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Reference Assets: Leveraging traditional photographic techniques to improve 3D object renditions

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Abstract

As 3D Imaging for cultural heritage continues to evolve, it's important to step back and assess the objective as well as the subjective attributes of image quality. The delivery and interchange of 3D content today is reminiscent of the early days of the analog to digital photography transition, when practitioners struggled to maintain quality for online and print representations. Traditional 2D photographic documentation techniques have matured thanks to decades of collective photographic knowledge and the development of international standards that support global archiving and interchange. Because of this maturation, still photography techniques and existing standards play a key role in shaping 3D standards for delivery, archiving and interchange. This paper outlines specific techniques to leverage ISO-19264-1[1] objective image quality analysis for 3D color rendition validation, and methods to translate important aesthetic photographic camera and lighting techniques from physical studio sets to rendered 3D scenes. Creating high-fidelity still reference photography of collection objects as a benchmark to assess 3D image quality for renders and online representations has and will continue to help bridge the current gaps between 2D and 3D imaging practice. The accessible techniques outlined in this paper have vastly improved the rendition of online 3D objects and will be presented in a companion workshop.

Motivation:

The motivation for this work is a mission-driven goal to improve the visual continuity between 2D and 3D imaging of cultural heritage objects. Additionally, the work aims to forefront the standards necessary to archive and deliver consistent high-fidelity 3D object representations to our global audience. Museums and other cultural institutions continue to invest in 3D imaging in an ongoing quest to record, preserve, and share the worlds heritage. While the benefits of 3D imaging are well-documented, when compared to traditional photographic documentation, most agree that a well-executed still photograph conveys an objects volume, construction, material qualities, condition and dimensionality in a fraction of the time it takes to create a 3D model. From a resource point of view, Photographic documentation is a mature, efficient process.

This is not an accident; the standards and file formats for still imaging have advanced over the decades to allow for efficient archiving delivery and interchange. In short, still photography remains the globally accepted primary method of visually representing objects. For computer graphics, and even AI generated images, the general measure of success is achieving "Photographic Quality". To that end, this paper explores the direct application of objective still imaging quality standards (such as ISO19264-1) and translation of time-tested photographic stylization and lighting techniques as benchmarks to assess and improve the quality of 3D content, with a focus on rendition and online delivery.

Background:

What is Photographic Quality? Is it spatial resolution? Is it color fidelity? Is it accurate Metrology or material quality? What makes a successful object photograph? It turns out it's a combination of all the above, with the added element of carefully considered lighting and composition. For successful 2D and 3D imaging, the color accuracy, lighting and primary camera view are key to visually conveying volume and depth. As it stands today, a well-executed two-dimensional photograph can potentially convey volume and depth more effectively than a 3D model rendered or displayed to the observer with unintended lighting, color fidelity, or camera view. Presenting a 3D model complete with attention to lighting, camera composition, accurate color tone, carries the best attributes of still photography forward in addition to the obvious benefits of 3D data.

An early test of 3D web delivery on our object pages, captures the essence of our investigations into photographic quality versus 3D Imaging. The traditional photography of the object (left) incorporates the lighting and primary camera view necessary to convey the important qualities of the object. Even though the 3D model (right) is technically accurate, without the correct camera view and lighting stylization, the perceived image quality suffers. Even to the casual observer, the 2D and 3D images are visually incompatible. The challenge of maintaining image quality is one reason we have hesitated to broadly share 3D images online.

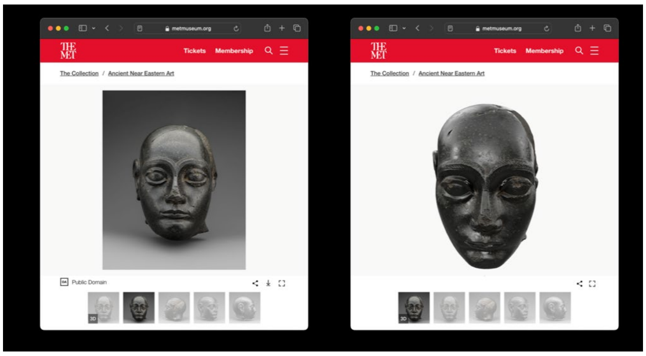

***Figure 1**. The Head of Gudea Object Page: Left 2D Photography, Right 3D Model. The 2D Photographs successfully convey the form and surface quality of the object. The online 3D rendition is less effective and is visually incompatible. Accession Number 49.26 (Link to Met Collection Page)*

Methodology:

Our process is based upon first establishing objective imaging performance criteria for 3D renditions based on existing 2D imaging performance benchmarks. Once an objective baseline is established, studio photography lighting reference sets are replicated to introduce traditional photographic stylization to 3D renditions.

