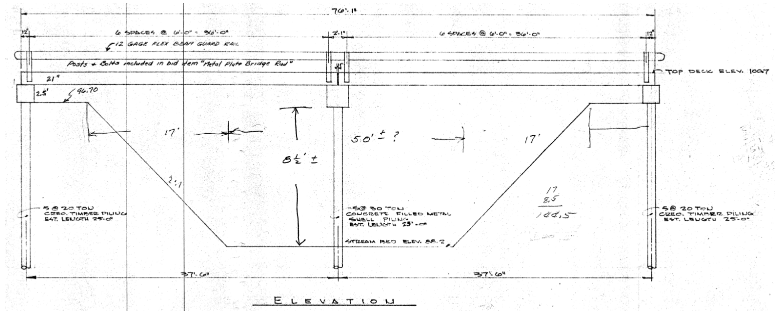

Design and Implementation of Digital Twin Models for Continuous Monitoring and Performance Prediction of Precast Concrete Bridges

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Overall Project Goals

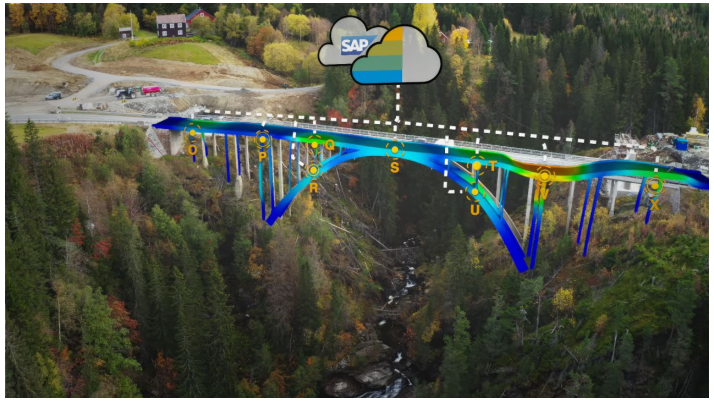
- Design and validate a digital twin model of a precast concrete bridge structure, subsequently integrating this model with sensor data derived from a real-world bridge.
  - This integration will serve as the foundation for driving the simulation and analysis of the bridge model.
- The digital twin model will be constructed utilizing NVIDIA Omniverse, an innovative platform that facilitates the creation of collaborative and immersive 3D objects, equipped with real-time simulation capabilities.

Research Plan

- **Digital Model Development**
  - Explore how to use technical drawings and the design and inspection data that may exist for the bridge itself or the precast parts used in its construction in order to rapidly implement a digital twin model.
  - The outcome of this task is a methodology for rapidly prototyping a 3D model of a PC bridge based on the above-mentioned sources of initial information.
- **Digital Model Implementation**
  - Study how NVIDIA Omniverse platform for digital twins operates and how to build new models within the platform's capabilities, including linking it with external data sources.
  - The outcome of this task is a PC bridge twin model implemented in NVIDIA Omniverse environment.
- **Bridge Analysis and Simulation using Real-Time Data**
  - Enable ingesting real-time data from a specific PC bridge to be incorporated with the digital twin model as well as any readily available environmental data, such as weather, traffic, any imagery. Such data will be used to model the bridge performance and predict its response to different usage conditions.
  - The outcome of this task will be a data-driven digital twin model of a PC bridge updated each time new data about the bridge is available.

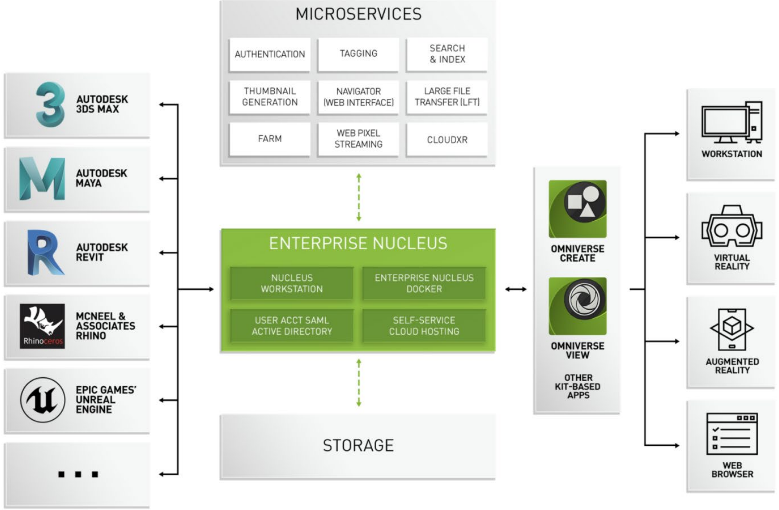
Background: Digital Twins

- A digital twin model is a digital representation that simulates a physical object throughout its lifecycle.
  - It leverages actual data from the object to monitor its status or predict its behavior.
- In the context of bridge monitoring, a digital twin includes a virtual model that reflects the real-time data of the bridge's physical structure.
  - This model utilizes the data to create simulations and forecasts, enabling engineers to assess how the bridge might react or perform under various real-world scenarios.



