*, or brochure, for the exhibition (Liepmannssohn, 1870). Dimensions are listed for many of the pieces of artwork. These dimensions and descriptions (examples in Tables 1 and 2), in combination with Pietro Martini's engraving for the 1785 Salon (Figure 1), have assisted in identifying paintings in the exhibition that still exist today. The works continue to be placed into the scene according to the orientation depicted in Martini's engraving. Once identified, images of the corresponding paintings are found online and used as a base texture file. The UVs for the resulting materials were adjusted to match the scale of the paintings.

Optimizing Textures

With VR being a newer technology, there are many methods described for optimizing the textures (Huo et al., 2021; Tricart, 2018). Larger objects in the scene were textured using 8K resolution images downloaded and implemented using the Quixel Megascans Bridge Plugin. These include the "Old Wooden Floor," tinted with orange to resemble cedar wood; Magny limestone that resembles the limestone used in the construction of the Louvre; and 18th century Arabescato marble. The wood texture was used on the floor, ceilings, staircase, and walls. A patterned carpet texture was later placed on the walls to mimic the red drapery that was hung during many 18th and 19th century French art exhibits. The Arabescato marble was placed in the door frames and molding. The magny limestone is not currently in the scene until it can be verified where and how it was used in the Louvre.

Once base textures and materials for paintings were created and implemented into the scene, they were optimized for VR using a variety of best practices. Material metallic and roughness were packaged in separate channels. The original image files were padded with blank space to reach a multiple of 2. For instance, in a Jean-Joseph Taillasson painting (Figure 7), the initial download size was 1660 x 2048. This was padded to reach 2048x2048, a multiple of 2 for both length and width. The textures were then downscaled by powers of 2 to determine when the paintings began to become blurry within the scene. Finally, the image files were compressed with the Oodle Kraken decoder and were ready for distribution. Any of the original image files with a resolution greater than 2048 pixels in either length or width were reduced to 2048 to give a standardized resolution. Anything less than 2048 pixels, while greater than 1024 pixels in either length or width, was reduced to the next power of 2 in scale on the shorter edge of the image. The files with 1024 or lower resolutions were not downscaled in the editor.

Scene Lighting

Scene lighting was implemented as described in Scorpio et al. (2022). The difference in their methods comes from the use of Lumen in Unreal Engine 5. In the engine rendering settings, Lumen was set as the dynamic global illumination method. The reflection method was also set to Lumen with the lightmap mixing reduction setting enabled. Hardware ray tracing was disabled with the software mode set to global tracing. A post-process volume was used to have the setting affect the entire scene. Both Lumen and the beta version of screen space methods for post-process illumination were analyzed. A low intensity lens flare was added with a bokeh size of 10.0 to give the windows a more authentic sun glare effect.

Volumetric lighting was constructed using a fog density of 0.015. The albedo, the light reflected towards the viewer, was shifted by 20% in the green and blue channels. The main directional light was reduced to 1 lux. Volumetric scattering was increased to the maximum of 4.0, while the specular scale for shadows was reduced to 0. A point light was placed in the center of the scene with a soft source radius covering the entire room. This light source was used as the main illumination for the paintings.

Digital Art Production

Artificial intelligence art programs were used to fix damaged paintings for incorporation into the scene. Files downloaded from the web were uploaded into the AI programs. Eraser, fix, background removal, object removal, and colorization methods were used where applicable. The resultant AI generated products were compared to the original damaged copies to discern whether any details were lost. Manual restoration techniques were also used (Figure 10). Manual brush strokes were averaged into the painting. The brush strokes used colors consistent with the surrounding area. Once the desired scratches were painted over, the brush strokes were blurred.

The eraser tool was used to correct any instances where the blurred strokes would lower the fidelity of objects or details in the painting.

Various artificial intelligence art programs were used to generate entire works that could not be identified or located. For this study, Wonder, Hotpot.ai, Bluewillow, DreamArt, B^Discover, Illusion, and DreamStudio were tested. Wonder, Hotpot.ai, and Bluewillow were used for the majority of the images included because of their ease of use during prompting (examples shown in Figures 11-13). Anywhere from 4 to 20 images were produced from each prompt. Prompts also included extra terms to adjust the resultant images in the direction of the artist’s style, technique, or color usage.

RESULTS

Scene Construction

The scene has been progressing through reconstruction based on Pietro Martini's engraving of the Salon de 1785 (Figure 1). The initial boxing out of the scene was accomplished using some of the original blueprints for the Louvre (Figure 3). The 172 cm ruler was used for measuring out the length, width, and height of the room. The length used was 13.23 ruler blocks. The width of the room was 7.41 blocks, and the height was measured at 8.10 blocks. The interior embellishments, such as doors, corner scaffolding, curved ceilings, windows, and a staircase, were all constructed using the engravings and paintings (as seen in Figures 1 and 2) of the Salon to estimate their positions and shapes. The initial boxing out is shown in Figure 4, inside the Unreal Engine editor, with the south wall set to transparent for a wider-angle view. The initial boxing out of the scene also included a few paintings to compare the view in Figure 4 to Martini's engraving.

