AUGMENTING VIRTUAL LUNAR TERRAIN WITH PROCEDURAL AND MACHINE LEARNING MODELS IN REAL-TIME J. M. Gauthier[1] and F. B. Wróblewski[1], [1]Department of Virtual Technology and Design, University of Idaho, 875 Perimeter Drive MS 3021, Moscow, ID (gauthier@uidaho.edu)

Introduction: The creation of 3D environments is time-consuming and requires teams of skilled workers to produce realistic and geometrically accurate environments. Breakthroughs in virtual design technology have introduced procedural modeling, texturing, and machine learning models to help create natural, virtual, landscapes more quickly. Now, the virtual design workspace allows for 3D environments to be generated and populated with content in real time or multiple times a second; tasks that traditionally would require days or weeks when completed manually [1].

NASA has established interest for virtual environments to survey mission objectives and explore science targets through programs like crowdsourced national tournaments [2] and virtual reality departments [3]. Subsequently, the augmentation of mission data has shown proven success through automated delineation of geological features [4] and detection of topographic structures like craters [5], or rock outcrops [6].

We present our concept merging virtual topography and automated augmentation at lunar south pole to create a real-time procedural landscape. We populate digital elevation models (DEMs) of Leibnitz beta plateau with procedurally generated crater geometry to visually model lunar materials and potential hazards in real time. We feed DEM data to simulate a live data stream into Abode Substance and Unreal Engine 5 (UE5) to create a hyper-elevation model: a DEM where the 3D mesh of the local scene is adjusted in higher resolution than the original DEM. Through the generation of craters with this hyper-elevation model, by seeding or random distribution, we consider the potential for exploring dynamic new environments with complex maneuvers, scientific observation, and for Artemis mission objectives.

Data and Software: We create a large-scale level of detail map (LoD) using LRO LOLA DEMs from the Lunar south pole to 85°S at 10 m per pixel. The local scene at Leibnitz beta plateau, and simulated data input, uses laser altimetry DEMs at 5 m per pixel [7].

Unreal Engine 5: We use UE5, a game engine, to render billions of polygons seamlessly from DEMs. This rendering is improved by UE5's Nanite technology, which batches scale-invariant triangles and renders these groups based upon frustum and two-pass occlusion culling [8]. The LoD of UE5 is driven by raytracing, calculated from the local scene and camera geometry, optimizing billions of polycounts from hyper DEMs and displaying the augmented model to the surface.

Adobe Substance Designer: We use Adobe Substance to blend and mix the DEM bitmaps to model craters as individua graphical maps of elements, textures, depth, and structures simultaneously. Adobe Substance is a procedural 3D painter which uses deep-learning models of graphical maps according to surface geometry and scene position. Substance does not require resolution limits like UE5, where visual models may be applied to image data discretely without image tiling.

Data Pipeline: DEM image data was converted to .png formats. LOLA DEMs were divided into a 16 raster grid of 8129 x 8129 cells using ArcGIS Pro and TerraSculptor to form a baseline heightmap. Rasters were then converted to .bmp for Substance encoding.

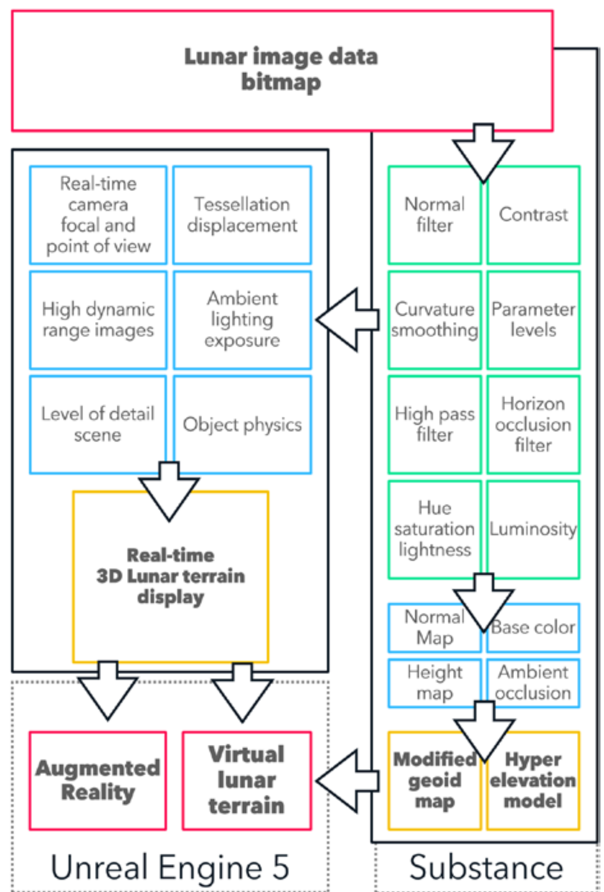

Figure 1: Model pipeline of Adobe Substance (left) and UE5 (right). Substance toolsets are for creating 2D data, UE5 toolsets are for augmenting 3D data.

To generate crater geometry, we use an averaged topographic profile of lunar craters <2km diameter to serve as a template element. Once the final texturing elements are created in Substance, we assign these textures to topographic regions based upon the crater geometry and illumination. In this abstract, we show this step as an adjustment of the laser altimetry DEM at the km- and meter-scale [Fig. 2]. To create the hyper-elevation model, 3D photogrammetry of the *virtual* scene data is used to form a tessellated surface; this is due to the limited export feature of Substance. The photogrammetric height map's 3D mesh is then exported at 8129 x 8129 resolution and coordinated with UE5. In this process, we deadlock real-time elements within view of the free roaming camera in UE5 for a seamless update. This produces the illusion of an animated surface being constructed in real time.

