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DIGITAL TWIN TECHNOLOGIES TOWARDS UNDERSTANDING THE INTERACTIONS BETWEEN TRANSPORTATION AND OTHER CIVIL INFRASTRUCTURE SYSTEMS: PHASE 2

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16. Abstract

The advent of Digital Twin (DT) technology signifies a significant stride towards the progressive transformation from physical to digital paradigms within the realm of civil engineering. Its predecessors, namely Computer-Aided Drafting (CAD) and Building Information Modeling (BIM), have revolutionized the industry by streamlining the documentation of designs, curtailing both time and cost investments. The primary objective of this research was to explore different ways to create Digital Twins for civil infrastructure and to explore the effectiveness of DT technology as a tool to create new visualizations and understand interactions between transportation and other related civil infrastructure systems. We used The University of Texas at El Paso (UTEP) campus as a living lab by creating DT models based on transportation network, structural modelling, and LiDAR scans of different parts of the campus. The transportation network and 3D model of the entire campus was combined for traffic simulation and real-time sensing at a roundabout, while the digital model of a pedestrian bridge was made for structural simulations with provisions for strain and tilt sensors. In addition, LiDAR scans of campus buildings were integrated into virtual reality (VR) applications for visualization in VR headsets.

Multiple scenarios were tested for each DT to showcase how the technology can be applied to real world problems, resulting in greater ease of use and more informed design decisions. The project concluded with a stakeholder engagement workshop focused on utilizing DT technologies for research relevant to civil infrastructure in the El Paso region.

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Digital Twin Technologies Towards Understanding the Interactions between Transportation and other Civil Infrastructure Systems: Phase 2

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C2SMART Center is a USDOT Tier 1 University Transportation Center taking on some of today's most pressing urban mobility challenges. Some of the areas C2SMART focuses on include:

Urban Mobility and Connected Citizens

Urban Analytics for Smart Cities

Resilient, Smart, & Secure Infrastructure

Disruptive Technologies and their impacts on transportation systems. Our aim is to develop innovative solutions to accelerate technology transfer from the research phase to the real world.

Unconventional Big Data Applications from field tests and non-traditional sensing technologies for decision-makers to address a wide range of urban mobility problems with the best information available.

Impactful Engagement overcoming institutional barriers to innovation to hear and meet the needs of city and state stakeholders, including government agencies, policy makers, the private sector, non-profit organizations, and entrepreneurs.

Forward-thinking Training and Development dedicated to training the workforce of tomorrow to deal with new mobility problems in ways that are not covered in existing transportation curricula.

Led by New York University's Tandon School of Engineering, **C2SMART** is a consortium of leading research universities, including Rutgers University, University of Washington, the University of Texas at El Paso.

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Executive Summary

The advent of Digital Twin (DT) technology signifies a significant stride towards the progressive transformation from physical to digital paradigms within the realm of civil engineering. Its predecessors, namely Computer-Aided Drafting (CAD) and Building Information Modeling (BIM), have revolutionized the industry by streamlining the documentation of designs, curtailing both time and cost investments. BIM has eliminated the need for physical design descriptors (i.e., drawings or physical models). Building upon the foundations of CAD and BIM, DT models assume a pivotal role as management tools, facilitating continuous utilization throughout the operational lifespan of infrastructure. Typically conceptualized as abstractions of physical assets, DTs find frequent employment in modeling, enhancing, and governing manufacturing systems. While the employment of DTs in civil engineering applications is gradually gaining ground, their successful integration into the domain of transportation infrastructure poses a formidable challenge due to its extensive spatial scale and dynamically evolving data. Nevertheless, DTs hold immense potential as formidable decision support mechanisms for the design, maintenance, and administration of transportation infrastructure. Particularly noteworthy is their use as a tool to analyze interdependencies between transportation systems and other components of infrastructure, a critical consideration in the context of smart cities.

The primary objective of this research was to explore different ways to create DTs for civil infrastructure and to explore the effectiveness of DT technology as a tool to create new visualizations and understand interactions between transportation and other related civil infrastructure systems. We used **The University of Texas at El Paso (UTEP)** campus as a living lab by creating DT models based on transportation network, structural modelling, and LiDAR scans of different parts of the campus. The transportation network and 3D model of the entire campus was combined for traffic simulation and real-time sensing at a roundabout, while the digital model of a pedestrian bridge was made for structural simulations with provisions for strain and tilt sensors. In addition, LiDAR scans of campus buildings were integrated into virtual reality (VR) applications for visualization in VR headsets.

Multiple scenarios were tested for each DT to showcase how the technology can be applied to real world problems, resulting in greater ease of use and more informed design decisions. The project concluded with a stakeholder engagement workshop focused on utilizing DT technologies for research relevant to civil infrastructure in the El Paso region.

Table of Contents

List of Figures

List of Tables

Introduction

Digital Twin (DT) technology is a cyber-physical system consisting of a real system with some capacity for dynamic control, a real-time sensing data stream from the real system, a digital model of that real system capable of ingesting data from and simulating behavior of the real system, some sort of decision-making intelligence, and a feedback loop to induce change in the real system. This project explores DT as a tool for management of civil infrastructure. Specifically, this project explores DT as a paradigm to implement a smart living lab (SLL), the principles of which may be scaled to a campus-wide DT with a focus on transportation, construction, and planning. A conceptual overview of an SLL for the systems selected for this project, namely a roundabout, a pedestrian bridge, and a building, is shown in Figure 1.

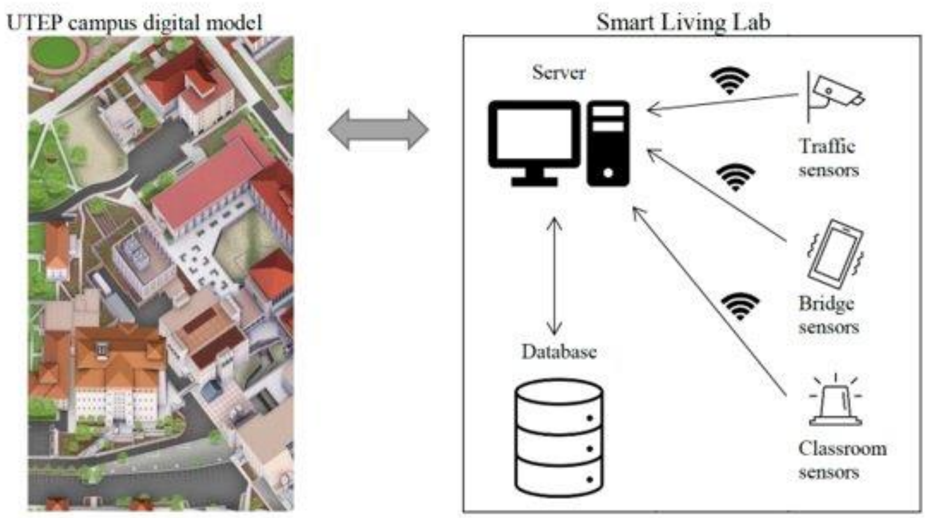

Figure 1. Conceptual Overview Smart Living Lab (SLL)

The real physical systems for this concept are the road network of the roundabout at Schuster parking garage, a pedestrian bridge on campus, and the recently constructed Interdisciplinary Research Building (IDRB). The right-hand portion of Figure 1 depicts the physical half of the DT along with sensing and communication. On the left, the digital system includes a traffic model of the roundabout, 3D models of the built environment, structural model of the bridge, and LiDAR scans.

This was the second phase of the Digital Twin project from 2022 to 2023 and was broken into eight tasks as shown in Figure 2.