Material compositions have changed throughout the process of building the scene. The original materials for the floors, walls, and ceilings used a basic wood pattern that is included in the Unreal Engine Starter Content. Quixel Megascans of Arabescato marble and reclaimed wood floors were implemented in the scene to give it more realistic textures (Figure 5). Photos taken at the present-day Louvre show a marble texture in the doorways of the Salon Carrè (not shown). At the time, hardwood floors, walls, and ceilings are thought to have been used during construction. The Quixel marble texture was therefore used in the doorways, and the reclaimed wood texture was used everywhere else. Samuel Morse painted a gallery at the Louvre in the 1830's (https://www.seattleartmuseum.org/exhibitions/morse). While this was around forty years after the time period of this project, the red drapery in the background seemed to be common for art exhibits. A carpet texture was manipulated to look more like patterned satin and draped around the walls of the scene.

Lighting was tested with different illumination settings. Lumen is best suited for indirect lighting in a scene. Since the Salon is mostly flat and has smooth surfaces, the indirect lighting did not have an effect. The screen space global illumination method produced a higher quality lighting effect for the space. Emissive lighting sources, one of the special effects included with Lumen, also did not have an effect when compared to standard spotlights and directional lights. The lens flare method attached to the post-process module gave a soft bloom effect to the scene (on display on the right side of Figure 5). The shadows cast by the windows were toned down and lightened to minimize the darker tones. The reflected light in the shadows was adjusted from 5-10% toward white to brighten the scene while the user has the windows in view. The shift towards red in the directional light gave a more natural scene lighting in order to reduce eye strain. These alterations in the lighting and shadows allows for more consistent coloring on the paintings when viewed from all angles. Volumetric lighting was also included to further increase immersion in the scene. The final product of material manipulation, lighting, shadows, and volumetrics can be seen in Figure 6.

Creating the Paintings

Paintings from the Salon of 1785 have been identified using the event brochure, called the *Livret* (Liepmannssohn, 1870). There are 324 works listed in the *Livret* for Salon. In many cases, the name of the artwork is vague, such as number 5 in the listing, which describes two paintings of a farm with animals - translated from the French "*Deux tableaux représentant des fermes avec des animaux*." Some of the listings are impossible to discern because they do not even list a name for the work. Two examples are listing number 102, which says, "several portraits under the same number," and number 137, which translates to, "various drawings." Because the Salon was a larger public event, many of the portraits have the names left blank to maintain the sitter's anonymity. For the more identifiable pieces of work, Pietro Martini's engraving of the Salon has been used to verify whether the image found is correct and where to place it in the scene. In all, 27 paintings have been placed in the scene. Table 1 shows a representative list of artworks and the corresponding number in the *Livret*.

The paintings in the scene, at the time the screenshots in Figures 4, 5, and 6 were produced, were obtained from online sources. These sources had quality ranging from 4K resolution prints to destroyed or low-resolution images. One example of a damaged piece is Taraval's painting depicting the infant Hercules strangling snakes in his bed, as seen in Figure 5 (the second painting on the top row). After adjusting the image files for each painting to the nearest power of 2, the imported textures were padded, downscaled, and compressed. The compressed sizes compared to the original imported file sizes are listed in Table 2. In most of the represented data sets, there was around a 6-fold reduction in file size after optimization. One painting in particular, Taillasson's depiction of Ulysses and Neoptolemus (shown in Figure 7), was reduced by over 23-fold in file size (Table 2, *Livret* number 110).

Taillasson's painting was used as a proof of concept for further development of the materials in the scene. The mesh was created and scaled, as previously described, with the stretch and skew adjusted to fit the size listed in the *Livret* (Figure 7, middle left). The painting material was enhanced with metallic and roughness channels set to 0.8 (Figure 7, top right). This resulted in a deeper color and less light reflection. The scene lighting and reflective capture were optimized for the reflectivity of the materials. The final screenshot from these modifications, along with texture optimization and compression, is shown in the bottom of Figure 7. The resources for the final render are one-sixth the original file size.

Further enhancements were made to determine whether the paintings in the scene could mimic the original materials used. The embossed pattern is shown in Figure 8, on the left. As described in Luo et al. (2012), the normal and reflective normals were averaged together. The Taillasson painting did not have as many deep brush strokes as the examples Luo used. Instead, a normal and embossed normal were averaged together with a dirt mask to create more grain in the picture. This image was uploaded into a normal map generator (https://cpetry.github.io/NormalMap-Online/) to create the finalized normal map in Figure 8, on the right. The normal was then uploaded and flattened in the Unreal Engine material blueprint. As shown in Figure 9, the difference between the painting with a normal map and one without is minimal. The painting with a normal map, on the top right of Figure 9, has slightly more vibrance in the coloring when viewed from a distance. Before the lighting was enhanced in the scene, the difference between it and a normal map was more significant. The true effect of the new lighting system in the scene can be seen from various angles when closer to the painting. Without the normal map, the painting has a flat color at all angles (not shown). With the normal map applied, there is a wet or glossy texture to the painting, mimicking the sheen that oil paintings generally have when freshly painted.