Establishing a baseline for imaging performance:
• Create a baseline method for exposure and color assessment
• Validate 3D exposure and color rendition (ISO 19264-1) [1] [2]

Create and translate studio lighting to 3D renditions:
• Create reference studio photography sets
• Replicate studio lighting in 3D scenes
• Apply studio lighting to 3D renditions

Creating a Baseline Method for 3D Exposure Assessment:

Photography quality and process control begins with exposure. To establish a basis for 3D rendition exposure (as well as tonal response), we created a synthetic 3D Linear Grayscale chart model. The chart model includes the L* values between 5 and 95, as well as dimensional cube and sphere elements that indicate the sRGB equivalent values of L* 5, 50 and 95. Because this target is an original design, we can share it with the community.

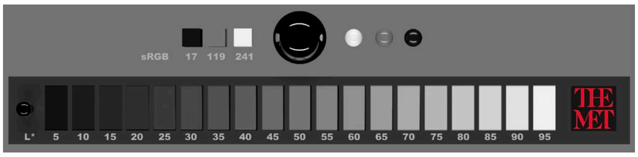

Figure 2*. A Synthetic L* based grayscale model with sRGB values for objective exposure validation. The metallic sphere is used to record the scene illumination geometry*

Creating a Baseline Method for 3D Color Assessment:

Based upon the early work of Chris Heins on evaluating color for Photogrammetry, Wilson Santiago and Deepa Paulus from our Imaging team created a Synthetic 3D color chart based upon spectral measurements of a DCSG color chart. A Myro handheld Spectrophotometer was used for chart measurement. While we have been using this virtual chart for internal testing for quite some time, it's our goal to create a virtual version of the FADGI ISO target that could be broadly distributed.

Why Virtual Charts?

While it is possible to create a 3D model of a color chart using Photogrammetry or other capture methods, there will always be deviations from the original chart values. The focus of this work is to establish a basis for the evaluation of output renditions for 3D scenes. The use of measured source chart reference data values provides the necessary ground truth for objective assessment of scene renditions. [3]

Creating a Copy Stand 3D Scene:

Our approach begins with creating a 3D "Digital Twin"- A 3D replication of a typical 2D copy stand. The illumination distances and geometry were translated from a physical copy stand, and the elements were brought together as a 3D scene in Adobe Stager. Area lights were positioned to simulate traditional reprographic lighting. The virtual DSCG and Linear Grayscale are placed into the scene. One camera is situated to view the copy stand set, and one positioned to frame the color charts.

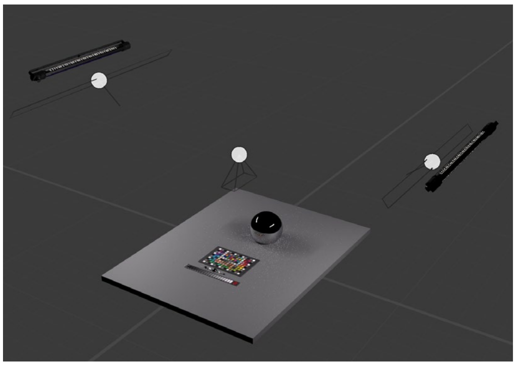

Figure 3*. A 3D copy stand scene used for ISO19264-1 rendered color validation. Note the camera and lighting elements*

Establishing Correct Scene Exposure:

Establishing exposure for a virtual scene is not a straightforward or standardized process across 3D applications. Deconstructing the problem to its basic elements helps provide a roadmap: In our scene we have a virtual linear grayscale and color chart with known values, we have known lighting geometry, and we know the color encoding space. If we render the scene to a Tiff, and read the chart values in Adobe Photoshop, the light output in the scene can be adjusted until the chart (L*95) patch is correctly exposed in the resulting output file. This can be a slow iterative process but will work with any software capable of rendering 3D scenes to still images.

