Visualizing a Particle-based Simulation of an Aggregate Drum Dryer for Hot Mix Asphalt Production

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Abstract

Asphalt pavement consists of various sizes of aggregates coated with liquid bitumen binder and is commonly used for road construction. Producing the asphalt mixture involves heating and drying the aggregates in a rotary drum dryer before the bitumen is added. This process is very energy intensive, so thermal efficiency is a key consideration in equipment design. Using particle-based simulations engineers can investigate the effects of different drum geometries and process conditions to improve dryer efficiency. Improvements to the drying process provide economic benefit to the plant operator in the form of lower fuel costs as well as environmental benefits in reduced emissions. Visualizing the simulation data provides engineers with greater insight into the drying process and permits more effective and efficient designs. In this explanatory visualization, we leverage several platforms and scientific visualization tools to illustrate the asphalt drying process in a very high-fidelity, photo-realistic animation.

Keywords:
scientific visualization, particle visualization, ray tracing, omniverse

1. Introduction

Most roads in Europe and in the United States of America are constructed with asphalt pavement, 90 and 93 percent respectively [1]. Hot mix asphalt (HMA) is the most common method of producing asphalt pavement. In this process various sizes of aggregate, sand, and dust are heated and mixed with liquid bitumen binder at temperatures around 180 °C. ASTEC Industries[1] is a global leader in the design and manufacture of hot mix asphalt equipment. In the ASTEC Double Barrel™ drum mixer, heating aggregates is accomplished in the inner drum which functions as the aggregate dryer. Heat is supplied by a burner, and internal flights lift and veil the aggregates through the hot gasses as the drum rotates. ASTEC engineers used simulation to optimize the internal flighting to maximize heat transfer to the aggregates. Discrete element method (DEM) has been used extensively by ASTEC to design proprietary flights that allow ASTEC dryers to perform efficiently over a range of operating conditions. This simulation methodology has been described previously [2]. Notably, the quantity and complexity of the DEM particle data makes analysis and visualization a challenge. At steady state the simulation contains approximately 640,000 bi-sphered particles along with the drum and flighting geometry. Improved visualization of the particle data permits a better understanding of the drum operation and helps ASTEC engineers improve the drum design. Our explanatory visualization was created to communicate the functions of the drum dryer to customers and the general public. In the future, this visualization will be bifurcated into an explanatory and an exploratory visualization to help engineers better understand and optimize the dryer performance.

2. Visualization Method

To create our visualization we leveraged a couple of well-known scientific visualization tools, VisIt [3] and ParaView [4, 5], and NVIDIA's Omniverse[2] platform that allowed us to create visualizations and animations of varying degrees of fidelity and realism. NVIDIA Omniverse is a multi-GPU, real-time simulation and collaboration platform for 3D production pipelines based on Pixar's Universal Scene Description (USD) and NVIDIA RTX[3]. Omniverse aims for universal interoperability across different applications and 3D ecosystem vendors. It provides efficient real-time scene updates and is based on open-standards and protocols. The Omniverse Platform is designed to act as a hub, enabling new capabilities to be exposed as micro-services to any connected clients and applications.

NVIDIA's Prometheus Linux Cluster was used to run our scientific visualization tools so they could run in parallel and take advantage of the resources available on the cluster. These resources include thirty-six DGX-1V 16 GB nodes with two CPU chips each with 20 cores and IBM Elastic Storage GS4S appliance with 276 TB of SSD storage. All nodes and storage are connected via an InfiniBand EDR network.