Paintings with significant flaws were passed through rounds of digital reconstruction techniques. AI art programs were used for initial scratch reduction. Paintings, such as Callet's painting depicting Achilles and Hector (Figure 10), had too much damage to properly utilize an AI program. Any attempt to remove a scratch resulted in details of the original painting being lost. Instead, manual brush strokes were averaged into the painting. Once merged, the blemishes were not entirely removed, but their impact on the painting was greatly reduced.

A collection of AI generated paintings is being built, with samples shown in Figures 11-13 (examples are not included in the scene Figures 4-6). The starting prompts included the title of the work and the artist's name. For instance, number 54 in the *Livret* is titled "Other paintings and drawings" by Hubert Robert. The initial prompt for the AI art program called Wonder was "paintings, by Hubert Robert." The resulting artwork for this program and all of the others are vibrant and colorful. Most of the paintings of the period were not bright and saturated. Additional prompts were included, such as, oil painting on canvas, muted colors, and faded. These extra prompts toned down the colors and produced a more similar result to Robert's actual works. The AI programs were able to mimic styles from Lépicié, Vernet, and Lagrenée, among others. While the capriccio style of a fantastical scene was easy to prompt, the AI had difficulty with the brush stroke techniques (as seen in Figure 13).

DISCUSSION

This project has focused on creating a workflow for recreating historical events in VR. The methodology presented can be used to fully create scenes that will be used in real-time simulations. One of the caveats of attempting this type of project is that information about past events is skewed by the viewer's perception. The prime example of this is Figures 1 and 2, showing the same space of the Salon Carré, yet all five images look different from each other. The number of windows changes, the layout of the room itself seems variable, and the scale of the visitors compared to the doorways and room is drastically different. Saint-Aubin's painting from 1765 makes the Salon look like a banquet hall (Figure 2, top right). However, the written accounts of the events describe crowds of people with little walking space (Hallam, n.d.). When recreating this type of event, based on variable sources, it is imperative to keep an open mind and select the most logical information. For instance, the staircase is shown in various locations as compared to the windows, or not at all (Figure 2). Descriptions of the space during the 1800s state that the Salon Carré was connected to the Galerie d'Apollon (Hallam, n.d.). The windows face the Seine River in the present day, and most likely were also originally placed on the south side of the room. The Galerie d'Apollon is on the west side of the Salon. The staircase would logically have to be on the east side of the Salon, meaning Chereau's engraving of the Salon may be the most accurate representation (Figure 2, top left).

The depictions often show three, five, or no windows. If the assumption that Chereau's version is more accurate holds true, then there would be three windows in the Salon on the south wall. There would be one doorway on the west side of the room, closer to the windows, and one on the north side. For orienting the artwork within the room, the assumption could also be made that Pietro Martini was standing by the windows or sitting on the windowsill, looking at the north wall, when he made his engraving in 1785 (Figure 1). This assumption gives a rough placement for the north doorway and the surrounding paintings. In this project, the orientation of the paintings is based on Martini's engraving (Figure 1), the staircase construction is based on St. Aubin's engraving (Figure 2, bottom left), and the orientation of the room and windows is based on Chereau's print on the top left of Figure 2. The scene mood, feel, and lighting were based more on the two paintings in Figure 2 (top right and bottom right).

The driving force for any historical reconstruction project should be the learning outcomes for users (Hutson & Olsen, 2021). This work is meant for art history classrooms and museums. The focus is on having the user feel connected to the intellectual discourse and period pieces on display. To accomplish this goal, immersion in the simulation is key. The paintings themselves allow the user to experience the Salon, but the atmosphere will make what they see more pertinent (Loureiro et al., 2021; Johnson, 2018; Robinson, 2009). Immersion in the historical event is key to creating memories and engaging the users (Loureiro et al., 2021; Nebel et al., 2020). Immersion is when the user stops being aware that they are in a virtual environment and can view the space as reality. Visual and auditory cues are one of the best ways to accomplish this objective (Hammady & Ma, 2021). Using realistic scenery from the 8K resolution Quixel textures is one step made to increase visual stimulation in the user. Lighting and painting material composition play a significant role. While performance and file size (listed in Table 2) will increase the framerate of the application, the focus is still on producing high quality images for the users to stay connected to the space. Digital restoration and AI art generation are two techniques that will further increase immersion for the end product.

CONCLUSIONS

This work originally focused on boxing out the scene to begin creating an immersive environment. The latency of VR simulations was a concern because any drop in framerate will prevent the user from living in the moment. The work itself became a balancing act to find the best performance optimization options without losing any of the resolution of the works displayed in the scene. Even with this statistical approach to interactive VR and immersive learning experiences, the quality of the textures and materials was always the number one priority. With research into the *Livret*, it became apparent that to truly create a digital twin, the quality of the entire scene, rather than individual materials, had to become the top priority. To achieve the goal of creating a comprehensive twin for the 1785 Salon Carrè, new avenues were opened up for the research project.