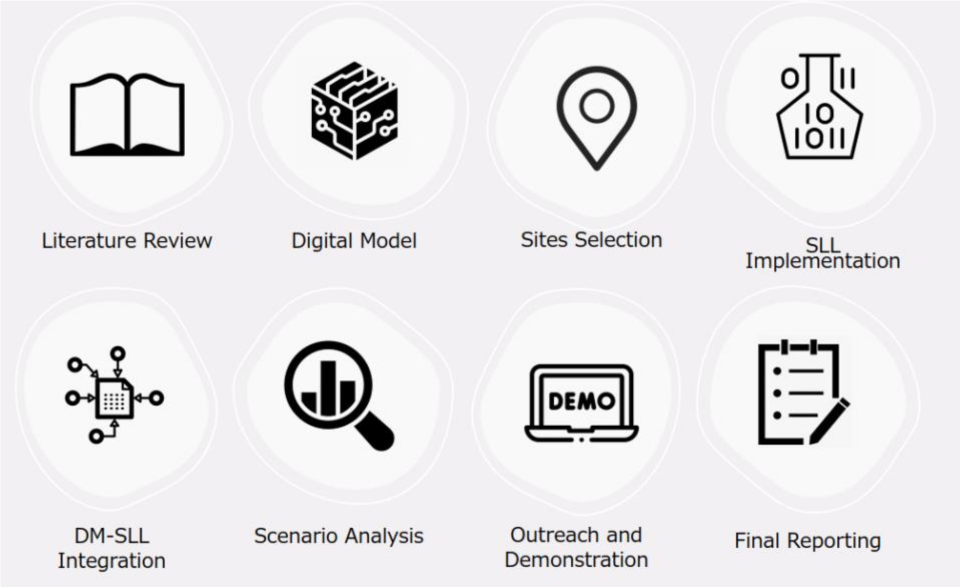

Figure 2. Phase 2 Project Tasks

Report Organization

This report is structured as follows:

- Introduction: Describes the structure of the report and provides an overview of the project, including challenges and assumptions
- Task 1 – Literature review: an overview of the historical and current practices in Digital Twin technologies as they relate to civil infrastructure, simulation, and intelligent transportation systems
- Task 2 – Digital Model: the process of creating digital models for DT, along with simulation and visualization
- Task 3 – Site Selection: a description of the locations chosen for the DT
- Task 4 – Implementation of Prototype Smart Living Lab (SLL): plans for the implementation of sensing, analysis, and data management
- Task 5 – Digital Model and SLL integration: description of data integration into the DT, including testing, and a discussion of challenges
- Task 6 – Scenario Analysis: a look into specific scenarios to display the analytical capabilities of the DT using real-world data and assumptions
- Task 7 – Outreach Workshop: a summary of the discussions with workshop attendees
- Conclusions and Future Work

Project Overview

Continuing from Phase 1, this project seeks to make further progress towards a true DT system for civil infrastructure on the university campus. Instead of making a fully integrated campus DT, the tasks were divided into three separate locations based on their relevance to practical research. The project team set out to achieve the following project-specific goals:

- Understand what a DT for Civil Infrastructure is, and how it is different that DT for other domains and use cases
- Identify the best ways to create individual digital models (DM) for specific purposes and build a digital model of the entire campus
- Selecting sites on campus that can provide the appropriate data to be effective use cases for DT
- Exploration of the sensing, communication, and algorithms needed to create the DTs
- Testing the pipeline of the model, simulation, and analysis before actual sensor installation to finalize the placement and requirements
- Integration of the digital model with real world data, i.e., vehicle detection for roundabout, vibration sensors for bridge, and occupancy data for the building
- Scenario analysis based on real and augmented data on different configurations to aid in planning
- Outreach and demonstration in the form of a workshop to fuel future research directions

The case study for this effort was the campus of UTEP. In particular, the project team focused on three locations: the roundabout at Schuster garage, a pedestrian bridge, and the IDRB building. The roundabout is situated at the intersection of Schuster Ave and spur 1966. The location was selected as it faces congestion during peak hours and West Schuster Ave near the university is undergoing major construction which provided an opportunity to perform scenario analysis based on the real-world factors. The pedestrian bridge is located on the southeast side of the IDRB building and was selected to depict the effects of live load (pedestrian traffic) and environmental factors (temperature) on a bridge structure.

Task 1: Literature Review

This section presents a literature review of the existing practices on DT and related areas, with a focus on civil infrastructure systems. The reviewed materials are presented in five sub-sections: (1) DT definition and application in manufacturing purposes; (2) applications of DT technology and existing DT applications for the management of civil infrastructure; (3) available technologies for data collection and current simulation methods used in civil infrastructure systems; (4) comparison of modern techniques for modeling infrastructure systems such as BIM and Intelligent Transportation Systems (ITS); and (5) DT research gaps in manufacturing and infrastructure applications.

Review of Digital Twin application for Manufacturing

The fourth industrial revolution is known for the automation of data and noticeable advancements in manufacturing and other engineering technology. The Digital Twin in manufacturing was achieved thanks to the advances in artificial intelligence, cloud computing, and the Internet of Things (IoT). Initially, Grieves introduced the concept of a digital twin to follow an assembly process by using a virtual model to monitor the processes through information and data exchange (Dr. Grieves, 2015). The application of DT quickly expanded and improved on the idea of smart manufacturing (Lu et al., 2020). The DT concept was introduced for product life cycle management by using a virtual representation of the physical manufacturing process through the use of non-destructive sensors, gauges, lasers, and coordinate measuring equipment (Dr. Grieves, 2015). The DT was then expanded to predict behavior and operations of the equipment. A DT model for laboratory equipment was created to monitor equipment behavior, predict equipment failure, and improve laboratory operations by reducing the overall maintenance cost (Li et al., 2020).

A DT of the scheduling of a job-shop was developed to control the production of a small manufacturing assembly line process by using edge computing, virtual simulation, and data analysis to ultimately optimize the process (Xu & Xie, 2021). For a machining process, laser scanning was used to continuously monitor the geometric changes of a component and other processes occurring in the equipment, such as the speed of cutting and cutting the piece (S. Liu et al., 2020). Miller et al. investigated a model-based definition method to incorporate behavioral and product characteristic data via a plug-in directly into a 3D-CAD model (Miller et al., 2018). In addition, Miller et al. suggested that a behavioral model was not defined by the performance of a product but instead to the physical manifestations that occur in a specific part in response to external stimuli (Miller et al., 2018). Liu et al. explored the concept of biomimicry (perceive and simulate an environmental change) to simulate the geometric change response during the machining process of an air rudder into a DT model (S. Liu et al., 2020).

Review of Digital Twin application for Civil Infrastructure

DT for static processes in structures and transportation infrastructure presents challenges for prolonged data exchange and connectivity when compared to manufacturing processes. To understand the real-time behavior of civil systems, sensors such as accelerometers, inclinometers, displacement transducers, pressure cells, and temperature sensors can be used to measure the infrastructure's global response (Angjeliu et al., 2020). A case study by researchers in Cambridge Centre for Smart Infrastructure and Construction (CSIC) and statisticians at Alan Turing Institute (ATI) proposed Digital Twin for bridge assets to study risks and predict its performance by focusing on four areas of research: real-time data management using Building Information Modeling (BIM), physics-based approach, data-driven approach, and data-centric engineering approach (Ye et al., 2019). The study explored a DT coupled with statistical data obtained from multiple strain gauge sensors to develop a complete analysis.

Dawkins et al. created a Digital Twin model of a building using BIM and light detection and ranging (LiDAR) data and leveraged cell phone Bluetooth detection to monitor near real-time occupancy activity (Dawkins et al., 2018). For example, the current infrastructure design method utilizes BIM models for design but does not provide continuous feedback on the infrastructure system's performance. DT technology was used to predict and reproduce damage observed in current and historic masonry structures by monitoring heavy structural loads, continuous changes in environmental conditions (winds, earthquakes), and material degradation over time (Angjeliu et al., 2020). A Digital Twin model of a lightweight concrete roof with hydronic piping was leveraged to improve productivity and overall building efficiency (Lydon et al., 2019). The geometry of complex roof design, a lightweight concrete system (including hydronic piping), and the operational data from the piping system were used to correlate embodied energy of the building to operational energy (Lydon et al., 2019). Modern infrastructure management strategies and advanced modeling methods steer the development of future infrastructure systems.

DT technology was used to predict and reproduce damage observed in current and historic masonry structures by monitoring heavy structural loads, continuous changes in environmental conditions (e.g., winds, earthquakes), and material degradation over time (Angjeliu et al., 2020). In a study conducted by Curl, a Digital Twin simulation model was developed for water utility management to allow for simulation of maximum flow case scenarios and to fully replicate the facility's hydraulics, controls, and process performance (Curl et al., 2019). The DT optimized disaster management strategies by providing leaders forecasts of the disaster's impact for proposed decisions through reliable and inexpensive simulations.

Smart cities DT for a disaster management model was used to enable intelligent investment decisions, preparation, and disaster event mitigation (Ford & Wolf, 2020). In the recovery phase of a disaster, a proposed guide for resource allocation strategies can be prepared beforehand in anticipation of the simulated event to aid with the decision-making process and benefit most communities in the response phase to emphasize the efficient first responder deployment (Ford & Wolf, 2020). Infrastructure management value is provided when there are complex interconnected systems or unique operational challenges that would benefit from the use of a Digital Twin (Curl et al., 2019). Risk management for infrastructure can be assessed using DT to systematically analyze the threats and vulnerabilities, determine the degree of damage, and propose corrective measures. For instance, active connectivity provided by Digital Twin promotes maintenance, event detection, prediction, state monitoring, and event preparation for an impending event.