Implications and Future Work: The paramount goal of this research is to create a real-time image processing pipeline to generate material and accurate lighting for terrain seen on the Moon. A visually accurate landscape should replicate photographs. We find that previous material assets were inadequate to represent the lunar landscape, instead, our Adobe Substance pipeline has partially filled this gap with the generation of topographically sensitive texturing. Further, the Moon has been attractive for this pipeline due to its greyscale nature.

We show km and meter scales to highlight limitations of instrument observations within radar (~500m) [9], or from a crewed traverse (sub-meter) [Fig. 2]. The live processing of the lunar surface at these scales may be used for virtually modeling the navigation of lunar vehicles and improving the safety of small-distance walks with collision detection. Because of the wide range of scale, the creation of entirely new heightmaps would be data intensive. We augment the original elevation data without modification in real time, with less processing power overall.

Our streamlined process produces a fully rendered mesh from a single DEM, independent of resolution or scale. From the ground view in we note two observations: 1) lighting and shadows change the perception of the terrain due to extreme shadowing and 2) the size of obstacles results in different potential hazards that may or may not be detected with satellite image data.

Rather than modeling a random position of our crater elements, accurate placement of crater or texturing elements may be derived from higher-resolution image data from NAC image data or low-elevation satellites. Future augmentation may derive from rover or crewed observations, which could feed data in real-time. Our method of augmenting data is sensitive to point and polygon vector features, which may be generated from machine learning models of the surface and further improve placement of fine-scale structures and textures.

References: [1] Fischer et al., 2020 *The Vis. Comp. 36,* 2263-2272. [2] https://www.nasa.gov/coeci/ntl [3] https://www.nasa.gov/centers/johnson/partnerships/eddc/ra/virtual-reality-laboratory [4] Francis R. et al., 2017, *Sci. Rob. 2, 7.* [5] Wagstaff K. L. et al., 2022 *Elsevier, 386, 115146.* [6] Kerner H. R. et al., 2020 *Data Mine. & Knwl. Disc., 34,* 1642-1675. [7] Barker M. K. et al., 2021 *PSS, 203, 1.* [8] Karis B. et al., 2021 *SIGGRAPH21.* [9] González-Saavedra J. P. et al, 2022, *Sensors, 22(8), 3040.*

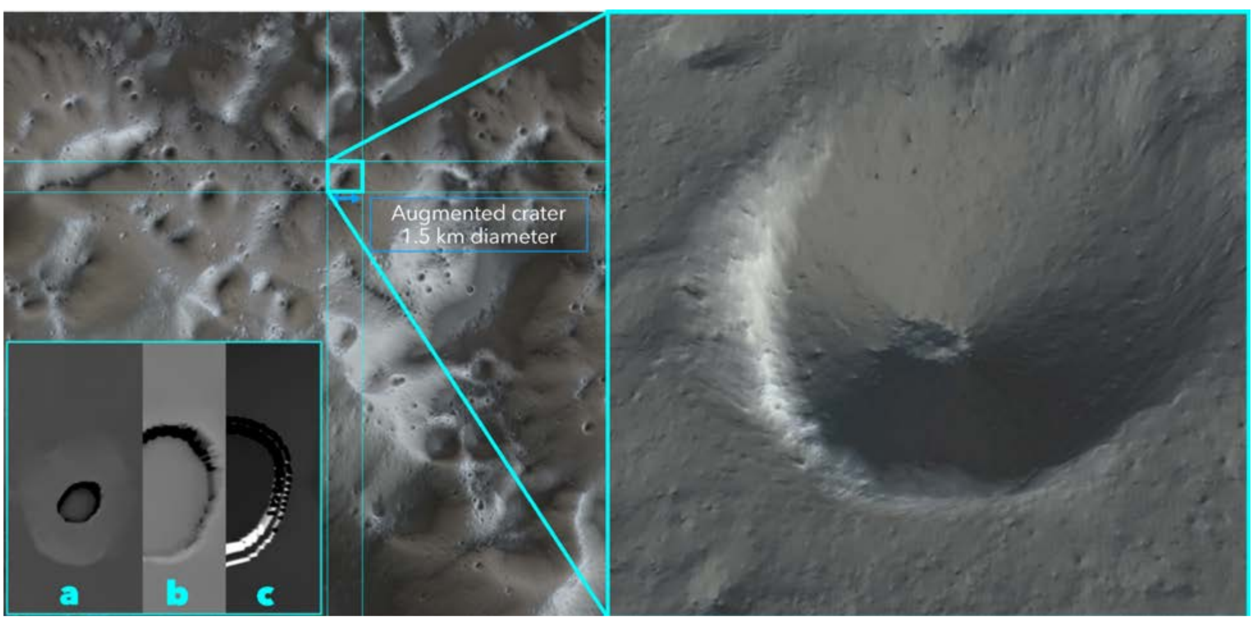

Figure 2: Example of augmenter 1.5 km diameter crater in 2D (left), the crater is generated from 3D height map (right) atop the laser altimetry DEM [7]. Inlaid image (left) shows intermediate steps for 10m diameter craters as a) height map edge detection, b) augmented slope, and c) physically based rendering of the height map.