The first new branch of study involved mimicking oil painting textures. The future directions on texture generation will also include watercolors, sculpture materials, and various paper and canvas types that would have been used in 1785. Having the lighting, reflections, and shadows in the scene calculated off of realistic looking materials will enhance the immersion immensely. Digital restoration was another direction explored in the project. The AI art scratch fixers and erasers, as well as the manual sampling methods, did not truly restore any of the pieces tested. The process of restoring materials included in a digital twin is not limited to simply removing the scratches. Artist portrayals of the scene, descriptions of the event, photographs, or any additional information needs to be considered when attempting to restore damaged materials for use in an immersive simulation. Digital restoration for this type of project would most likely require a graphic artist who excels in textures. The last subject area explored in this research project was a deep dive into AI art production. Even with extensive tests on prompting, it was difficult to mimic some of the painting styles. The end goal of creating a digital twin for a museum exhibit also means filling in the blank spaces where a painting may be misidentified, lost, stolen, or destroyed. While the AI replica would not have to be exact, it still assists in immersion if the new painting matches the same style as what the artist would have produced.

The main considerations when developing a digital twin for a historical event, such as this Parisian Salon de 1785 project, are having an immersive experience for the users to feel connected to the events; presenting clear learning outcomes for the simulation to focus on which parts are most important; and producing enough interactions for the user to feel like they influence the outcome of the events. This project addressed the first goal of creating an immersive environment. Researchers attempting to replicate these methods for immersive simulations need to keep the following points in mind: 1. Utilize all materials available for constructions of the scene. Even if depictions, portrayals, or written accounts conflict with each other, consider all of the data available. It may require taking pieces of information from each to create a consensus; 2. Utilize the data available when attempting to restore or reconstruct parts of the digital twin. Research and examine which materials would have been involved in the initial construction. Replicate textures or use photogrammetric scans to mimic the original look and feel of objects; and 3. Use methods, even unconventional techniques, to create an authentic environment.

FIGURES

Figure 1. View of the Salon of 1785 by Pietro Martini.

Figure 2. Perspectives of the Parisian Salons. (top left) Engraving of a Salon by Paul André Basset. (top right) Salon de 1779 by Gabriel de Saint-Aubin. (bottom left) Salon de 1753 by Gabriel de Saint-Aubin. (bottom right) Grand Salon Carré de 1861 by Giuseppe Castiglione.