[1] `https://www.astecindustries.com`

[2] `https://www.nvidia.com/en-us/omniverse/`

[3] `https://www.nvidia.com/en-us/design-visualization/technologies/rtx/`

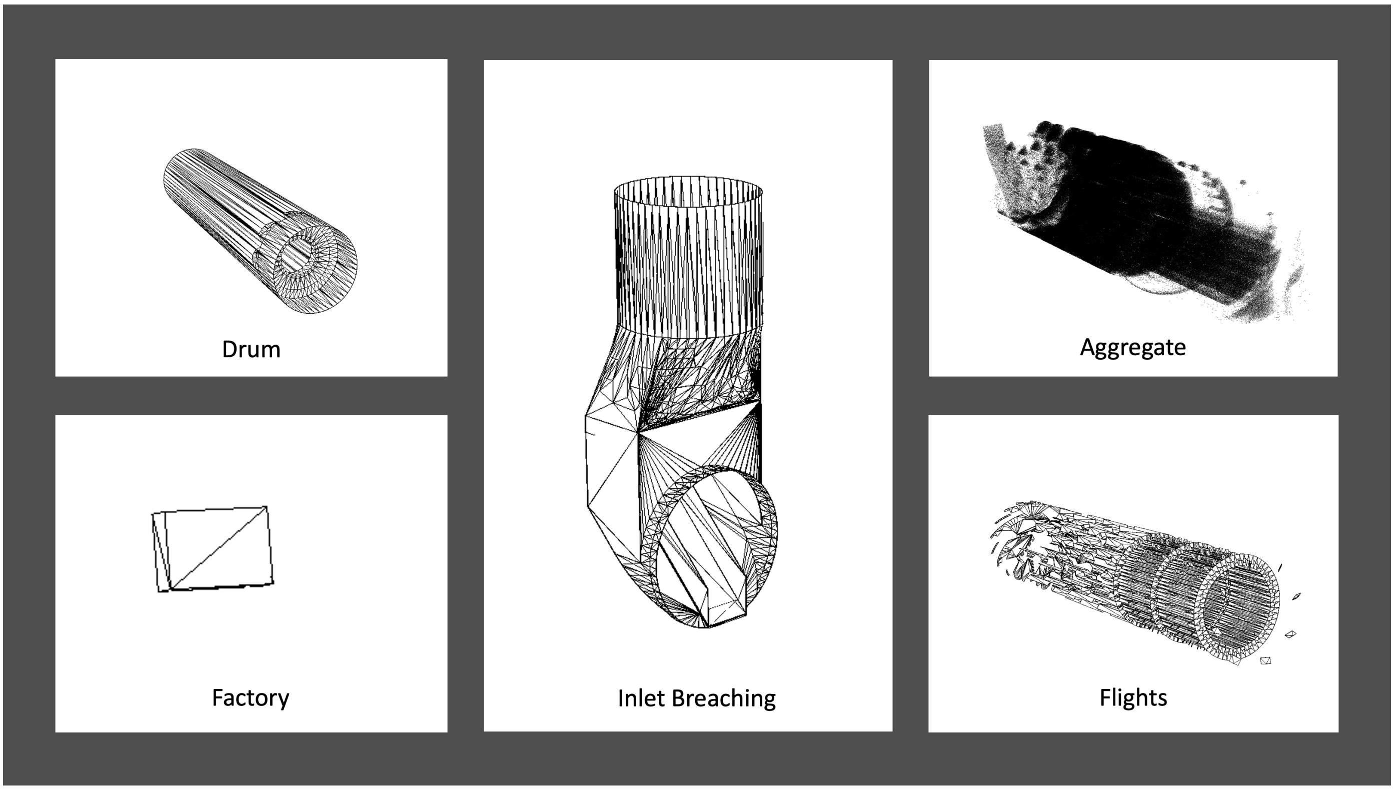

Figure 1: The ASTEC aggregate drum dryer dataset consists of five separate geometries (drum, factory, inlet breaching, flights, aggregate). The drum, inlet breaching, and flights combine to form the drum dryer while the factory is used to generate the particles representing the virgin aggregate used to create the asphalt.

The ASTEC aggregate drum dryer [4] dataset used for our visualization has 750 time steps with each time step containing approximately 1.4 million points and 1.4 million cells (see Figure 1). We converted the dataset from an EnSight [6] file format to VTK's XML binary format for better loading and processing by ParaView. The details of our visualization method are described in Sections 2.1 to 2.4 and shown in Figure 3.

2.1. VisIt

VisIt is a distributed, parallel scientific visualization and graphical analysis tool for data defined on two- and three-dimensional meshes, and can be deployed on a wide range of compute platforms. These platforms range from laptops to the world's most powerful supercomputers. VisIt offers data interfaces to more than one hundred data encoding formats. We leveraged these capabilities to preview the raw ASTEC dataset and convert the data into different formats for better loading and processing on the Prometheus Linux cluster.

2.2. ParaView

ParaView, an open-source, multi-platform data analysis and visualization application, enables users to quickly build visualizations so they can analyze and explore their data using qualitative and quantitative techniques. Researchers use ParaView to analyze massive datasets, and typically run the application on supercomputers to analyze datasets of petascale, as well as on laptops for smaller data.

We used ParaView's infrastructure to load and filter the ASTEC dataset before importing it into Omniverse to create a very impactful, photo realistic visualization (Figure 2). Importing the dataset into Omniverse enabled us to edit and sync our data with any Omniverse Connect application and rendering tools. This is made possible by two main components: Pixar's Universal Scene Description (USD) and the Omniverse ParaView Connector.