Additional lab and field research found that Digital Twin applications in civil infrastructure extend to steel structures, bridges, and disaster management. Research conducted on safety risk assessment of pre-stressed steel structures shows Digital Twin technology can achieve real-time monitoring of pre-stressed steel structures currently in use and can provide timely predictions of the safety level (Z. Liu et al., 2020). The use of social and building infrastructure management makes leadership decisions more accurate, yet additional work is required to develop Digital Twin for community management of disrupting infrastructure systems and their interactions with them during a disaster (Ford & Wolf, 2020). To effectively apply DT, the use of multiple sensory automated data acquisition technologies is needed to increase the accuracy of data collected based on the complexity of each project and considering the limitations of technology (Moselhi et al., 2020).

Review of Available Technologies for Data Collection and Simulation Methods

DT modeling methods, such as Building Information Modeling (BIM) paired with automated data from remote sensing equipment, improves feedback to manage infrastructure systems, monitor performance, optimize maintenance, and anticipate potential risks. The virtual modeling is done through tools such as Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), or BIM, while the data acquisition is made through sensor and laser scanning using LiDAR or photogrammetry. This method is used for an accurate digital replica of the existing physical infrastructure. The application of DT technology for the management of infrastructure faces challenges with unpredictable environmental conditions and external stimuli. Therefore, there is a need to build a reliable and accurate application of the technology (Ford & Wolf, 2020). Data acquisition tools for Digital Twin models include LiDAR and photogrammetry coupled with sensors, artificial intelligence, and IoT to provide automation in real-time data of existing infrastructure (Angjeliu et al., 2020). LiDAR, a remote-sensing technology, is used to assist in mapping, monitoring, and assessing forest resources and can be used to create a large-scale virtual model of an infrastructure system by measuring the distance of a beam of light to determine the time of the reflected signal (Angjeliu et al., 2020). A study conducted by Lantz used LiDAR technology coupled with ArcGIS data and cost analysis to predict impacted areas due to flooding and estimate the cost of the building due to the damage(Lantz et al., 2020).

In Germany, a combination of both optical and radar data was used to determine building height, cost-effective mapping, and physical analysis of structures using public high spatial resolution data to determine the impact of vertical structures on the environment in urban areas (Frantz et al., 2021). In addition, building height, infrastructure covered area, and occupancy of the building can be leveraged from the analysis (Frantz et al., 2021).

Massive data collected from cell phones can be used to model daily activity in a city and analyze activity time, duration, and land use by using a geolocated timestamp to represent trip chains using a trip extraction method to reveal activity behavioral patterns in cell phone traces (Widhalm et al., 2015). Widhalm et al. used a Relational Markov Network to input collected cell data (arrival time and duration) and model dependencies such as activity type, trip scheduling, and land use (Widhalm et al., 2015). In contrast, the use of sensing technology also presents disadvantages for data acquisition of infrastructure applications due to the use of wide or narrow divergences causing changes in the precision of the data (Gatziolis & Andersen, 2008). For example, LiDAR use is not suggested for mountains or undulating terrain or in fog, rain, or winter conditions. Therefore, it is not a reliable source of continuous real-time data due to uncertainties in climate conditions (Gatziolis & Andersen, 2008). The complete list of automated data acquisition technologies was researched by Moselhi with full capabilities, data acquisition effort, processing time, affordability, data accuracy and reliability, scalability, limitations, and accuracy (Moselhi et al., 2020).

Digital Twin vs. BIM vs. ITS

The use of Digital Twin technology for infrastructure management is in its infancy. The accuracy of the technology and the design of models for each application are separated into separate fields in civil engineering. Chen et al. researched Intelligent Transportation Systems in the management and security of traffic flow detection for real-time data acquisition using a deep learning algorithm for vehicle detection of urban roads through captured videos and cloud data storage (Chen et al., 2020). The technology uses vehicle detection, vehicle counting, and a vehicle tracking algorithm with an average accuracy of 92% (Chen et al., 2020). The use of DT technology encountered challenges to accurately model the behavior response of an infrastructure system, and there is a need to link the modeled systems among other systems.

Kučera et al. improved city logistics and transportation planning with the use of PTV VISSIM software for traffic infrastructure planning in an area in the Czech Republic and studied the impact of rebuilding an intersection on traffic flow in city logistics using microscopic models to simulate congestion, reduce vehicle delays, and improve road safety based on traffic flow (Kučera & Chocholáč, 2021). A real traffic simulation management tool was used for logistic planning suitable for achieving the concept of sustainable city logistics, visualizing real city traffic, designing efficient traffic management strategies, and test different construction scenarios of all intersections (Kučera & Chocholáč, 2021). Additionally, Moselhi explored automated data acquisition using remote sensing technologies, including a focus on multi-sensor data fusion models by integrating radio-frequency identification (RFID), a wireless sensor network (WSN), BIM, and digital imaging to enhance site data acquisition (Moselhi et al., 2020).

Moselhi researched a construction management DT application to mitigate schedule delays, cost overruns, and safety on site (Moselhi et al., 2020). Kamari et al. evaluate design alternatives using virtual reality to understand cost and sustainability life cycle assessment using building information modeling (Kamari et al., 2021). A study conducted by Ma et al. provided visual architectural changes monitored during the construction phase using BIM and researched a sustained laser scanning application to a suspension bridge by using sensor data to accurately model the main frame of suspension bridge bending deformation and performance using a high precision total station for 5 hours(Ma, n.d.). Kamari et al. demonstrate an understanding of the preference of economy and sustainability using virtual reality (VR) experiences to enable improved design, decision making, and carbon footprint tracking using BIM (Kamari et al., 2021). The energy expenditure of the real-time monitoring system also requires a sustained amount of energy and additional resources.

Gaps in Digital Twin Research

During the review of research in manufacturing and infrastructure applications of Digital Twin, three main gaps in the literature were apparent. First, various lab and field studies have been conducted for individual civil infrastructural systems, but research on the impact of interactions between multiple systems is needed. A connection between systems can alleviate the outcome of disasters by forecasting an event and providing feedback on the impact of the actions taken. Secondly, studies recommended a DT model with a lower focus on geometric perfection by instead focusing on the representational accuracy of the model and on the systems' interactions to improve decision-making strategies. Thirdly, automated data acquisition methods, big data storage, efficient construction processes, and the benefits of a well-maintained system (or infrastructure) need to be investigated further.

At present, Digital Twin can only predict failures and their life cycles through internal operational data but cannot predict the failure caused by external physical effects (Li et al., 2020). The use of automated sensor scanning technology needs sustainable economic justification, in addition to the need for research on more extensive data acquisition methods and compatibility of automated data acquisition technologies (Moselhi et al., 2020). DT sustainability benefits need to be established based on economic, social, and environmental impacts. DT technology aids in the efforts of sustainability goals by working with industry and academia to determine the efficacy of this modern technology for the life assessment of current infrastructure and assess the viability of DT for infrastructure management. Additionally, DT technology can align with United Nations sustainability goals for clean and affordable energy, promoting economic growth, clean water and sanitation, industry innovation and infrastructure, sustainable cities and communities, responsible consumption and production, climate action, and expand partnerships in the world.

Current infrastructure is maintained and inspected using methods that have not been updated in several decades; the adoption of Digital Twin technology presents a solution to improve infrastructure quality and current management practices. The United States 2021 ASCE Infrastructure Report Card obtained an overall rating of C minus (in terms of capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation) for the overall rating of the infrastructure (roads, bridges, transit, rail, etc.). DT presents an alternative to improve the current infrastructure rating by improving quality and safety conditions (DiLoreto et al., 2020). The use of this technology has encountered challenges in accurately modeling a specific system, but the capability of continuous data acquisition has the potential to improve the management and operational tasks of the infrastructure system.

DT modeling methods using data available from the construction of IDRB on the UTEP campus, LiDAR (aerial and ground sources), and existing transportation data (signage, bus stops, and traffic lights), a DT model will aid in the policy decision-making process for the creation of visualization models, simulated traffic interruption scenarios, and construction management improvements.

Task 2: Digital Model

Campus Digital Model and Road Network

This task focused on the fast and efficient creation of the 3D model of the campus that can support road network for traffic simulation. While a DT has many components for functionality, much of the perceived value lies in the digital model for visualization and user interface. Road networks are often simulated and analyzed in two dimensions but to provide a more realistic visual representation, manual 3D modeling from scratch is the most common option. This creates a significant barrier to the research process of simulation, integration, and analysis. With this motivation, a procedure was developed to create a transportation network digital twin using freely available data and software, shown in Figure 3.