For our reference asset testing we utilized Adobe Stager because its accessible to users that don't have extensive 3D experience. Plus the direct integration with Adobe Photoshop helps to bridge between 3D and 2D. Like many 3D Digital Content Creation (DCC) software, Stager does not have a traditional eyedropper tool to directly readout scene values. To avoid the time-consuming iteration of renders to assess exposure we created a workable interim solution:

The virtual Linear Scale includes a dimensional cube target element corresponding to L*95 (sRGB base color 241,241,241). This is a key element to assess scene exposure. The output RGB value can be measured when in ray tracing mode by selecting the object's base color material property and using the eyedropper tool to read the values. We have reached out to Adobe to consider adding a digital light meter tool that would help with verifying exposure in the main UI.

Once the correct white exposure is achieved, the DCSG scene can be rendered to a TIFF file. This TIFF file is verified using the same tools used for traditional ISO19264 based Imaging. An ISO 19264 “Pass” result is critical to establish an objective link between 2D and 3D imaging. Note the copy light reflected in the metallic sphere.

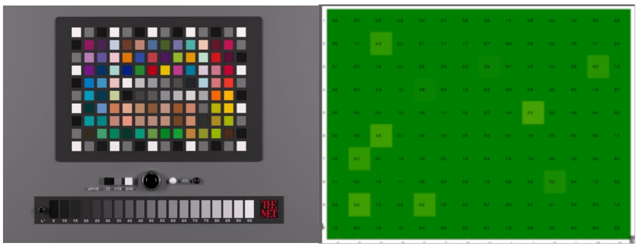

Figure 4. A Stager rendition of a 3D color chart and Linear Grayscale (left) and an ISO19264-1 IQ Analyzer Color Validation Report (right)

Saving the Scene:

Once output is validated, the Stager copy stand scene is saved as a native “.SSG” file. For interchange testing, the scene is also saved as a USDZ file. The USDZ file includes the camera(s), lights, the virtual color charts, the tabletop and associated material maps. The USDZ scene can be opened natively or imported into any DCC application or viewer that supports USD for further evaluation or editing. While the USD file contains all of the necessary elements, each application might utilize different units, world space, color pipeline, UI readouts etc. The goal of 3D interchange is to open, save and collaborate with 3D content across multiple platforms and applications with no visual degradation.

Explorations in 2.5D:

Using the verified copy stand scene, 3D models of paintings and other 2D/2.5D objects can be placed onto the virtual copy stand. As in real life, object colors can be measured with spectrophotometers and verified via sampling colors from rendered Tiffs. This process of placing 3D models into the ISO 19264-1 verified virtual copy stand scene is an important control step for rendered image quality. Objective analysis is key to understanding and evaluating successful 3D interchange.

As an example, we created a still reference photograph and a photogrammetry model of the Van Gogh Wheatfields with Cypresses (accession number 1993.132). In addition to validating the source images to ISO 19264-1, we also captured direct spectral measurements from the artwork.[2] When the 3D model of the painting is placed into the 3D scene, the color is faithful. Of course, while the scene with the chart and painting is color accurate, the copy lighting geometry is not aesthetically pleasing. This underscores the importance of lighting for 3D artwork representations. If the original Van Gogh painting is not flattering under copy stand lighting in the physical world, it won’t look flattering under copy lighting in the virtual world.

Figure 5*. ISO 19263-1 Aims and tolerances can apply to objects in virtual copy lighting scenes. Pictured: 3D Model of 1993.132 Wheat Field with Cypresses with synthetic DSCG, targets and reflective sphere*

Transferring 2D Lighting to 3D Scenes:

Establishing a method for objective validation of color and exposure provides the necessary foundation for creating 3D reference assets. The process outlined in this section has been successfully applied across a collection of Met objects. It is strongly recommended to validate your digital content creation software, and/or viewer pipeline using a repeatable 2D scene (as described above) before attempting to light and render 3D objects. DCCs and web viewers are not standardized and were not built from the ground up with interchange in mind, so establishing a baseline is essential.