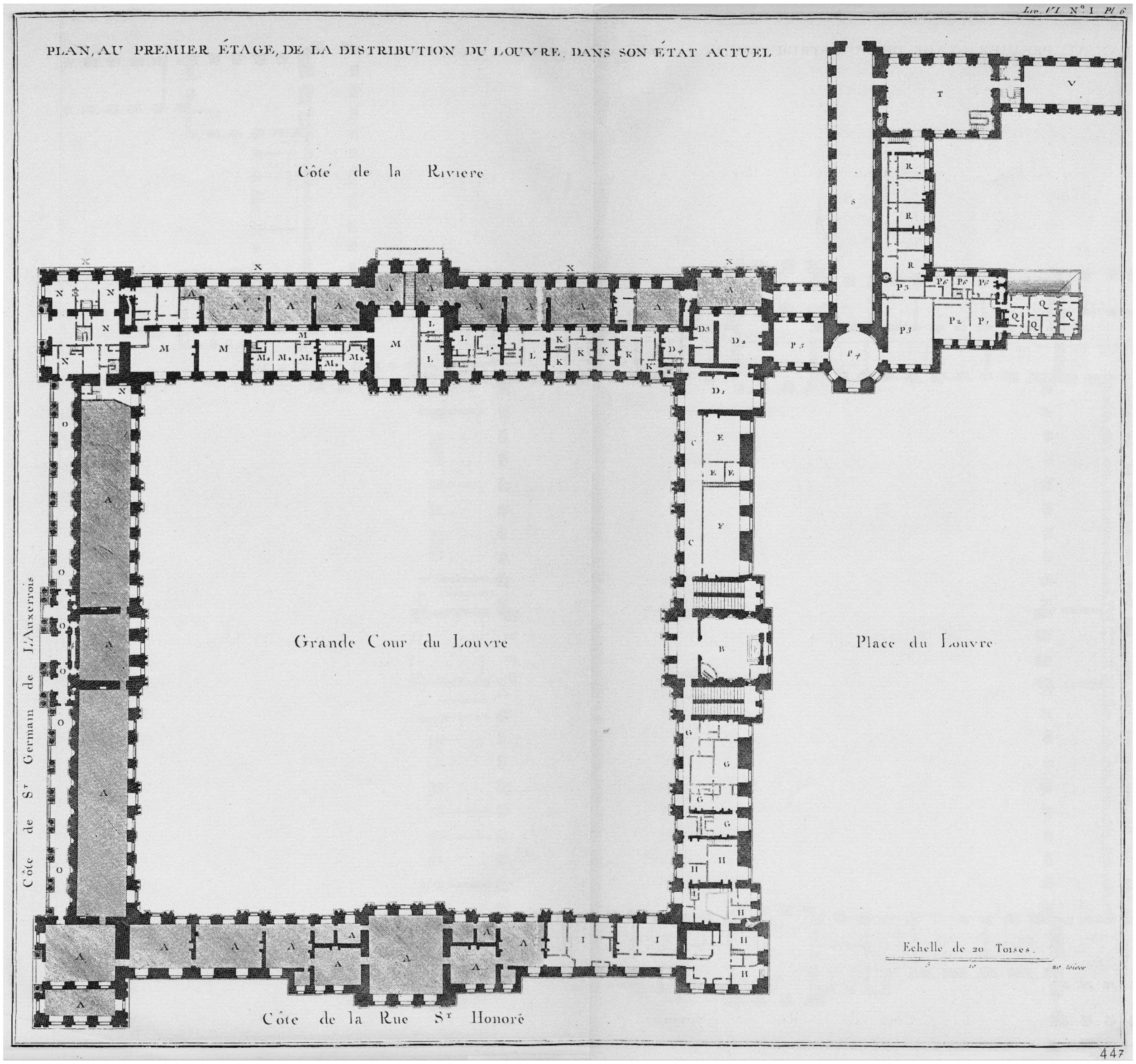

Figure 3. Blueprints for the Louvre. The Salon Carré is building T in the top right corner. As of 1779, the Salon Carré was not yet connected to the main palace of the Louvre.

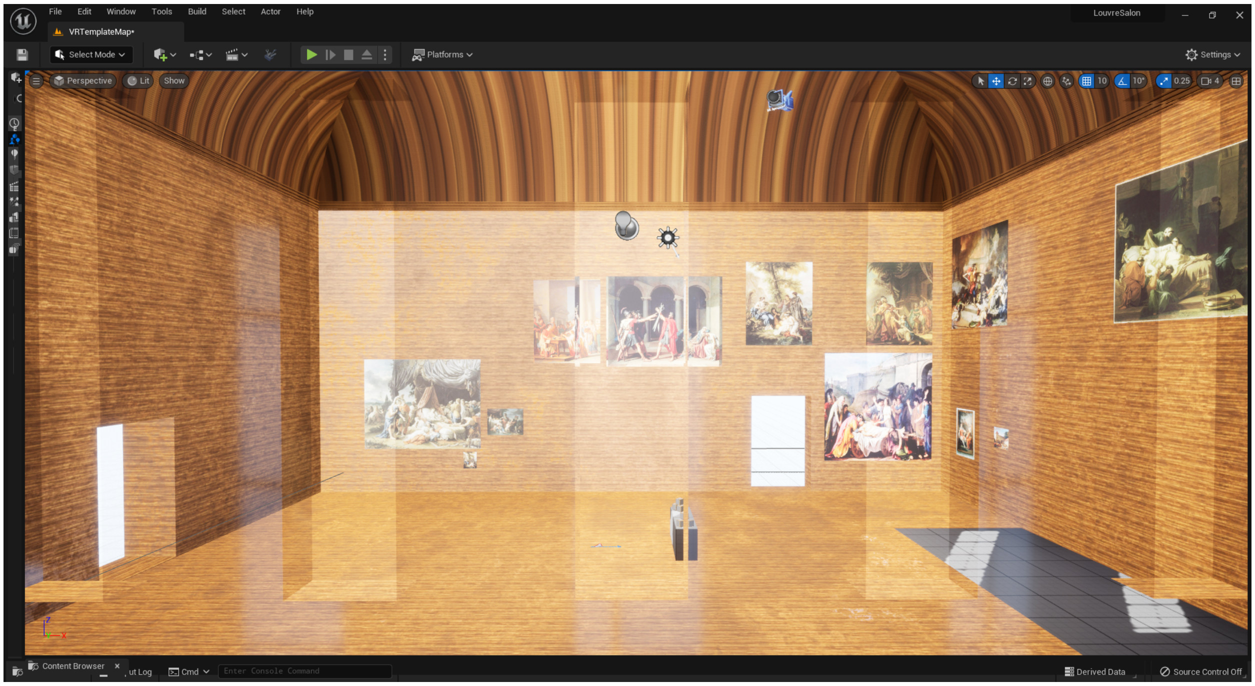

Figure 4. Initial construction and boxing out of the scene. Screenshot taken within the Unreal Engine 5.0 scene editor.

Figure 5. Enhancing the scene. Screenshot taken while running a simulation of the scene.

Figure 6. Further scene enhancements. Screenshot taken while running a simulation of the scene.

Figure 7. Optimization of painting textures. (top left) Original texture image for *Ulysse et Néoptolème enlevant à Philoctète les flèches d'Hercule* by Jean-Joseph Taillasson. (top right) Enhanced with metallic and roughness. (middle left) Texture scale and skew adjusted for the size and shape of the painting. (middle right) Scene lighting and reflective capture optimized. (bottom) Final render, including texture compression.