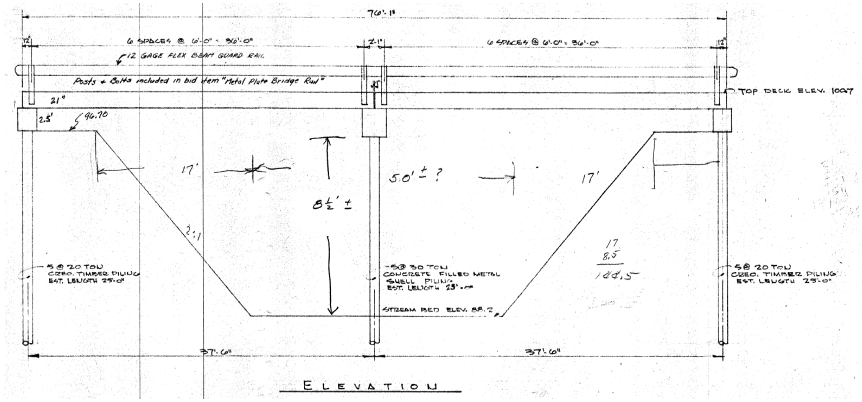
Background: NVIDIA Omniverse

- NVIDIA Omniverse is a comprehensive platform designed for virtual collaboration and real-time, physics-based simulation in 3D design.
  - It establishes a seamless workflow for developers, allowing them to integrate their existing design, analysis, and simulation software to develop digital twin applications.
  - Omniverse offers the flexibility to create custom plugins, known as kit-extensions, which enhance the platform’s capabilities and functionality.

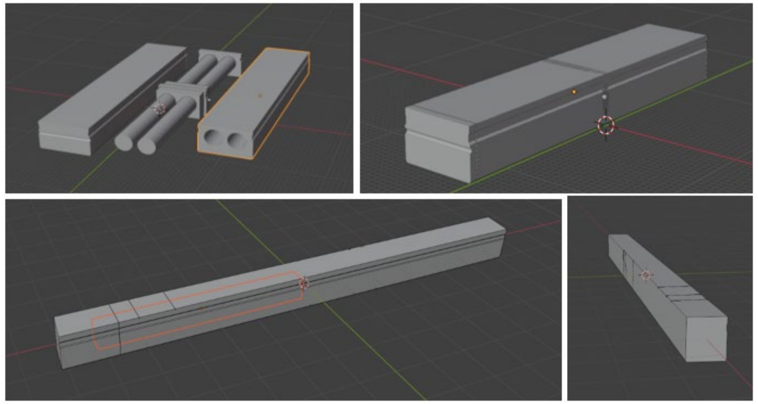


Digital Model Development

We have constructed 3D models of a PPC deck girder measuring 838mm by 914mm and a precast bridge, using Blender based on the provided beam drafts. These models consist of individual components such as beams, columns, and supports, which are crafted separately and then exported in the Universal Scene Description (USD) format. Once exported, these components serve as building blocks that are assembled within NVIDIA Omniverse software to create a comprehensive visual model of a bridge.