Photograph an Object:

1) Create a studio photograph of a collection object. When the camera and lighting are completed for the primary view, the set is ready for documentation

Figure 6*. Reference photograph of a Ewer 44.15 by Met Senior Photographer Oi-Cheong Lee (100MP Hasselblad with Studio Lighting)*

2) Using a smartphone phone and 3D App, capture a 3D model of the set making sure to record the camera position and all lighting elements and fill cards. (Scaniverse works well but it’s helpful to experiment with other Apps to find the best quality). Typically the 3D mesh will carry enough information, but it’s possible to explore Splats as well.

3) Capture additional cell phone still images to help document the scene, with special attention to small scrims and diffusors as these do not always record in 3D

Building the Virtual Set (Adobe Stager):

1) Create a new Adobe Stager project
Import your cell phone reference set model

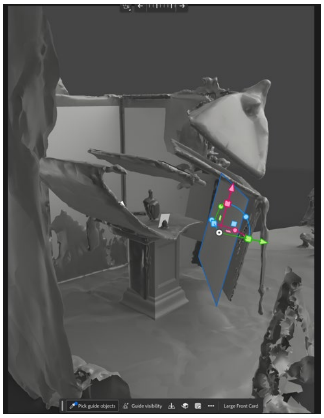

Figure 7*. A 3D Cell Phone model of the photographer's reference lighting set. (Scaniverse iPhone 15Pro) Imported into Adobe Stager. The model is not high-fidelity but provides critical documentation of the lighting geometry and camera position*

2) Add and align the various set elements with the reference model
   a. Insert and scale planes for creating flats and scrims.
   Note: A plane renders as single sided in some 3D tools
   b. Make note of materials i.e. matte/silver cards, foamcore, diffusion materials. Select objects and apply simple material properties for diffusion transparency and reflectivity. The use of basic material properties helps to improve interchange

3) Add a light source to the scene
   a. Scale an area light to the size of the primary light source (in this case a 3X4 soft box). You can group the light source with the soft box model downloaded from the Adobe asset library to facilitate moving the elements
   b. The Exposure and Intensity sliders will need to be close to full brightness

Note: There are different approaches to illuminating 3D scenes. While lights typically interchange between 3D applications via USDZ, units and behaviors vary. Depending on your mix of applications you may use Emissive textures or procedural light sources to illuminate your scene(s). Its best to use the linear grayscale and copy light scene to evaluate the best approach to lighting for the applications you wish to utilize in your workflow.

4) At this stage, you can disable the low-resolution studio set model and import your 3D object model to the virtual set.

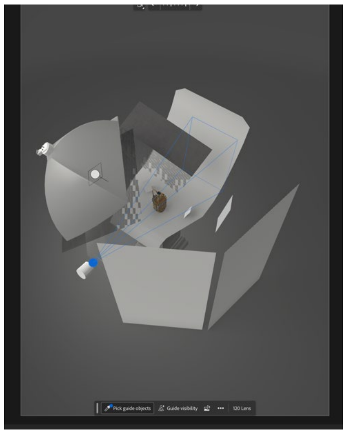

Figure 8 *Using the cell phone scan as a reference, lighting set elements are added and positioned in Adobe Stager. Stands and other supports are omitted*

Note: The shape of the seamless is important. While there are seamless models in the Adobe asset library and online, you can use the 3D cell phone scan as a reference to model the original seamless profile in a program such as Blender for more accurate results.

5) Add a camera to the scene and set the focal length. When the camera is selected, you can fine-tune the camera focal length and view, as well as the desired output resolution in the Transform menu

6) Enable Ray Tracing to preview your work

7) Disable the Environment light leaving the soft box (or other light sources from the original set) as the only source of Illumination in the scene

Figure 9*. The completed set scene with 3D model, camera, lights, fill cards, background and scrims in position with Ray Tracing enabled*

Adjust camera, and fine-tune lighting/reflectors to complete your photographic render using the original photograph as a reference. You can toggle Ray Tracing on and off to help with refresh rates.