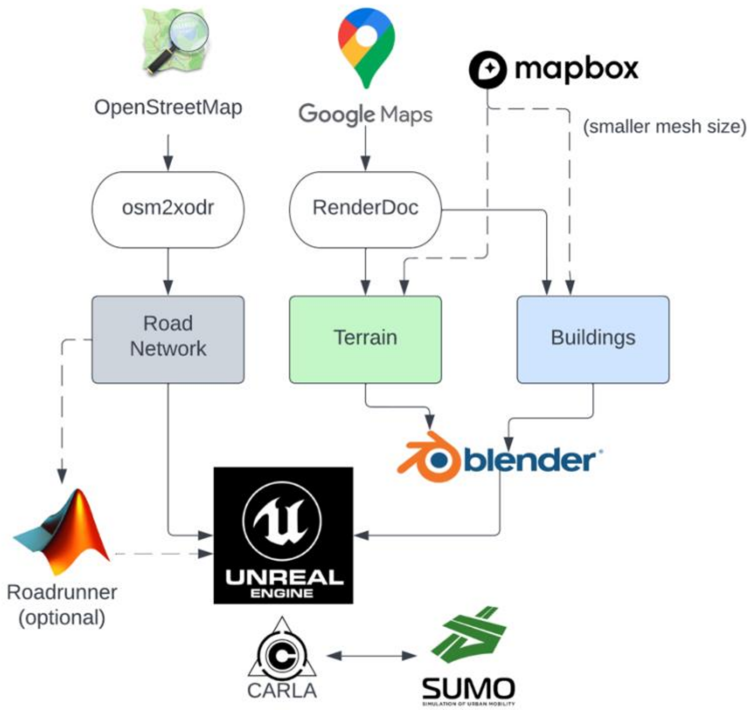

Figure 3. Procedure to create campus digital model

While Google has one of the most up to date and accurate maps, the non-proprietary collaborative project OpenStreetMap (OSM) uses data from freely available sources presented in a convenient manner with options to export the data in OSM files. These files are XML formatted, containing road network information in the form of nodes, ways, and relations, which can be used for multimodal microscopic transportation simulations in free software like SUMO or proprietary software like VISSIM. In the case of SUMO, it comes with a utility called netconvert, that can take many arguments for customization including default signal times, which converts the OSM file into road network XML files that can be used for simulation. Some preprocessing needs to be performed since missing information like the number of lanes, intersection links, or speed limits can be added or updated before simulation. The OSM file can also be converted to a popular JSON based GIS format, General Modeling Network Specification (GMNS) using a tool called osm2gmns. This allows visualization, editing, and simulations in free geospatial analysis software like QGIS.

However, this approach only yields the road network with, at best, a satellite image of the area as background. The incorporation of contextual information like 3D buildings and terrain is usually manual and constrained by the capabilities of the software used. Mapbox provides a service to export terrain and 3D buildings from OpenStreetMap. The buildings lack texture, which can be added in 3D graphics software like Blender but are otherwise to scale and representative of the actual location. This 3D model can be improved by manually adjusting and editing in Blender, but a quick way of using preexisting 3D data is to extract it from Google maps.

RenderDoc is a graphics debugging tool that can be used to store and examine 3D graphics data that an application is displaying, for example Google maps 3D view. It is recommended to zoom into the map to view the highest level of detail. These debugging captures can be saved to disk and imported to Blender using MapsModelsImporter plugin. While the output of this process is relatively "low poly" buildings (low 3D resolution), and objects like trees and parked cars add to the noise in the 3D mesh, this is the most visually appealing result that does not involve manual 3D sculpting and texturing. It can be used as a starting point for a higher quality and smoother mesh if edited in Blender. It must be noted that data obtained from Google maps cannot be shared or used for commercial purposes.

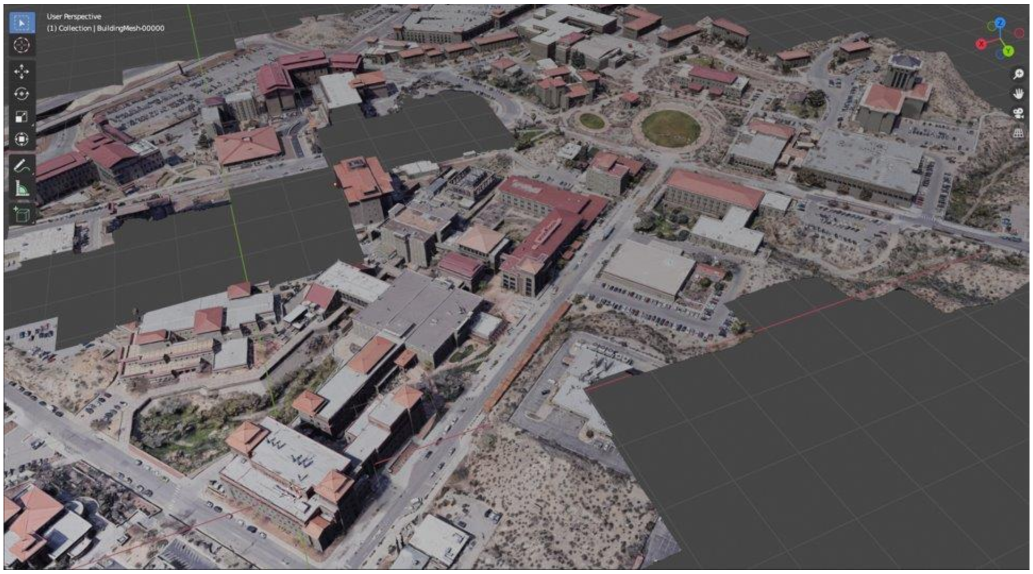

Figure 4. University campus 3D model in Blender software

Pedestrian Bridge

A structural model of the pedestrian bridge was created that would implement strain gauges and tiltmeters in the model to showcase the application of DT to larger bridges. The first step of this process is to determine how many sensors were needed and identify the primal spots for installation. It was decided that eight strain gauges and two tiltmeters were needed for this analysis. For this experiment, the Geokon Model 4000 Vibrating Wire Strain Gage and the Geokon Model 6350 Vibrating Wire Tiltmeter are the specific sensors that will be mounted to the pedestrian bridge.

Additional components were needed to measure, record, and store the data from the sensors onto a digital file that can be interpreted on a computer program. These components, from Campbell Scientific, were: CR6 Automated Monitoring Platform (CR6) and 8-Channel Dynamic Vibrating Wire Analyzer (VWIRE 300). Furthermore, the computer programs associated with the CR6 and VWIRE 200 were used to visualize the data. The programs, also from Campbell Scientific, were: LoggerNet, Device Configuration Utility, and Dynamic Vibrating-Wire Tool Box.

Autodesk Robot Structural Analysis is a structural load analysis software that is capable of data exchange with Autodesk Revit using BIM-integrated workflows. The software is designed to make resilient structures that are code compliant and accurate. The BIM integration enables the team to model and analyze the pedestrian bridge, then implement sensors in the model to create a real-time link with load and temperature deformations using other software. The model is created using LiDAR scans that collect point cloud data that allows the team to have accurate measurements of the bridge's structural components, such as columns and beams. Due to the recent construction of the pedestrian bridge, the LiDAR scan's measurements are compared to the dimensions noted in the construction drawings.

Extended Reality

Extended Reality (XR) is the term that encompasses all forms of technology used to expand the 3D world into the physical world. The different methods of obtaining this reality include Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). Augmented Reality is an interactive experience that uses real time information through computer generated images. Examples include Pokémon Go, Snapchat, Visual Live (iPad version), and Google glass. Virtual Reality is a computer simulated experience allowing a person to interact with a 3D visual environment to include Oculus Rift, Google Cardboard, and flight simulators. Finally, Mixed Reality is a blend of physical and digital environments through 3D interfaces and human interaction with examples such as the HoloLens and Holograms.

Simulation data was collected through Leica Geosystems and Revit to build point clouds and 3D visualization models. Such data was used to simulate the virtual environments in a physical environment to include labs that were used by the group. Data collected by the point clouds include the location of all objects within the laboratory, labels were further created to represent multiple key objects within the room. Similarly, a sample Revit model was used to represent architectural designs that can be implemented and visualized through the physical world.

Through the use of the Leica BLK360 from Lecia Geosystems we were able to conduct LiDAR scans of the existing conditions of campus laboratories, roundabouts, buildings, and parking garages. BLK 360 is a cutting-edge LiDAR (Light Detection and Ranging) scanner that has made a significant impact in the market. LiDAR technology utilizes laser pulses to accurately measure distances and create detailed 3D representations of environments. Developed by Leica Geosystems, a renowned provider of surveying and geomatics solutions, the BLK360 is a state-of-the-art device with enhanced portability, accuracy, and user-friendly interface. The scanner is small and lightweight, allowing users to easily transport it to various locations and capture data effortlessly. Its mobility was especially helpful for the team as we conducted on-site scanning near the busy campus roads.