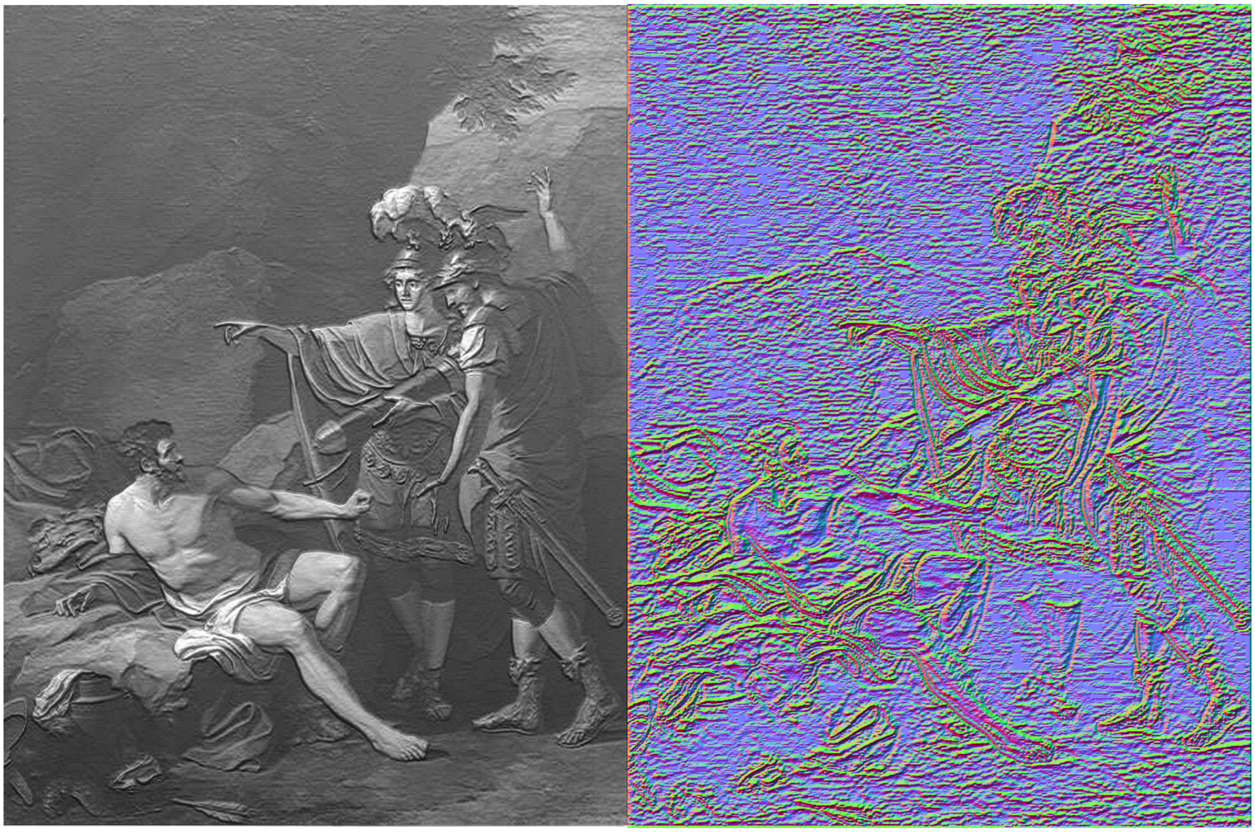

Figure 8. Normal map creation. Altered images for *Ulysse et Néoptolème enlevant à Philoctète les flèches d'Hercule* by Jean-Joseph Taillasson. (left) Averaged drop shadow and embossed rendered layers. (right) Final normal map generated from the previous image.