8) Switch to the Render mode, select your camera, resolution and quality. Select 16 bit .PSD. The rendered result will be a 16 bit layered .PSD file complete with background masks

Figure 10 *Reference photograph (Left) Initial 3D model render (Right) 3D Model created by Imaging Applications Manager Wilson Santiago*

9) If your rendered result does not match the reference photograph, you might consider adjusting the light exposure values or selecting the base color (or other texture channels) for editing. When you click edit in the Stager Base Color panel, the textures will open directly in Adobe Photoshop. After editing, the texture will be saved as a version and will replace the original texture

10) Re render the image and evaluate

Figure 11*. Reference photograph (left) Adjusted 3D model render (right)*

Note: It's important to document the unedited texture render results to better understand why the render does not match the reference photograph. In this exercise, it's critical to uncover and explore failure points such as:

•A color mismatch in the photogrammetry captures/model
• Incorrect scene light output values
• Incomplete or incorrect object material properties
• Color pipeline / viewport misconfiguration

11) Save the Stager Scene and Export the Scene as a USDZ file for future use. When saving the USDZ include the scene lighting

Note: This process can be performed in any application that supports ray tracing. The key is leveraging the linear grayscale and objective color validation under well-defined copy stand illumination to establish a baseline for exposure and color. Establishing control of as many variables as possible with a known baseline helps separate failures in the rendering pipeline from failures in the capture pipeline. (Capture errors are outside the scope of this paper)

The Problem with Online 3D Viewing:

We have successfully created and rendered a 3D scene that includes a camera, lights, and a color chart. We have illustrated that it's possible to render an image that compares well to a reference photograph, but sharing this 3D model online with the same fidelity introduces additional uncontrolled variables. Without establishing control of the important camera view(s) and lighting information, quality is unpredictable and difficult to control.

Figure 12*. The same 3D model as it presents online via Google Model Viewer with default settings. The original intention and ultimately image quality is lost*

Until very recently, the challenge with online 3D viewing and interchange is that the all-important lighting and tone mapping is often applied generically to assets in the DCC or web viewer. While a well-engineered 3D delivery pipeline can be configured to apply the correct lighting and tone mapping to assets, it's more common for generic defaults to be applied. The problem is that each tool utilizes different baseline interpretations for elements necessary to control image quality such as lighting, exposure, color, tone mapping etc. Under these circumstances, it's highly unlikely that your intended color, camera view, and lighting will be properly conveyed to the observer.

Steps to Improve Online 3D Viewing:

Utilizing the USDZ studio scene export, it's possible to create an HDRI lighting environment to improve online viewing quality while potentially improving consistency across 3D application viewport configurations. [4] An HDRI map (High Dynamic Range Image Map) is a common method in computer graphics that utilizes an Equirectangular High Dynamic Range image projection of the world surrounding a 3D object. When reprojected onto a 3D model in a scene, HDRIs can be effective to convey the original scene illumination. As a form of Image Based Lighting, HDRI has certain limitations. The primary limitation is that an HDRI environment illuminates the entire scene projected from the same distance. Aside from adjusting the orientation of the environment relative to the scene, the light relationships are fixed. An HDRI is not a substitute for the precision of Ray-Traced lighting in terms of realism, but the creation and application of custom HDRI lighting environments contributes to achieving the goal of improved image quality, especially for online representations.

Note: As of this writing, Adobe Stager does not export HDRIs from the area or emissive texture lights utilized in our virtual studio set scenes. While Stager does generate HDRIs from its own generative lighting tools, this approach does not lend itself to recreating still life sets. We anticipate improvements in HDRI creation and interchange. For the time being, we can take advantage of USDZ to export our studio sets from Stager to Blender to generate custom HDRI's.

Why not Camera-Based HDRI's?

HDRI's are typically created using 360 cameras to capture a series of exposure bracketed images of real environments. These images are stacked and processed into HDRI maps, but at least for still life applications there are some drawbacks:

1) Still Life photography is often captured using electronic flash. 360 captures of still life sets only capture the model lamps that are not proportional
2) Exposure and color accuracy are difficult to measure and control
3) Captures include everything in the environment including chairs, stands, people, and other non-essential information

Generating HDRI's via Blender from Adobe Stager via USDZ:

1) Import the USDZ studio set scene into Blender. You will see the art object model, light sources, fill cards, seamless, scrims and cameras are available.