Table 1. Scanner Characteristics

Distance measurement system	High speed time of flight enhanced by Waveform Digitizing (WFD) technology
Laser class	1(in accordance with IEC 60825-1:2016)
Wavelength	830nm
Field of view	360° (horizontal)/300° (vertical)
Range	min. 0.6-up to 60m
Ranging accuracy	4mm@10m/7mm@20m

A comprehensive 360-degree field of view with a range of up to 60 meters enabled team to capture detailed information (millions of data points per second) resulting in highly detailed and accurate point cloud representations of the scanned areas at UTEP campus (Schuster roundabout and parking garage, Interdisciplinary Research Building (IDRB), and a classroom). The scanned information as a point cloud was utilized for creating 3D models and virtual reality-based scenes. The device is also equipped with integrated sensors, including HDR imaging and thermal imaging capabilities. These features allowed team to capture additional visual information, such as color and temperature data, which can further enhance the quality and usefulness of the captured scans.

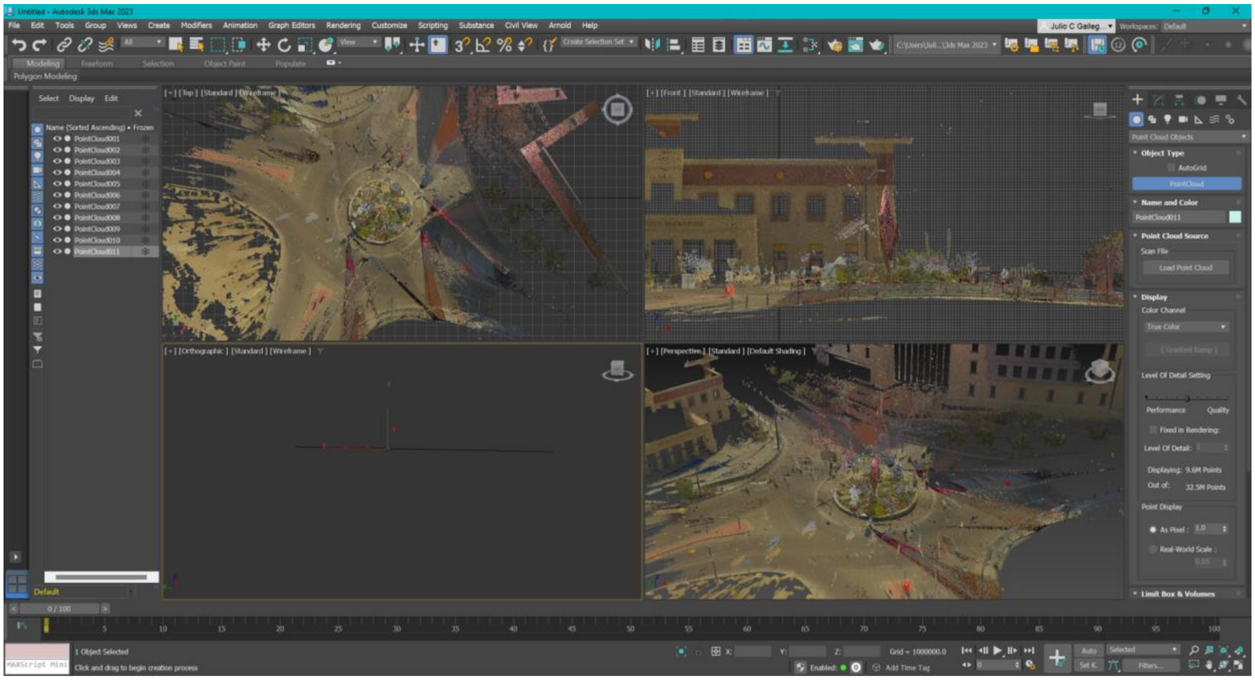

Figure 5. Point Cloud to 3D conversion

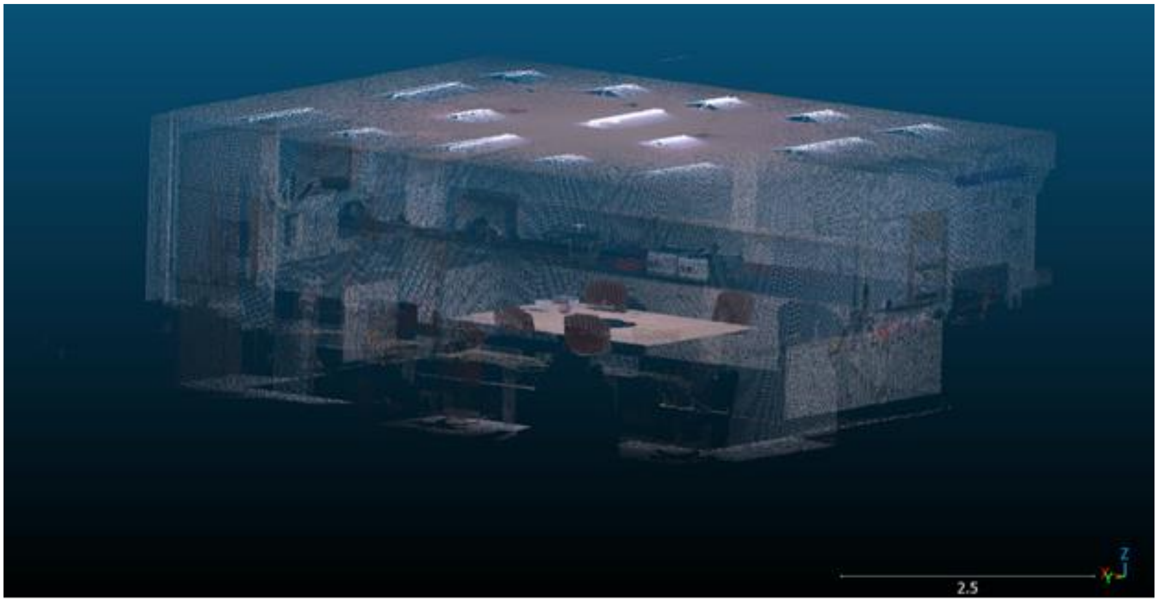

Figure 6. PASS Lab

Figure 7. Infrastructure Lab

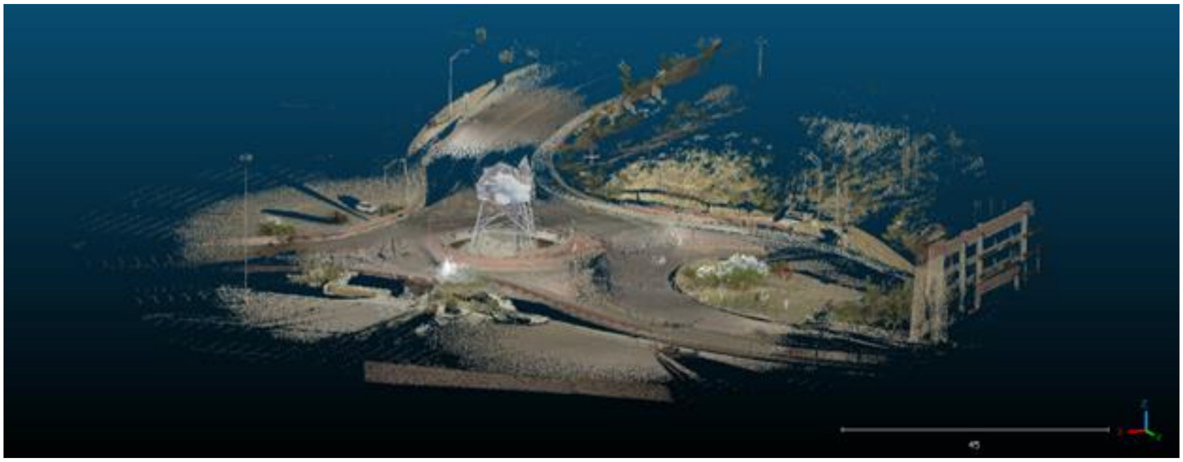

Figure 8. Schuster roundabout and parking garage

Figure 9. Sun bowl roundabout and parking garage

Roundabout

The roundabout, which hosts a large wind sculpture known as The Cloud, is located right outside Schuster parking garage. The four-story tall garage provides an ideal vantage point for observing all of the approaches to the roundabout. This roundabout connects to I-10, TX-375 Loop, and the CanAm Highway, and is often congested at peak times in the morning and evening as commuters from both the East and West sides of El Paso use this route to access the university.