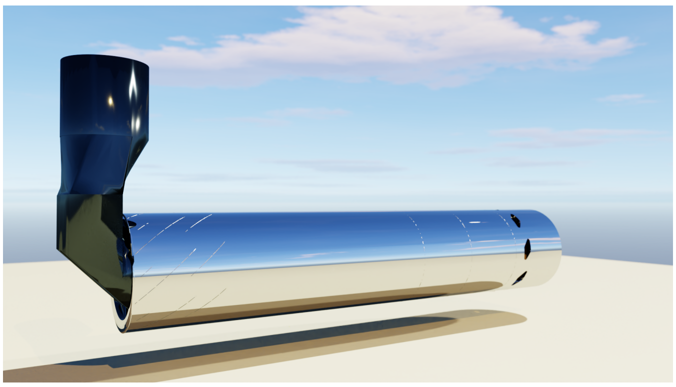

Figure 2: Image rendered using the Omniverse RTX renderer. As you can see, the RTX renderer was capable of simulating the physics of light transport to produce a photorealistic image complete with reflections and shadows.

[4] `/https://www.astecindustries.com/products/details/astec-double-barrel-x-drum-mixer`

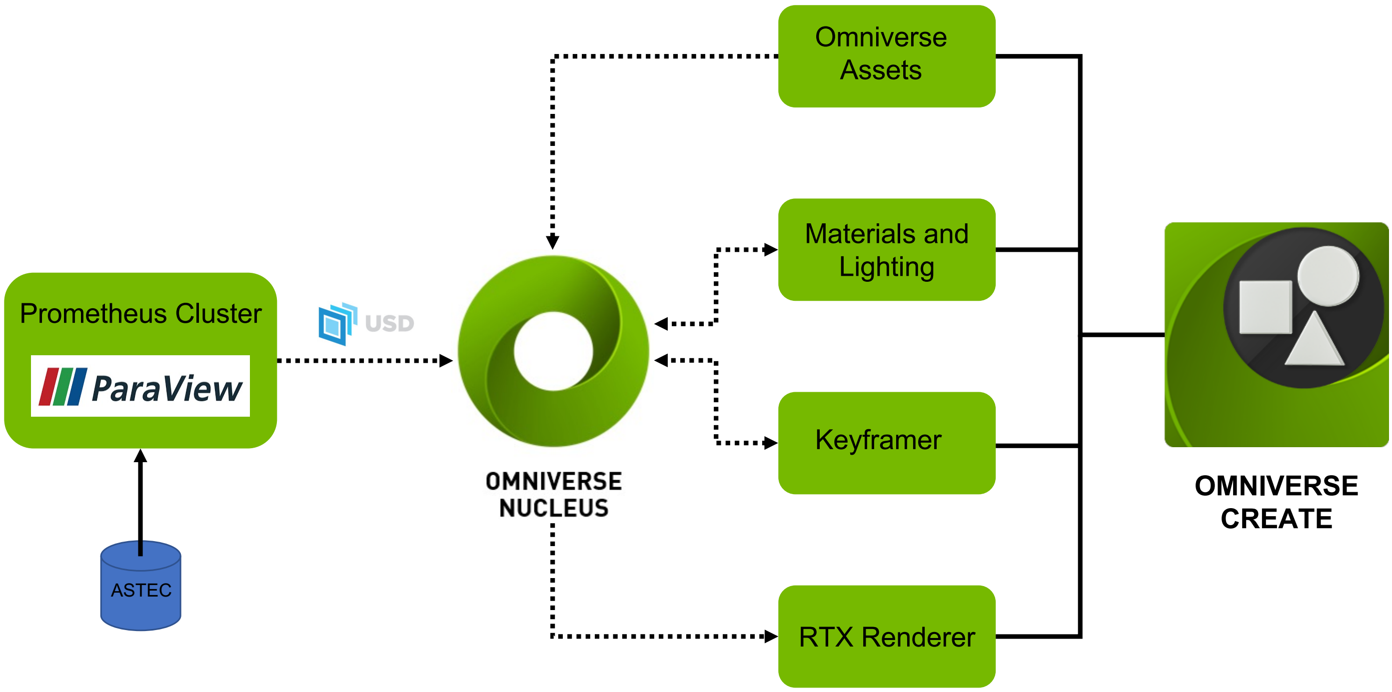

Figure 3: Visualization workflow for the aggregate drying process. The ASTEC simulation data was loaded into ParaView and then imported into Omniverse via the Connector exporting USD to Nucleus. Once in Omniverse, we used the extensions available in the Create application (represented by the solid black line) to create and render our scene.