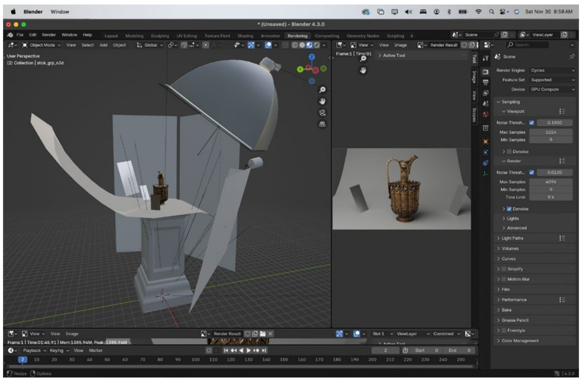

Figure 13. The lighting set scene exported as a USDZ shown imported to Blender. Cameras, lights, set elements, and the 3D Art object model are included in the single USDZ file

2) Configure a Camera in the Scene
    a. Hide the art object in the scene
    b. Place a new camera in the center of the set (artwork position) facing the original camera position.
    c. In the Object Properties dialog enter Camera Rotation X= -90Y= 90 Z= 0 (settings may vary)
    d. In the Camera Properties dialog select "Panoramic" and "Equirectangular"

3) Configure Blender for HDRI generation
    a. In the Render Dialog select "Cycles"
    b. Configure the Output Properties to "Radiance HDR", Resolution X=1024 Y=512(Maintain 2:1 proportions)

4) Select the light source(s) in the scene and adjust the output.

Note: Blender utilizes different illumination units than Adobe Stager, and neither correlate to physical real-world units. In practice, emissive texture lights seem to be the most successful for the Cycles rendering option. It's best to begin with the simple copy light chart scene to test exposure before working with more complex lighting sets.

5) Select "Render Image" from the Render dropdown to generate an HDRI

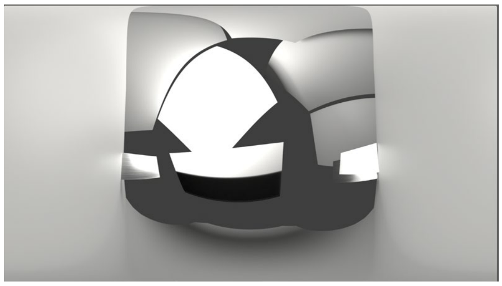

Figure 14. An HDRI environment generated via Blender

The advantages of generating custom HDRIs compared to camera-based HDRIs are as follows:

•More control over color and exposure values
•Easier to create lighting variations
•No need to align and process HDRI 360 camera image capture sets
•No need to clean up/remove unnecessary elements

Applying HDRIs to improve renditions in online viewers:

Some 3D DAMs and 3D web viewers support HDRIs to improve image quality such as Vntana or Google Model Viewer. In these web-based tools, HDRIs are associated with 3D models via a dropdown UI or HTML code. Other viewers and 3D applications support HDRI in viewport preference configurations.

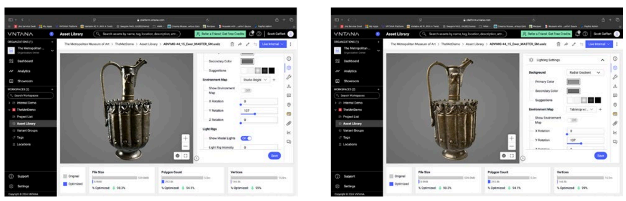

Figure 15. Default view in the Vntana DAM (Left) With Custom HDRI (right)

Recent Developments in HDR Imaging:

From a web delivery point of view, HDRI .exr/.hdr files can be large. While applying custom HDRI's improves the quality of online renditions via DAMs, DCC application viewport configurations, viewing platform configurations or HTML parameters, these lighting environments do not typically travel with 3D assets due to the additional file size. The net result is that HDRI environments are easily disassociated from 3D objects which does not help the reliable interchange of cultural heritage.