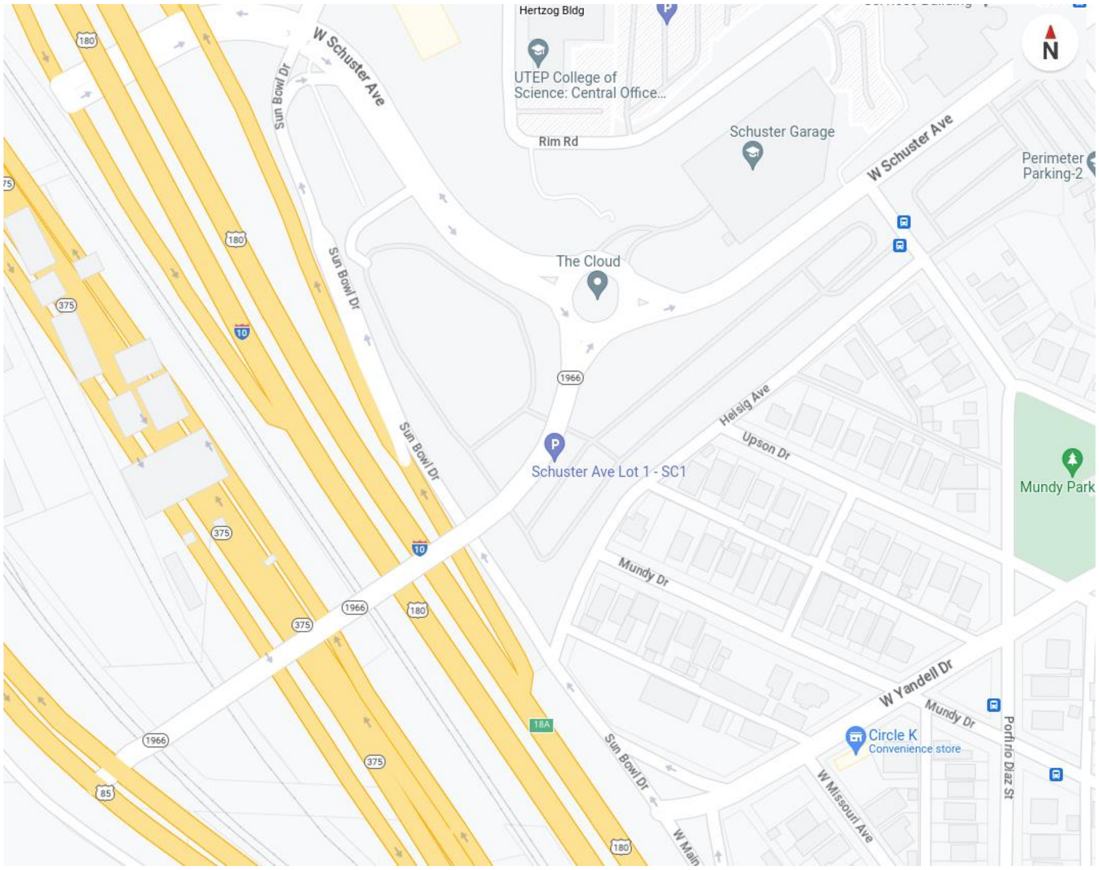

Figure 10. Google map of the roundabout and surrounding region

The Northeastern side of the roundabout is W Schuster Avenue is undergoing construction which has caused much longer queues that extend to the signalized intersections on Schuster. These complex and interesting traffic interactions with the infrastructure led the team to decide to create a digital twin of the location using real-time data.

Pedestrian Bridge

The pedestrian bridge is located southeast of the IDRB, which provides access between IDRB and the Undergraduate Learning Center (UGLC). The pedestrian bridge will experience the most traffic during regular work-day hours.

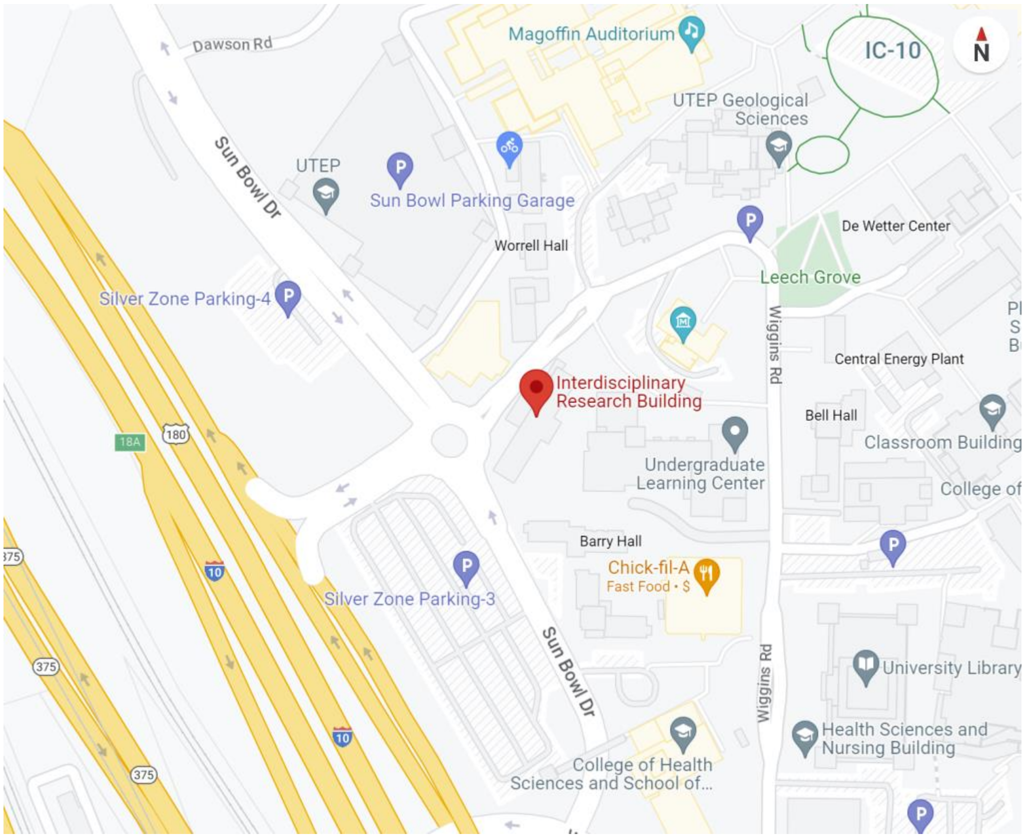

Figure 11. Google map of IDRB and surrounding region

The team decided to create a DT of the pedestrian bridge to highlight the importance of digital links to the physical entity for the purpose of bridge inventory and rehabilitation processes. The sensors installed to the digital model will demonstrate how pedestrian traffic and weather conditions affect the bridge's deformation.

Vehicle Detection and Tracking on Edge Device

The process is implemented based on the Nvidia DeepStream SDK (NVIDIA, 2022a) which provides a complete pipeline for developing computer vision algorithms and deploying them in edge computing devices. Developers only need to customize the content of each module, such as setting the object detection algorithm to yolov5, DeepStream SDK will complete a series of tasks from image capture to output results, which greatly improves the development efficiency of developers. Figure 12 is the complete flowchart of DeepStream SDK.

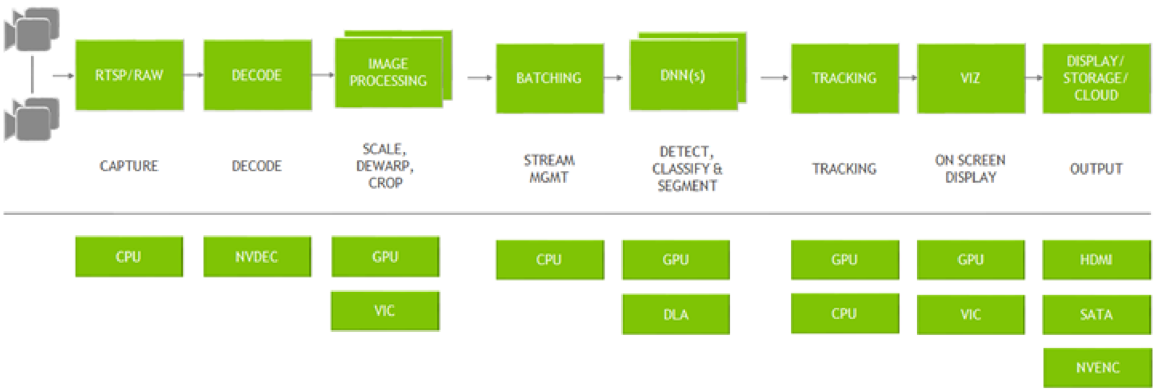

Figure 12. Flowchart of DeepStream SDK (NVIDIA, 2022a)

The Nvidia TAO Toolkit was originally the Nvidia Transfer Learning Toolkit, its main function is to customize the DNN module in the DeepStream SDK and give it different functions. Its input is pre-trained model provided by Nvidia from Nvidia NGC (https://catalog.ngc.nvidia.com/), and the developer's customized data. The TAO Toolkit (NVIDIA, 2022b) performs transfer learning to improve accuracy and generates models that can be deployed on edge computing devices with the Nvidia DeepStream SDK. Figure 13 is the flowchart of TAO Toolkit.