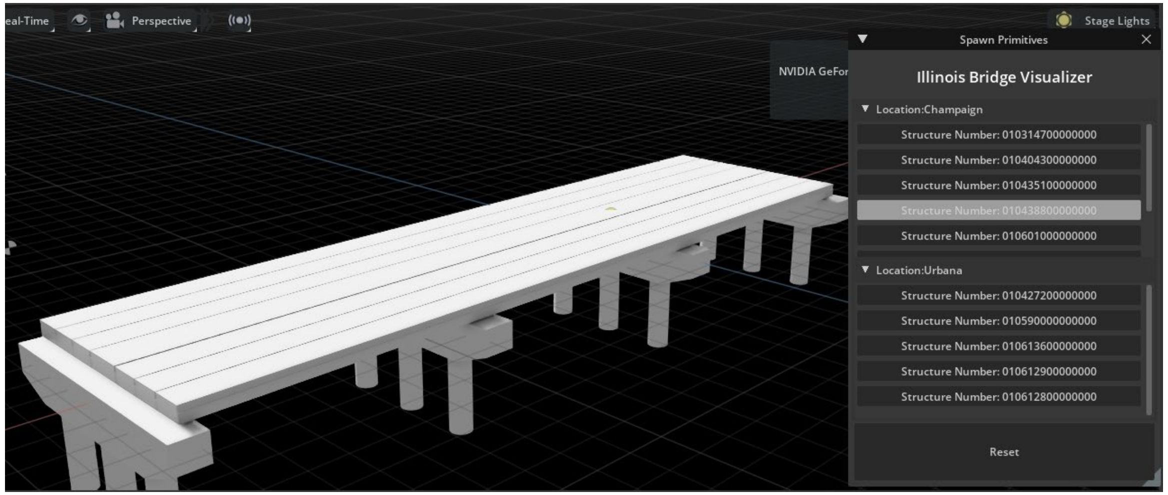
Data Source from sketches of bridge



Basic Beam components modeled in Blender

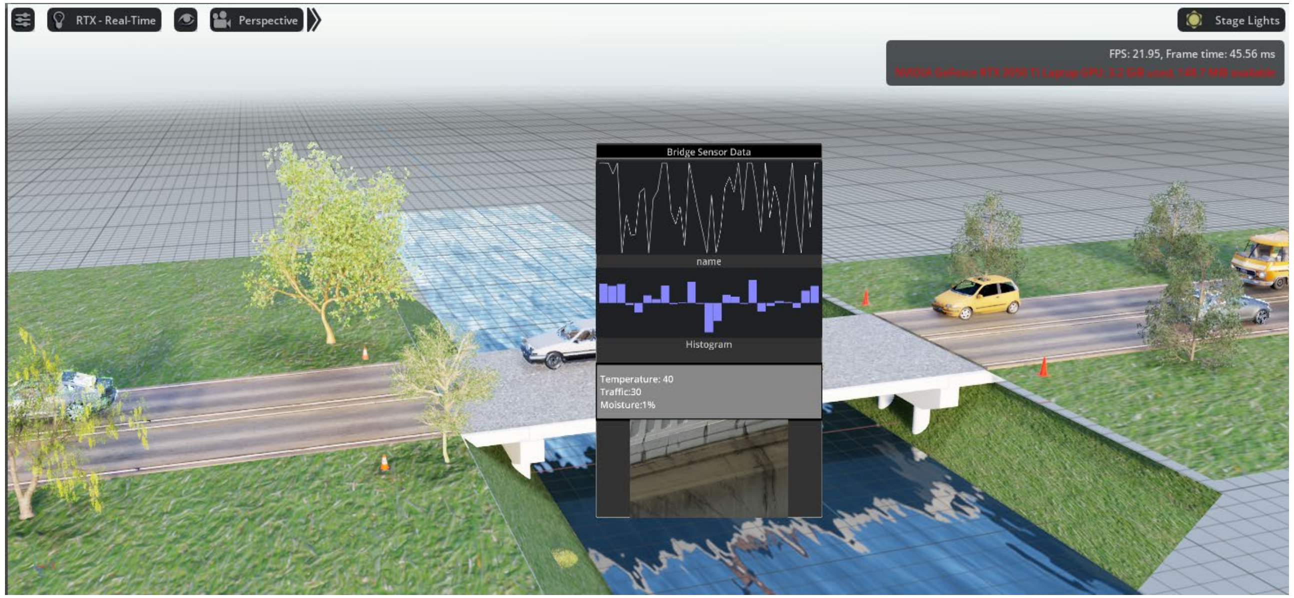
Digital Model Implementation

For the Digital Twin for Bridge Monitoring, we initially created manual representations of bridge models using 3D primitives directly within Omniverse. These models were based on actual bridge descriptions and drawings provided to us.



We have developed an Omniverse extension that, based on the bridge's metadata such as the number of spans, beam type, width, and length, can automatically generate a visual model of the bridge.

Bridge Analysis and Simulation



Customized Extension for Bridge Data Visualization

We have developed an extension for Omniverse that enables users to visualize data from the NBI database for a particular bridge. By selecting a specific bridge component within Omniverse, a widget will appear, presenting the relevant data for that component. Additionally, the extension can display any inspection images associated with that bridge part.

To integrate this extension with actual data, we have utilized recent beam test data collected by the UIUC Civil Engineering Department.