Thanks to the convergence of 2D and 3D imaging standards HDRI environment maps can now be compressed utilizing the soon to be ratified ISO Gain Map standard (ISO 21496-1) [5]. If you open an .EXR HDRI file in Adobe Photoshop, you can select the Camera Raw Plug-In to export a compressed gain map HDRI in Jpeg, JpegXL or AVIF format. Using a highly compressed HDRI brings us one step closer to encoding the necessary elements of a photographic quality scene into a single USDZ file. This is a new capability that will take time to gain adoption, but it's important to be aware of in terms of converging standards and interoperability.

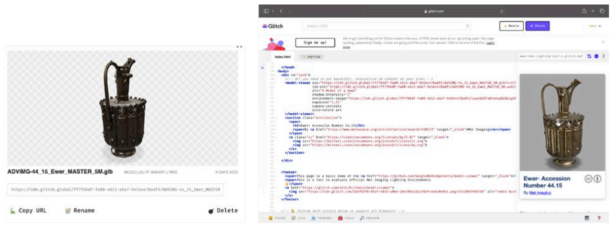

***Figure 16**. Default view in Google Model Viewer (Left) and with a custom HDRI Environment (right). In this example the HDRI was compressed and saved as a Jpeg with an embedded ISO (21496-1) gain map. This preliminary work shows promise for improved online delivery quality*

OpenUSD and Cultural Heritage

Maintaining image authenticity from asset creation to delivery is essential for cultural heritage documentation. Designed as an open interchange file format OpenUSD provides for the archiving and interchange of not only geometry, but also shading/materials, lights, rendering, and is highly extensible. A USDZ file is an uncompressed zipped archive of a USD and associated data. The unique architecture of OpenUSD is the result of decades of work to address real-world challenges unique to 3D content creation and interchange. File formats like OBJ and FBX do not provide for assembling assets or editing the data directly. [6] As methods of capturing complex material properties such as the Kintsugi mature, the extensibility of OpenUSD could enable scaling from a dedicated viewer to broad standardized support. [7] As an added benefit, the core architecture of OpenUSD is inherently aligned with the goals of iiiF. [8] The Alliance for OpenUSD (AOUSD) is an open, non-profit organization dedicated to promoting the interoperability of 3D content through Universal Scene Description. [9] [10] We are advocating for a Heritage USD working group as part of AOUSD to make sure our community is represented during the standardization process. Our reference assets efforts could provide useful data for evaluating the entire process from capture to archiving and delivery.

Reference Assets Findings:

Transferring existing best practice for 2D imaging to 3D imaging has proven to be an effective approach to improving quality.

• Established a practical method to verify 3D scene exposure and color using existing ISO 19654-1 objective analysis
• Established a practical method to create and apply traditional camera and studio lighting techniques to improve 3D rendering and online viewing
• Successfully employed compressed gain map HDRI environment maps (ISO 21496-1) for 3D web viewing
• Exploring 3D interchange format standardization via AOUSD and affiliates

As with any technology exploration, each step forward reveals new questions. Breaking down a complex problem to specific verifiable steps has helped clearly identify areas for further exploration. It is our goal to share selected reference asset datasets with the cultural heritage community, developers, and relevant standards bodies to encourage the dialog necessary to uplift the quality of 3D renditions and associated standards. Leveraging existing scene-referred standards created by and for the cultural heritage community backed by decades of work and scholarly study has been a significant contribution to the wider 3D computer graphics community. When it comes to faithful reproduction of real objects, the cultural heritage community plays an important role in shaping best practice. The first stereo photography (now called spatial imaging) dates back to the 1850's.[11] The development arc of 3D imaging is tightly intertwined with still photography and predates every company in Silicon Valley. Sometimes we need to look back to move forward.

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Author Biography

Scott Geffert is the General Manger of the Metropolitan Museum of Art Imaging Department. Scott is deeply involved with 2D and 3D standards development through the International Standards Organization (ISO), the Alliance for Open USD (AOUSD), and the Academy Software Foundation (ASWF) USD working group, Scott also participates in The Metaverse Standards Forum, Khronos and iiiF 3D and ICC working groups.