Figure 13. Flowchart of TAO Toolkit (NVIDIA, 2022b)

The purpose of this project is to place edge computing devices Jetson Xavier NX and cameras on the fourth and fifth floors of the Schuster Garage on the UTEP campus, then use Yolov5 (Jocher, 2022) and DeepSORT (Wojke, 2017) to complete object detection and tracking tasks at the roundabout near the UTEP campus and get real-time traffic flow information in all directions including the trajectory of each vehicle. Among them, Yolov5 is responsible for the target detection task, and DeepSORT is responsible for the tracking task.

The camera and edge device will be mounted in a NEMA rated box on top of the Schuster garage, see Figure 14.

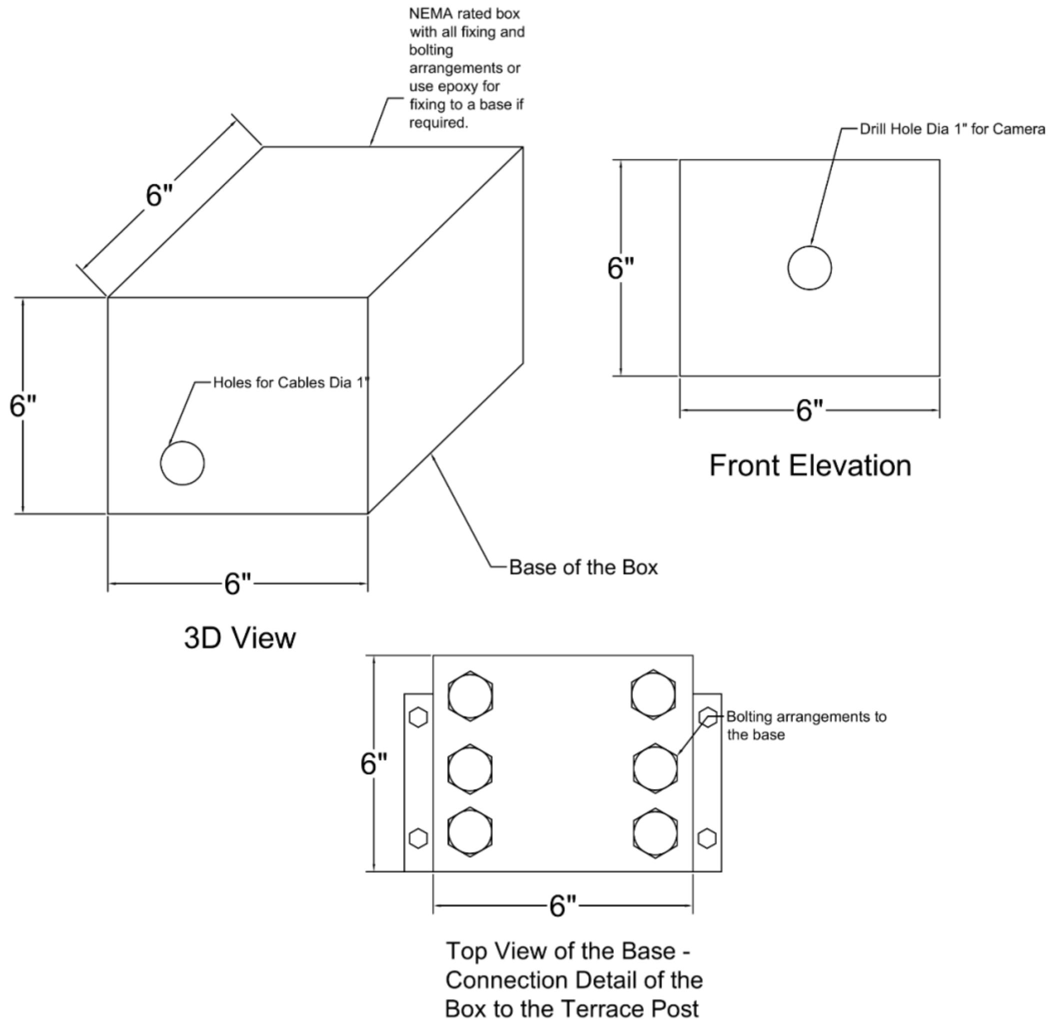

Figure 14. Box to house the camera and edge computing device

In the initial stages the team focused on testing target detection and tracking algorithms and counting the number of vehicles for every type. Some videos shot from the Schuster Garage at different times and from different angles are being tested using yolov5 and DeepSORT algorithms. Algorithms for calculating traffic flow in each direction have also been implemented.

Some issues have been observed in the experimentation. The first is the problem of detection accuracy. For example, some cars will be detected as trucks. The current solution is to use the Nvidia TAO Toolkit to further train the model to improve detection accuracy. The second problem is that there is a parking lot next to the roundabout, and many stationary vehicles are also detected. The current solution to this problem is to use a background subtraction algorithm to classify stationary vehicles as background. The third problem is that vehicles traveling on the I-10 highway far away from the roundabout will also be detected. Our solution to this problem is that vehicles whose detection area is outside the area will not be logged. The last problem is that there is an obstruction in the middle of the roundabout, which will partially occlude the vehicle, so the tracking algorithm will lose the target and cause the same vehicle to have different IDs. The tentative plan is to use vehicle recognition and image smoothing technology based on (Yang, 2020).

Figure 15. Advantech MIC-710AIX, AI Inference System based on NVIDIA Jetson NX

Team members have implemented the vehicle sensing algorithm on an edge device (Nvidia Jetson Xavier NX by Advantech shown in Figure 15) for real-time vehicle detection at the roundabout and potentially other locations. The implementation on the edge device supports the integration of DM and SLL in Task 5 by generating vehicle coordinates.

We are working with the UTEP Administration department on the sensor installation for the roundabout. Due to the potential for sensitive information in the video, the University required approvals from the Police department, Planning and Construction, Facilities, Legal Affairs, the Vice President of Business Affairs, and Information Technology. Real-time vehicle detection and every minute flow rate for each origin and destination pair of the roundabout has been obtained from video-based vehicle tracking using an edge device (Nvidia Jetson Xavier NX) and a sample video.

Pedestrian Bridge

For the bridge prototype, the sensor layout has been designed and the data acquisition equipment is being prepared. We are seeking approval from the structural engineer (as required by UTEP) for permission to install the sensors on the structure. The Geokon Model 4000 Vibrating Wire Strain Gages are held in place by two mounting blocks placed over the ends of the spacer bar, as shown below. Strain is measured by the sensor when the vibrating frequency of the wire changes due to deformation.

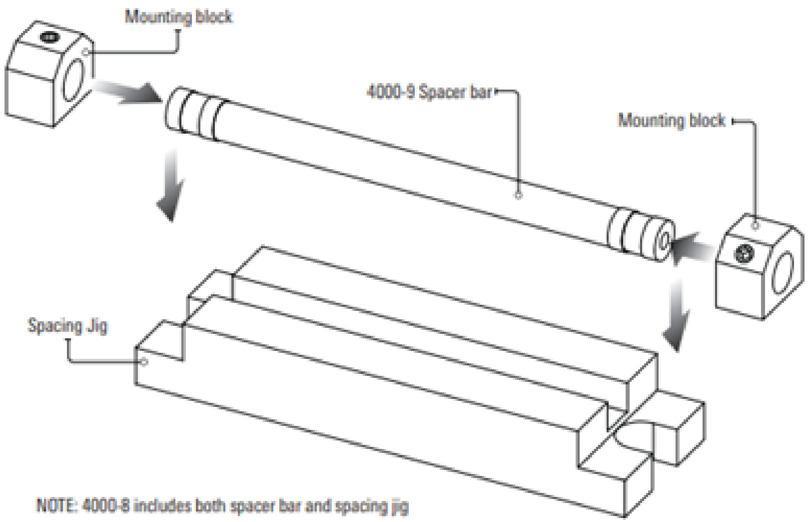

Figure 16. Spacing Jig from the user's manual

In the purpose of this project, the strain gauges are placed using epoxy cements to steel or concrete surfaces. For concrete surfaces, Devcon Underwater Putty and Loctite 410 Instant Adhesive are mixed for a 1/1 ratio and applied to the center two-thirds of the mounting block, after the surface is cleaned and grinded down. The curing time must be 24 hours before the mounting blocks are installed. For steel surfaces, the Loctite Speedbonder is used in a 10/1 ratio mix as an adhesive. Once the surface is determined along with the materials to use, the strain gage is mounted by sliding the strain gauge through the mounting blocks and tightening the setscrew in the mounting block. After it is slid into place, the gauge is then connected to the readout box, and the readout box is set in accordance with what type of strain is being taken.

The equation for strain, ε, is:

$$\varepsilon = \frac{4 \cdot f^2 \cdot \rho \cdot L_w^3}{L_g \cdot E \cdot g}$$

Where f is the frequency, ρ is density of the wire, L_w is the length of wire, L_g is the length of the gauge, E is the modulus of elasticity, and g is the acceleration due to gravity.