Lab Test of a Beam

1. Starting test

2. Induce Initial cracks

3. Applying load until failure

4. Beam Failure

Test Procedure

We conducted a four-point bending test on an 838mm x 914mm PPC deck girder beam.

Phase1:

- actuator applies incremental load and induces initial cracks to the beam

Phase2:

- increasing the load until the beam's ultimate failure, observing structural behavior, deflection and crack development

Lab Test of a Beam

Lab test on a 533mm x914 mm
IDOT PPC deck girder beam

Data Collection

Camera

Strain gauge + LVDT

Real-Time Data Transfer

1. Crack Segmentation
2. DIC Analysis
3. Experiment replay in Omniverse

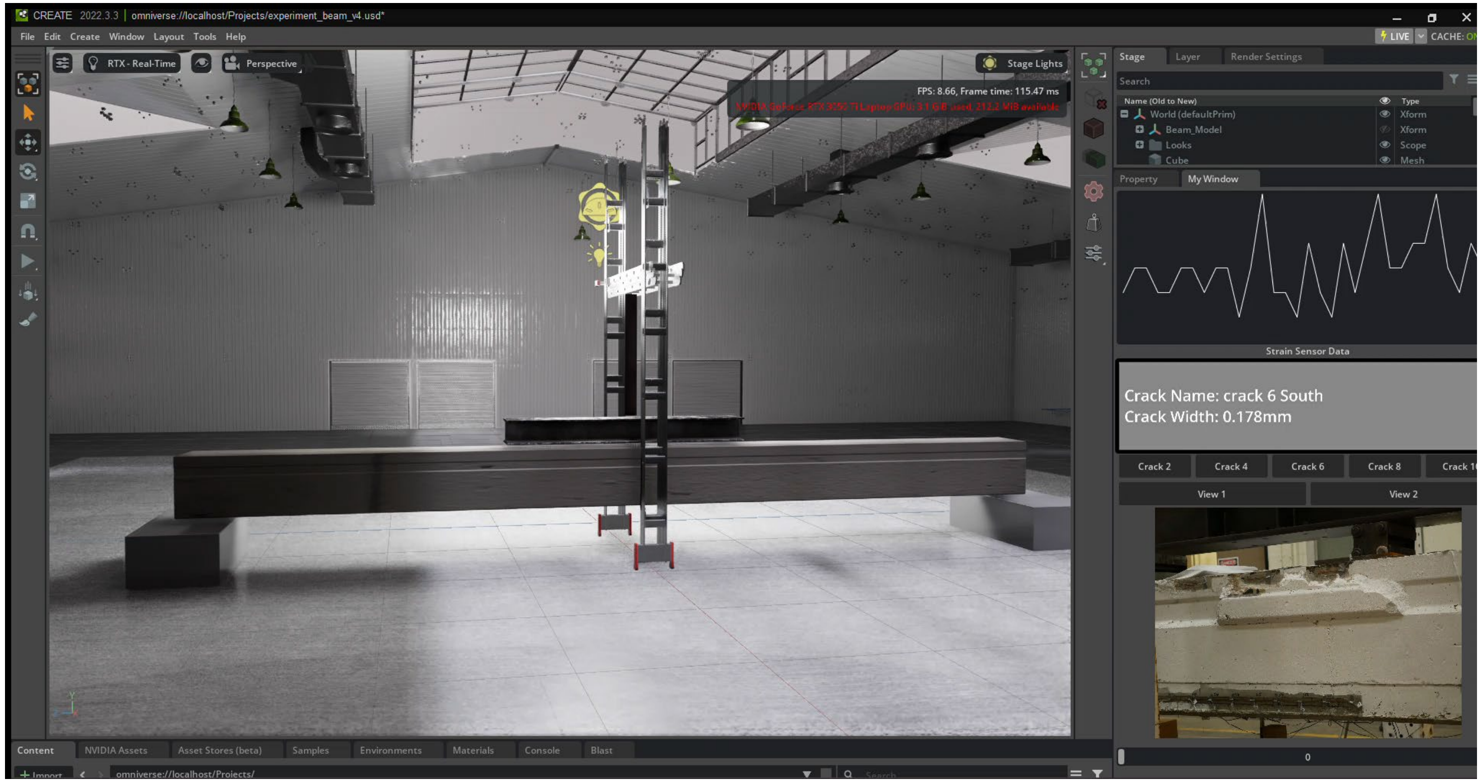
Analysis and Simulation

Digital Twin model for Beam testing

We utilize Blender software to export the beam model and construct the virtual laboratory and actuator within the Omniverse platform.