2.2.1. *Universal Scene Description*

USD is an open-source framework developed by Pixar[5] to provide a common language for defining, packaging, assembling, and editing 3D data [7]. Omniverse uses USD to represent assets and for interchange through the Omniverse Nucleus Database service (Section 2.3). Therefore, datasets loaded into ParaView are converted to USD when connecting to Nucleus for importing into Omniverse. Once in Omniverse, you have the ability to nest USD files in what is referred to as *Layers*. Layers provide a convenient way to organize and manage our scene while also providing a comprehensive workflow. For example, lighting, content, and the environment can each exist on separate layers (nested USDs). Additionally, layers can act to overlay changes onto existing sublayers so that the original content remains intact and multiple variants of the original content can be produced independently and non-destructively. Layers can be set to have a *live mode* for individual layers. The *live mode* feature will show updates in real time of other users working on either the layer directly or within the same root USD. Finally, layers have the capability to scale scenes over time by interpolating the geometry between two timesteps. Utilizing scaling within layers allowed us to create smoother animations for the ASTEC dataset which had a limited number of timesteps.

2.2.2. *Omniverse ParaView Connector*

NVIDIA Omniverse was expanded to address the scientific visualization community with a connector to Kitware ParaView. The connector for ParaView allowed us to output anything ParaView renders directly into Omniverse, or locally to USD, for a quick and easy starting point from which to enhance our scientific visualization. The connector only supports an output path and does not provide a mechanism to import USD data into ParaView.

The ParaView Connector is not a simple file converter, it allows incremental updates as we edit or animate the scene in ParaView. It therefore takes the shape of a *ParaView Omniverse Connector Render View*, which is a workspace that can be opened within ParaView allowing us to choose what parts of a pipeline are visible, and as such, should be transferred to Omniverse. Other render views may be open at the same time and may or may not have Omniverse capability. This allowed us to preview or prepare certain data before sending it to Omniverse or transfer different parts of the data to a different location (e.g., Nucleus server or locally).

2.3. *Omniverse Nucleus*

At the core of Omniverse is a set of services known as Nucleus that allow a variety of Omniverse-enabled client applications, like the ParaView Connector, to share and modify authoritative representations of virtual worlds. Nucleus sits on a network, with clients connected to it, sharing the same authoritative state of a virtual world. Nucleus allows live syncing in the form of a publish/subscribe model, where multiple clients connect to it in such a manner that once one of those clients submits a change (publishes it), every other client (subscriber) will immediately receive that change.

[5] https://www.pixar.com

2.4. *Omniverse Create*

NVIDIA Omniverse Create provided the capability to navigate, modify and render USD content exported by the ParaView Connector. Create is an application that connects to Nucleus and has access to the authoritative scene data shared by any App or Connector to include ParaView. Create takes advantage of advanced workflows of USD (layers, variants, instancing) which allowed us to have a simple but powerful visualization workflow (see Figure 3). By leveraging the stock assets, materials, custom keyframing, and the RTX-based renderer running on an NVIDIA A6000 RTX graphics card, we were able to generate visually compelling and physically accurate simulations of ASTEC's aggregate drying process using one of its aggregate dryers. Sections 2.4.1 and 2.4.2 detail the major components in Create that we used to make our ASTEC aggregate dryer visualization.

2.4.1. *Extensions*

Create provides *Browser Extensions*, or browsers, that allowed us to access a variety of existing asset types to fill out our scene. There are four types of browsers available in Create (sky, samples, assets, materials). The material browser served as a palette for applying different materials to various components in our scene. Materials in Omniverse are supported using the open-source Material Definition Language (MDL) which provides a convenient way to share physically based materials and lights between supporting applications [8]. Figure 4 shows some of the high quality materials we had access to using Create.

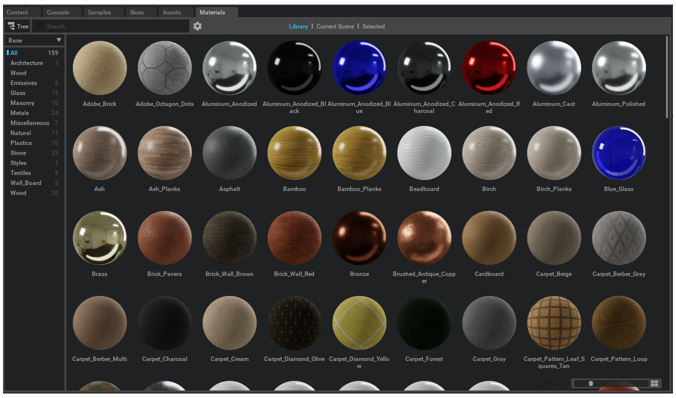

Figure 4: High quality MDL materials available in Create.