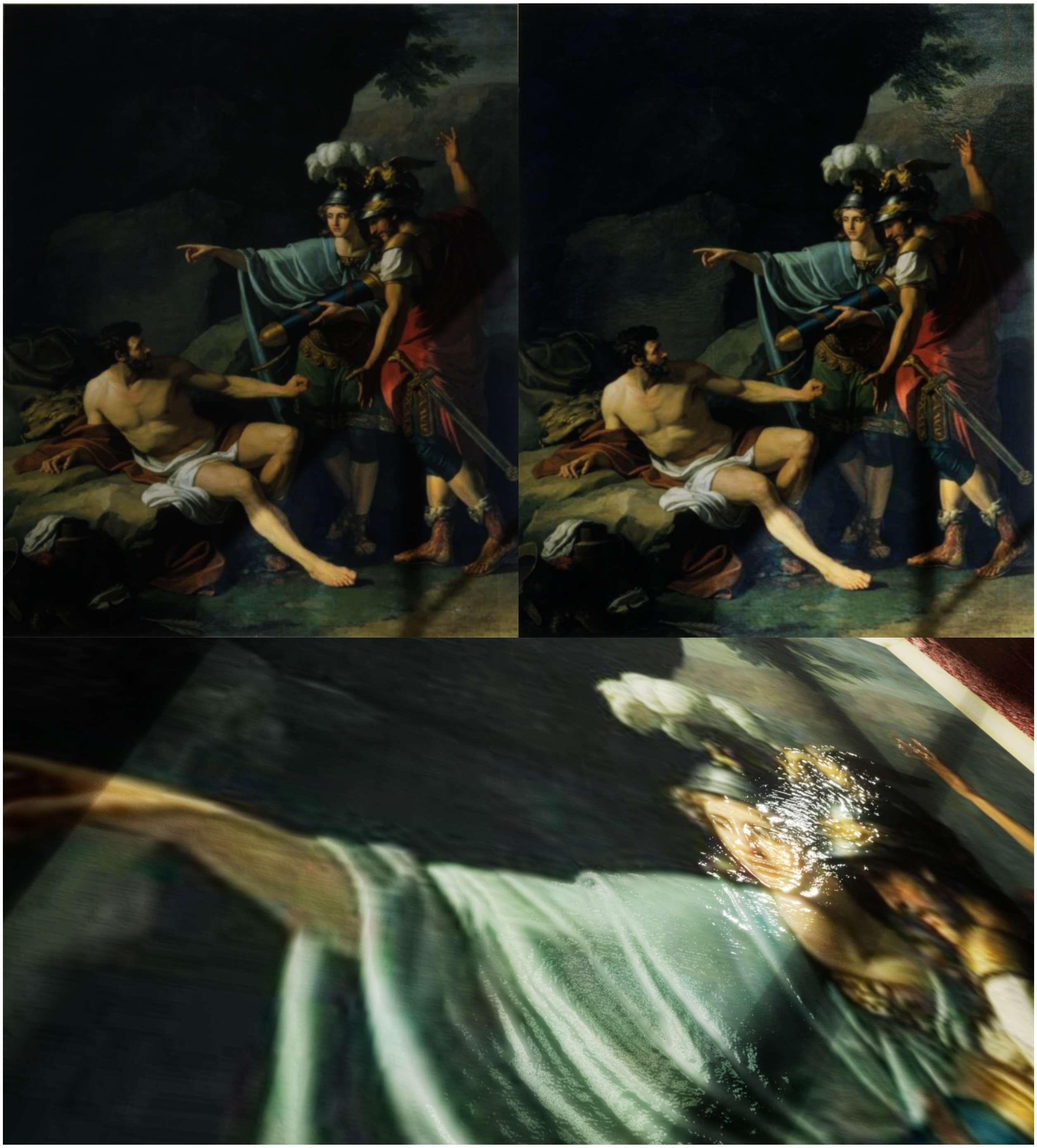

Figure 9. Effects of immersive lighting and enhanced painting textures. Techniques applied to Taillasson’s *Ulysse et Néoptolème enlevant à Philoctète les flèches d'Hercule* as a proof of concept. (top left) Screenshot with the new lighting system. (top right) After application of the normal map from Figure 8. (bottom) Screenshot of the previous image from a different angle.

Figure 10. Digital restoration. (left) Original image of *Achille traînant le corps d'Hector devant les murs de Troie et sous les yeux de Priam et d'Hécube, qui implorent le vainqueur* by Antoine François Callet. (right) After several rounds of digital enhancements.

Figure 11. AI art generation using Hotpot.ai. (top) Painting of farmhouse exterior produced by the Hotpot AI. (bottom) *Cour de Ferme* by Nicolas Bernard Lépicié.

Figure 12. AI art generation using Bluewillow. (top) Painting of a landscape produced by the Bluewillow AI. (bottom) *Grand View of the Sea Shore Enriched with Buildings, Shipping, and Figures* by Claude-Joseph Vernet.