The experiment data is then linked to the digital twin model. Our developed extension facilitates the visualization of the beam under test and displays the strain and crack data in real-time during the experiment. Additionally, images of the beam captured throughout the experiment are also presented alongside the data.

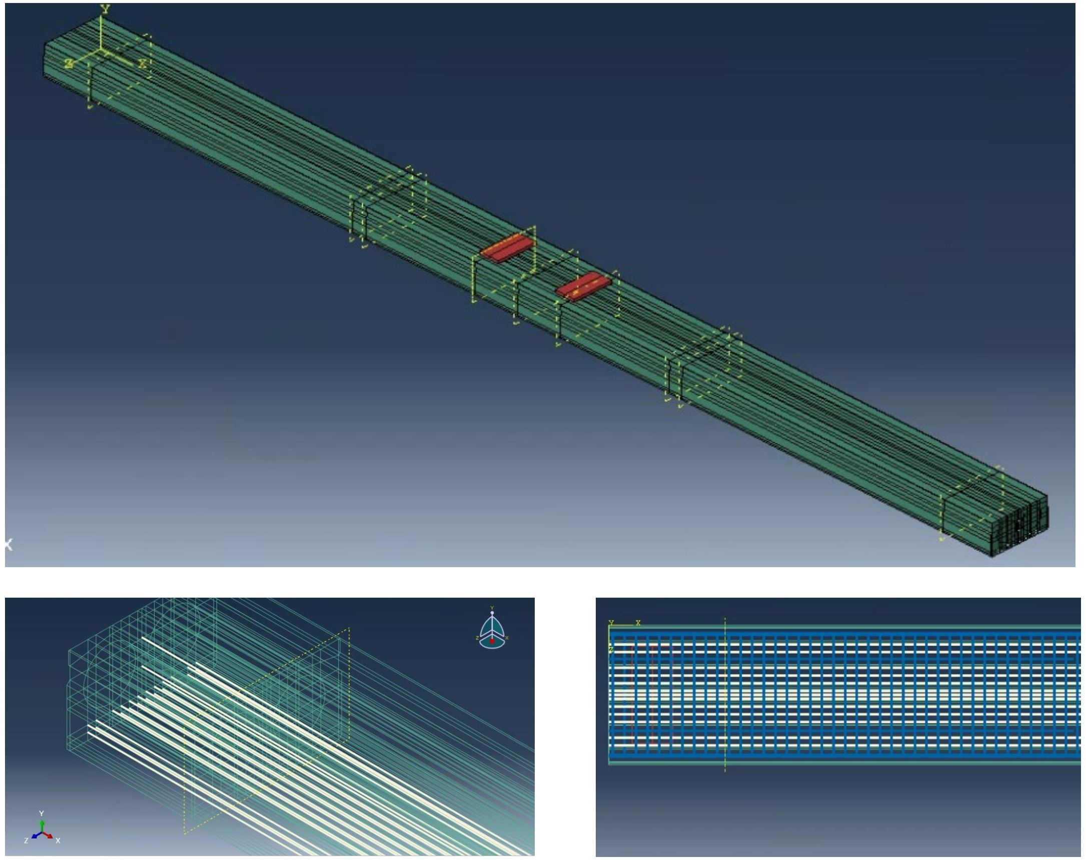
Analysis and Simulation



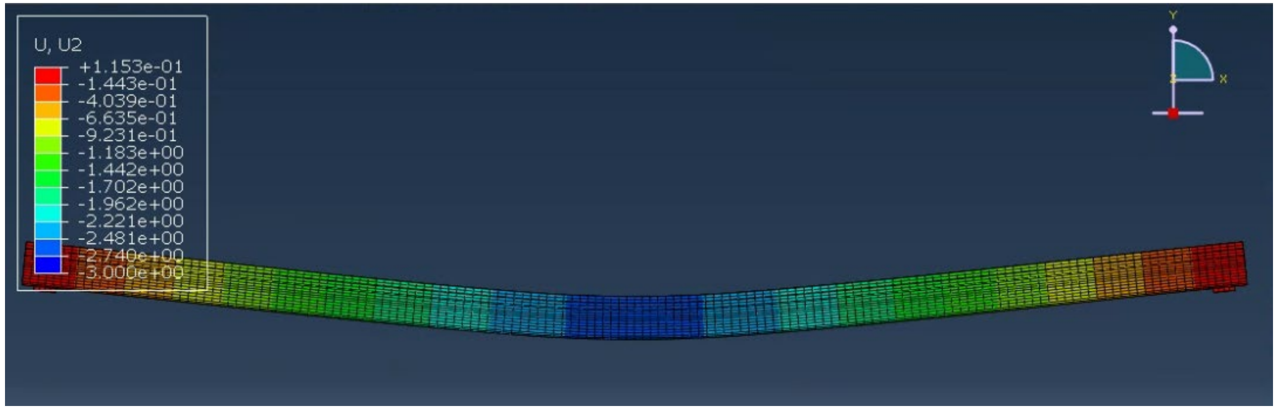
Experiment Replay

We also offer the functionality to replay the experiment. The extension includes a slider that represents the experiment's timeline. Users can interact with this slider, moving it left or right, to retrospectively examine the experiment data, images, and changes in the beam within Omniverse. This feature provides engineers with a convenient method to conduct a post-analysis of the entire beam testing process.