The asset browser allowed us to place assets in our scene with minimal effort. These assets were created by NVIDIA or imported from a Digital Content Creation (DCC) tool like Blender or Maya. Figure 5 shows some assets that were available to place in our scene.

One of the easiest and most effective ways to light a scene naturally is with High Dynamic Range Image (HDRI) Illumination using a sky-dome [9]. In Omniverse, a sky-dome is achieved by using a *Dome Light* and then attaching an HDRI image to the light. To make this process easier, NVIDIA has created a growing list of HDRI images to use in Omniverse Dome Lights. The sky browser offers easy access to a variety

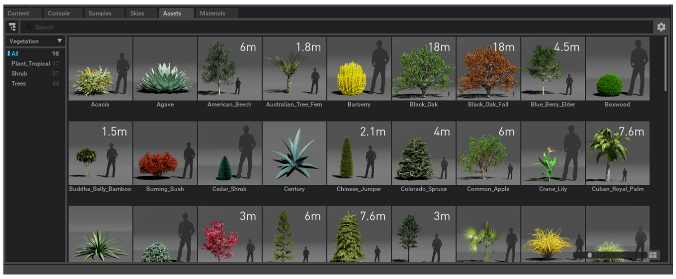

Figure 5: Vegetation assets made available through the asset browser.

of dynamic and HDRI skies which we used to light our scene (Figure 6). Create provided other lighting options that we used to include distant lights and sphere lights. Distant lights were used to emulate the sun and shine light rays on the entire scene. Sphere lights were used to light objects directly since they are pretty much equivalent to a light bulb in the real world.

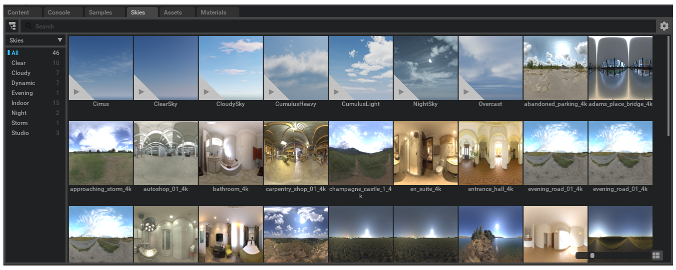

Figure 6: Examples of HDRI sky images for naturally lighting a scene.

2.4.2. *RTX Renderer*

The RTX Renderer was used for path tracing our scene which leveraged NVIDIA extensions to the Vulkan API [10]. As shown in Figure 7, the RTX renderer allowed us to create photorealistic objects and environments with accurate ambient occlusion, reflections, and refractions. NVIDIA's Ampere architecture was leveraged in the RTX A6000 GPU to provide the visual compute power needed to render the ultra high-fidelity path-traced images we used. The RTX Renderer was not only able to leverage the ray tracing cores provided by the A6000, but also the tensor cores which provided additional capabilities like Deep Learning Super Sampling and AI denoising that helped boost overall frame rates and aid in the high-fidelity of the rendered images.

3. Conclusion

The NVIDIA Omniverse platform proved to be a very effective tool for connecting scientific visualization tools, like ParaView, to create an explanatory visualization of ASTEC's aggregate drying process. Our visualization not only allows engineers and the broader community to understand the drying process, but also see the Double Barrel drum dryer interact in an environment that accurately represents the appearance of objects in the scene.

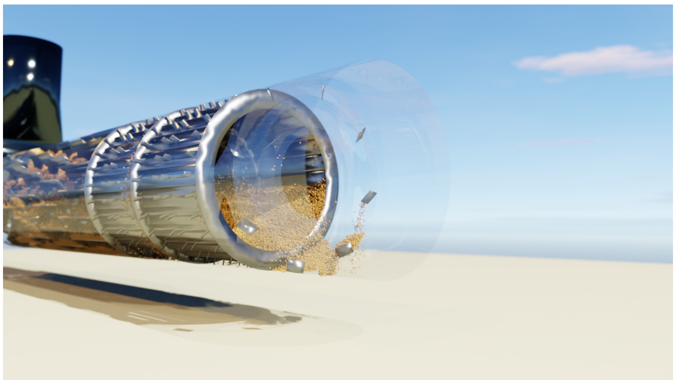

Figure 7: High-fidelity path-traced image with accurate ambient occlusion, reflection, and refraction produced by the RTX Renderer.

In the future, once other simulation elements like particle-fluid interaction with the hot burner gases and liquid bitumen coating and mixing are added to the dataset, this visualization will also be used by engineers to explore the entire HMA production process holistically with the goal to improve performance and efficiency at the plant level.

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