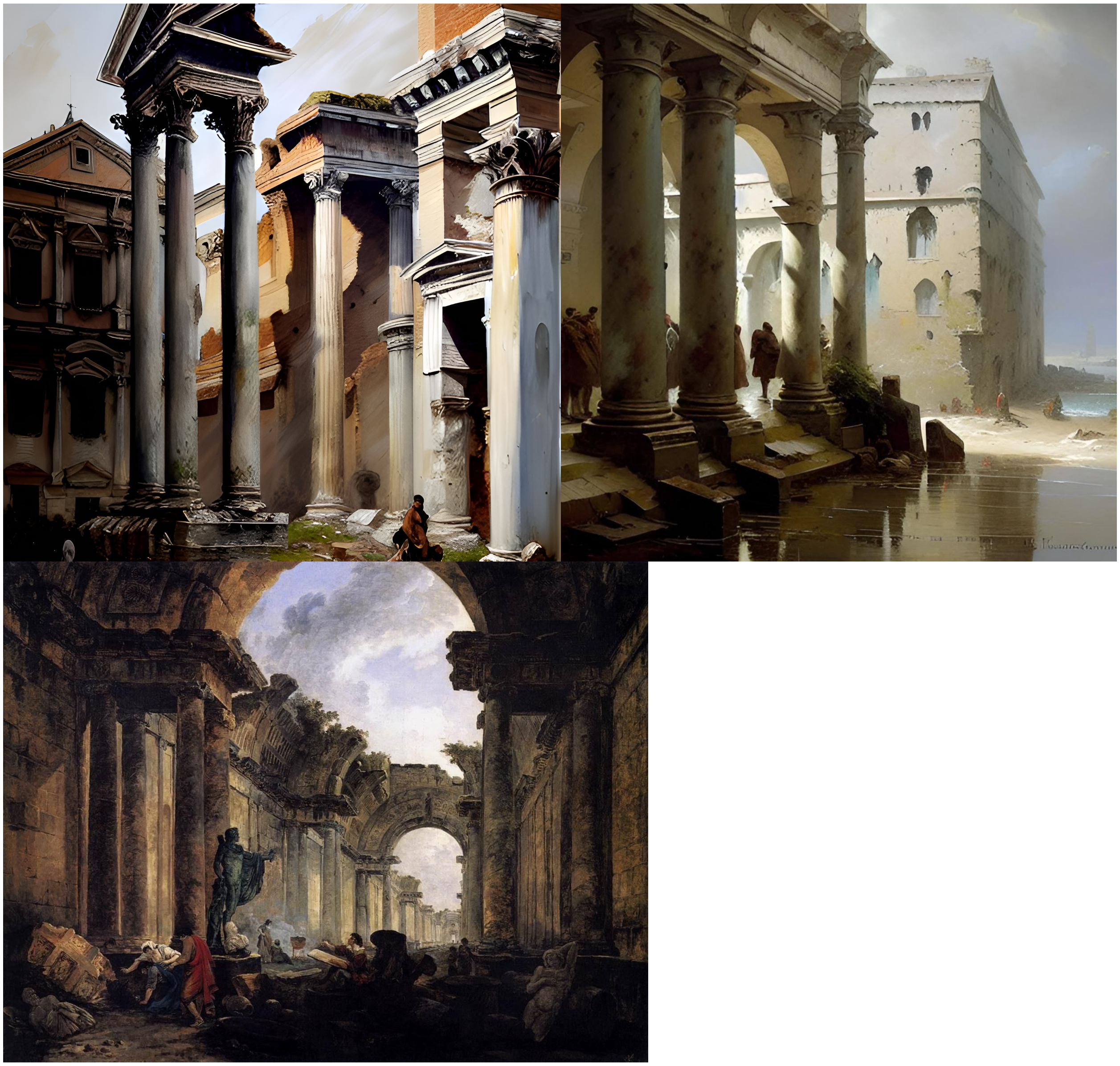

Figure 13. AI art generation using Wonder. (top left and top right) Paintings of Rome in ruins produced by the Wonder App. (bottom) *Imaginary View of the Grande Galerie in the Louvre in Ruin* by Hubert Robert.

TABLES

Table 1: Representative list of artwork in the scene. The list contains one chosen work from each of the painters on display in the scene. The listing numbers, artist names, and titles of the artwork are taken from the brochure for the Salon of 1785 (the *Livret* in Liepmannssohn, 1870).

#	Artist Name	Title of Work
1	Joseph-Marie Vien	*Retour de Priam avec le corps d'Hector*
4	Charles-André van Loo (Vanloo)	*La Fille de Jephté allant au - devant de son pere*
7	Nicholas Guy Antoine Brenet	*Piété & générosité des dames Romaines*
9	Louis Jean François Lagrenée	*Moyse sauvé des eaux par la fille de Pharaon*
18	Louis Gustave Taraval	*Hercule-Enfant étouffant deux serpens dans son berceau*
19	François Guillaume Ménageot	*Cléopâtre rendant son dernier hommage au tombeau d'Antoine*
22	Joseph-Benoît Suvée	*Aeneas fighting against the destruction of Troy*
63	Jean-Simon Berthélemy	*Manlius-Torquatus, condamnant à la mort son Fils*
68	François-André Vincent	*Arria and Poetus*
101	Adélaïde Labille-Guiard	*Portrait of a woman busy painting with her two students looking on*
103	Jacques-Louis David	*Serment des Horaces*
106	Jean Baptiste Regnault (Renaud)	*Mort de Priam*
110	Jean-Joseph Taillasson	*Philoctete à qui Ulisse & Néoptolème enlèvent les Alèches d'Hercule*
119	Adolf Ulrik Wertmüller	*Marie Antoinette and her children walking in the park at Trianon*
178	Jean-François Pierre Peyron	*L'héroïsme de l'amour conjugal Alceste*

Table 2: Details about the representative works of art. The scene location refers to which wall of the Salon the painting was located on, as seen in Pietro Martini's *Salon de 1785* engraving. The width and height were taken from the *Livret* (Liepmannssohn, 1870). Texture file sizes are listed before and after optimization and compression.

Livret Number	Scene Location (wall)	Width (cm)	Height (cm)	Edited for Power of 2 Size (kb)	Optimized Texture File Size (kb)
1	North	396.2	396.2	1940	285
4	North	243.8	304.8	506	80
7	North	243.8	304.8	571	84
9	North	243.8	304.8	573	88
18	North	304.8	304.8	654	102
19	North	304.8	304.8	591	98
22	North	243.8	304.8	835	235
63	East	243.8	304.8	807	122
68	West	243.8	304.8	2120	284
101	East	142.2	198.1	1710	253
103	North	396.2	304.8	803	129
106	East	304.8	304.8	643	99
110	East	228.6	284.5	6030	258
119	North	228.6	304.8	1710	262
178	East	304.8	304.8	1940	307

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