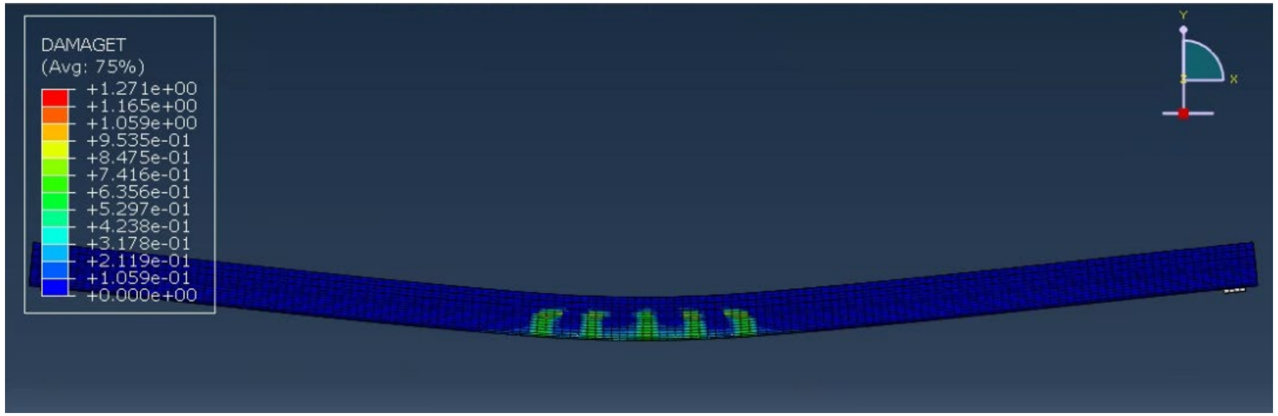
Finite Element Analysis



Rebar and Strand Layout

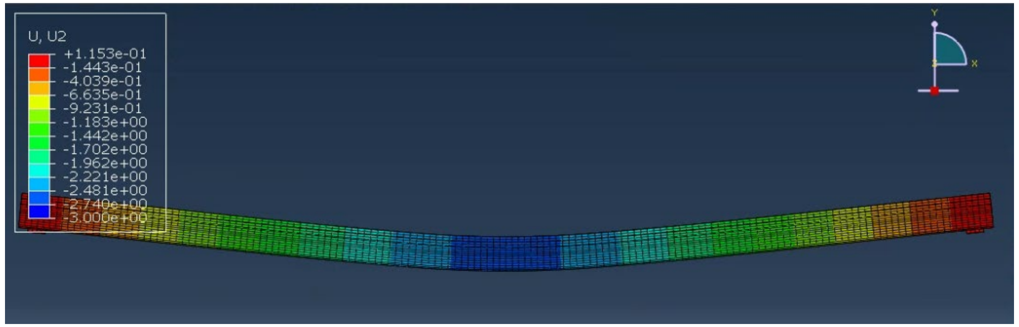


Displacement Result

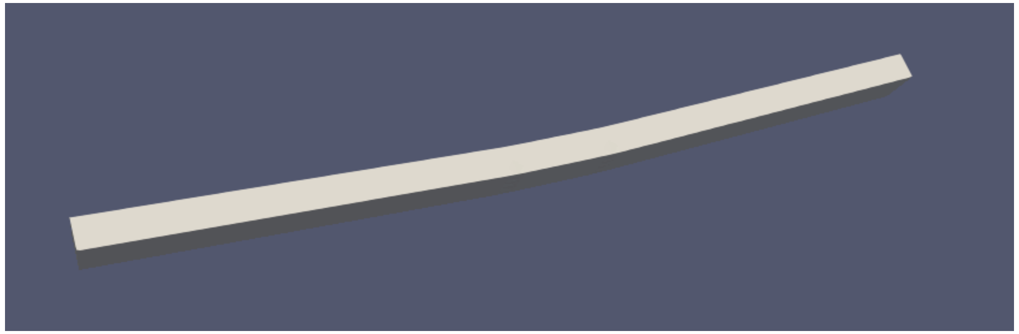


Damage Result

Finite Element Analysis



1. FEA results from Abaqus

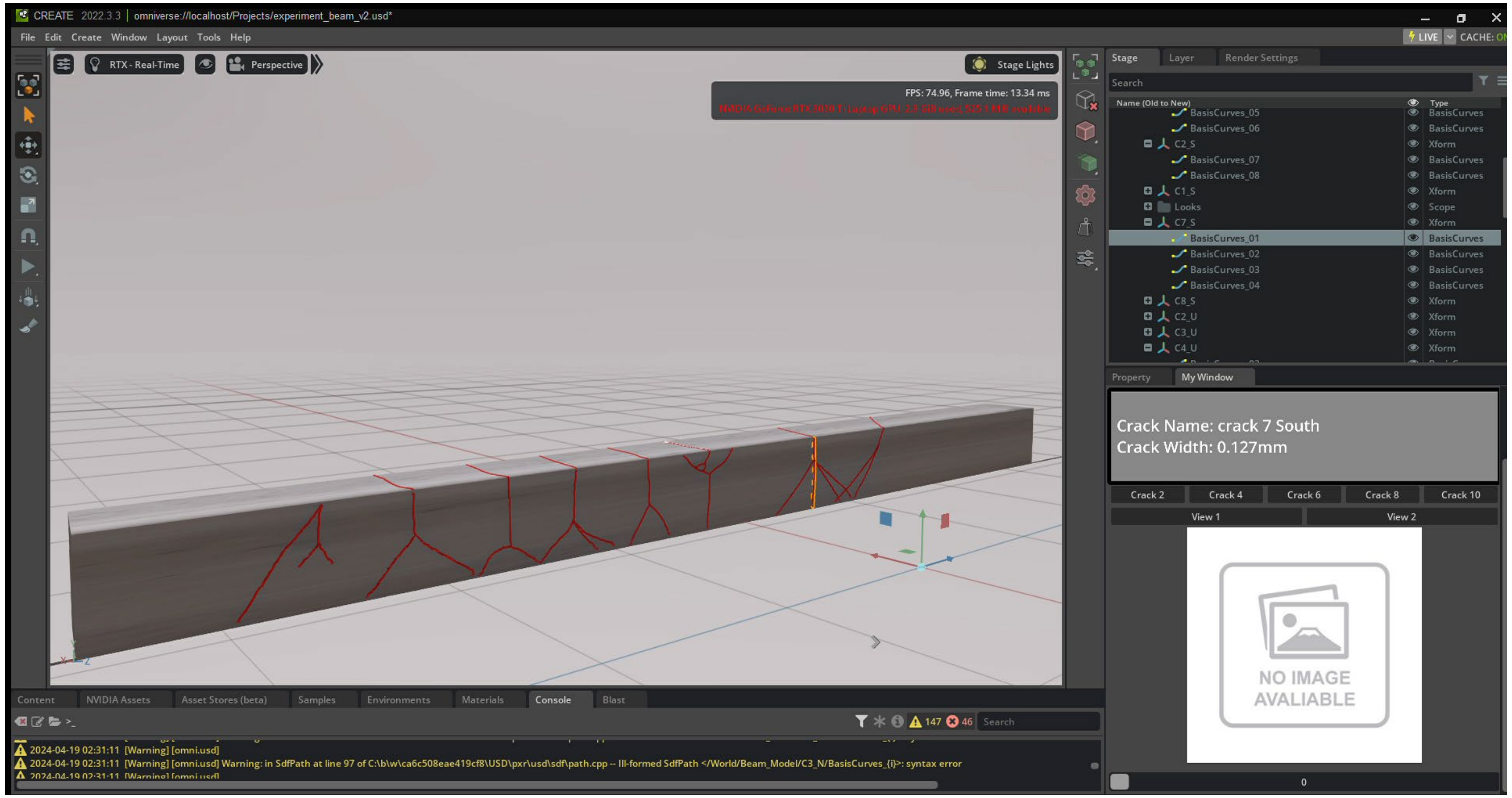


2. Geometry exported into ParaView

NVIDIA Omniverse Connector

3. More accurate bending model

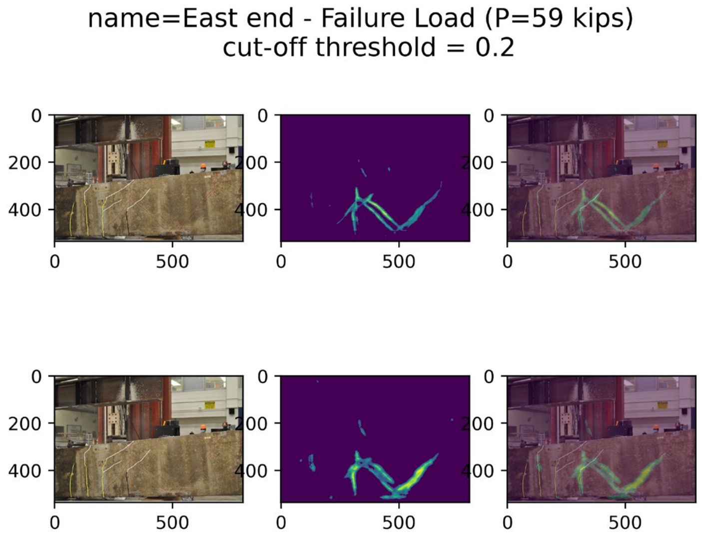
Cracks Segmentation

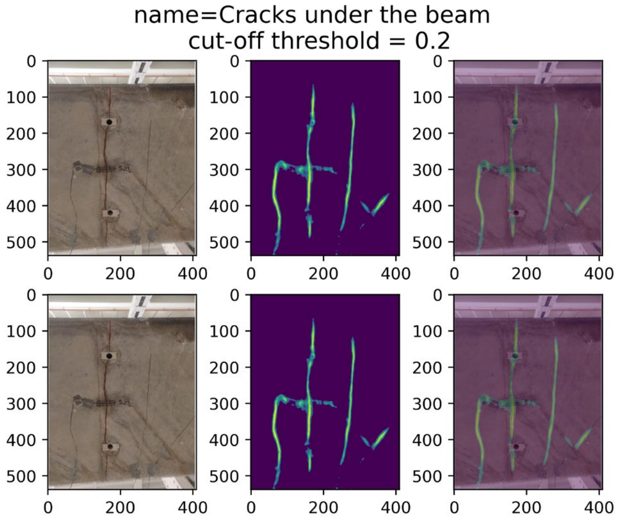


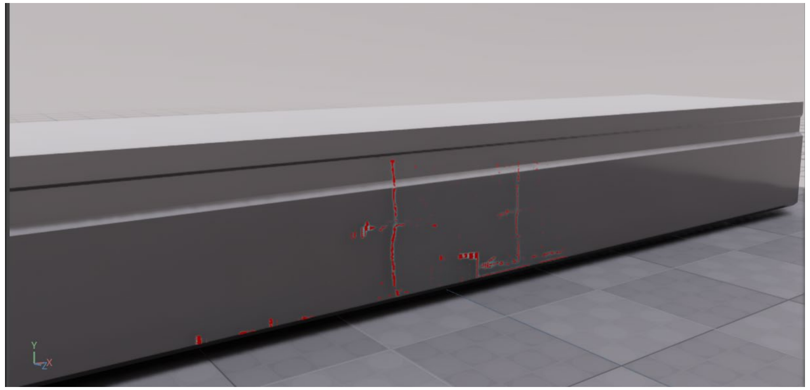
We have developed an extension that showcases bridge cracks in detail. Users can select a specific crack of interest, and the extension will display information about that crack and any nearby strain gauges in a dedicated panel. Additionally, by manipulating the slider bar, users can visualize the formation and progression of cracks throughout the experiment, offering a dynamic view of the structural changes.

Cracks Segmentation

We have explored methods to automatically extract cracks from images and integrate them into the 3D model of the beam. Utilizing OpenCV and a Unet based convolutional neural network, we extract cracks from images taken during the experiment and import them into the Omniverse platform. This allows us to superimpose the crack imagery onto the beam model, providing a visual representation of the cracks that developed during the test.







Conclusions and Future Work

- We have investigated the technologies and methodologies required to create digital twin models of precast concrete bridges and have identified several challenges associated with constructing these models and linking them with measured and simulated data.
- Our future objectives include:
  - Developing an automated process for real-time crack segmentation and integration with the digital twin model.
  - Establishing a connection between real-world bridge inspection data and the digital twin model.
  - Associating the results of Finite Element Analysis with the digital twin model.
  - Preparing a conference paper to document our findings and progress.
- These steps will enhance the accuracy and utility of digital twin models in monitoring and analyzing the structural integrity of bridges.