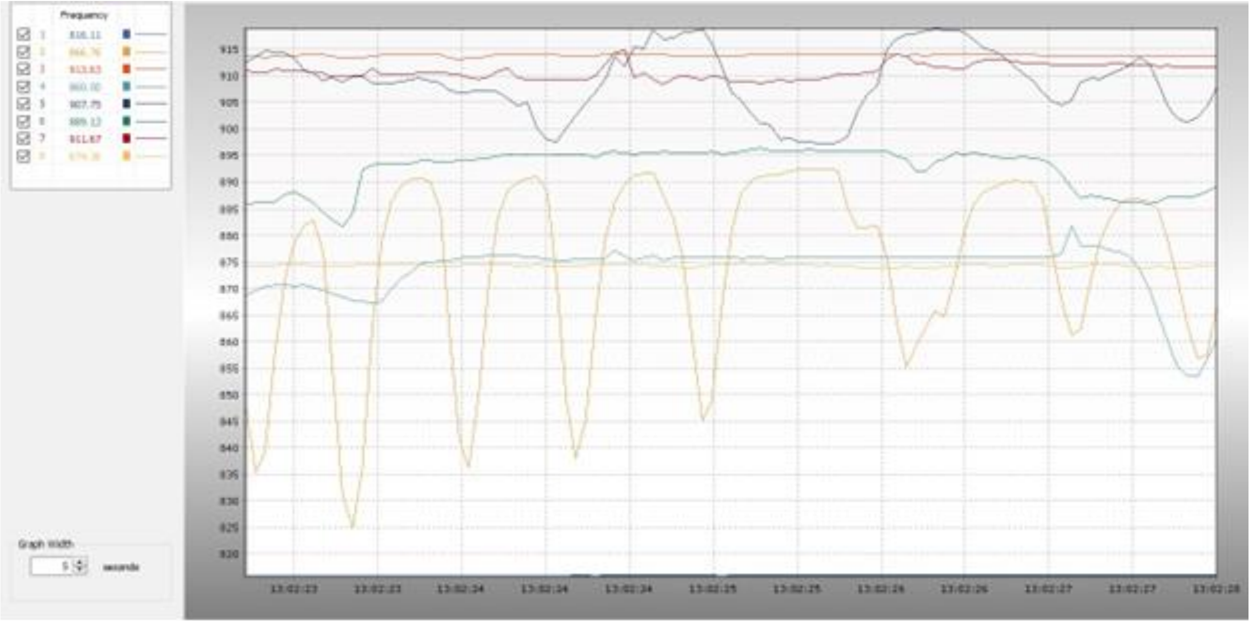

Figure 17. Strain gauge output graph

This graph above shows the output of the sensors when pressing on the gauge itself. The eight strain sensors vibrate in place and are depicted by their respective color. The horizontal axis is time, the vertical axis is the frequency value. Here the frequency values are determined. Five sensors experienced pulse compressive forces, and the remaining three did not experience any force. This procedure demonstrates that the sensors operate, and display data expected in an unload/loading stage and are ready when the team can install them onto the pedestrian bridge. The maximum and minimum values are set to be 1250 Hz and 450 Hz respectively. Once the frequency for a specific sensor is determined, the strain can be calculated by plugging the value of frequency into the strain equation.

Reality Capture

The Leica BLK360 LiDAR captures point clouds at a rate of million points per second and completes a scan with spherical images in 20 seconds. It was used with the iPad app to wirelessly obtain the scans as soon as they were done. The equipment also maintains positional information and can combine different scans automatically with minimal manual alignment.

Roundabout

Team members have also developed an approach to incorporate vehicle detection results via edge computing on the campus DM. One major step towards a true campus digital twin is the integration of real-world data into the virtual model. From a transportation perspective, it would be beneficial to have a representation of vehicles on the roads for visualization and analysis. Vehicle detection can be carried out automatically using many computer vision algorithms, but for real world practical implementation, the challenge lies in performing this detection on a low power edge device in real time. Since the vehicles detected in the video are a two-dimensional projection of the 3D scene, they do not directly correspond to the real location, and the coordinates must be transformed somehow to be usable. The resulting virtual depiction also needs to be dynamically similar in terms of vehicle orientation and movement.

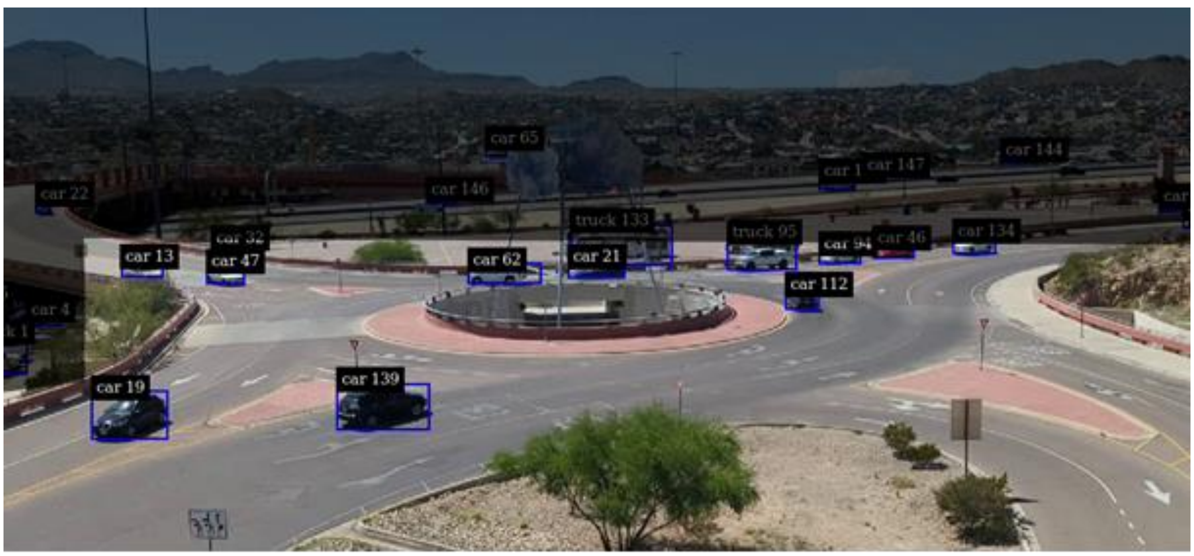

Figure 18. Cars detected from video and their bounding boxes with rejection region marked as dark

The raw detection data was transferred to a desktop computer to be read into a Pandas dataframe, and each detection was considered sequentially. For every detection there was a class ID, coordinated of the top left corner of the bounding box, the width and height of the box, and a vehicle ID unique to every new detection. If the top left corner of the bounding box lay outside the manually defined bounds of the roundabout, it was ignored. The rejection region is shown in Figure 18. For vehicles in, or close to, the roundabout the 2D coordinates of the bounding box centers were converted to 2D coordinated in the plane on the digital model with a constant Z (height) component. This was achieved by sampling points in different regions around the video frame, shown using red dots in Figure 19, and the corresponding points in the digital model were then used to perform regression, resulting in a linear transformation between the two coordinate systems. Mathematically, it can be expressed as follows:

$$x_{model} = a_1 x_{image} + b_1 y_{image} + c_1$$

$$y_{model} = a_2 x_{image} + b_2 y_{image} + c_2$$

Where (x_{model} , y_{model}) are coordinates in the digital model, (x_{image} , y_{image}) are coordinates from the image, and a_1, a_2, b_1, b_2, c_1, and c_2 are coefficients obtained from the linear regression from the sampled points.

If a particular vehicle ID was encountered for the first time, a new vehicle was spawned in that location, otherwise the location of the existing vehicle was updated. Since the detections from the video do not smoothly transition from one frame to the next, the resultant movement was visibly jittery. However, using the average of the new location and old location for movement produced smoother results. Additionally, when some vehicles were not successfully tracked, the same vehicle could be assigned a new vehicle ID, thus spawning a new vehicle in the model, while the old one did not get updated. To deal with this issue, the list of vehicles was refreshed after every 30 seconds to only include the most up to date detections.

The orientation of the vehicles presented a challenge since detections from YOLO do not have any information about the orientation. Within the radius of the roundabout all vehicles were given the direction tangent to the circle, while cars outside the roundabout were assigned orientation based on the running average of the direction of their movement. The resulting rotations only roughly match the real-world orientations since there is significant variation in the bounding boxes between each frame. In order to have a consistent depiction of the vehicles on the digital model, physics simulation was not enabled for the vehicles, and their trajectory was exclusively controlled by the detection results.

Figure 19. Points chosen to find linear transformation between two coordinate systems

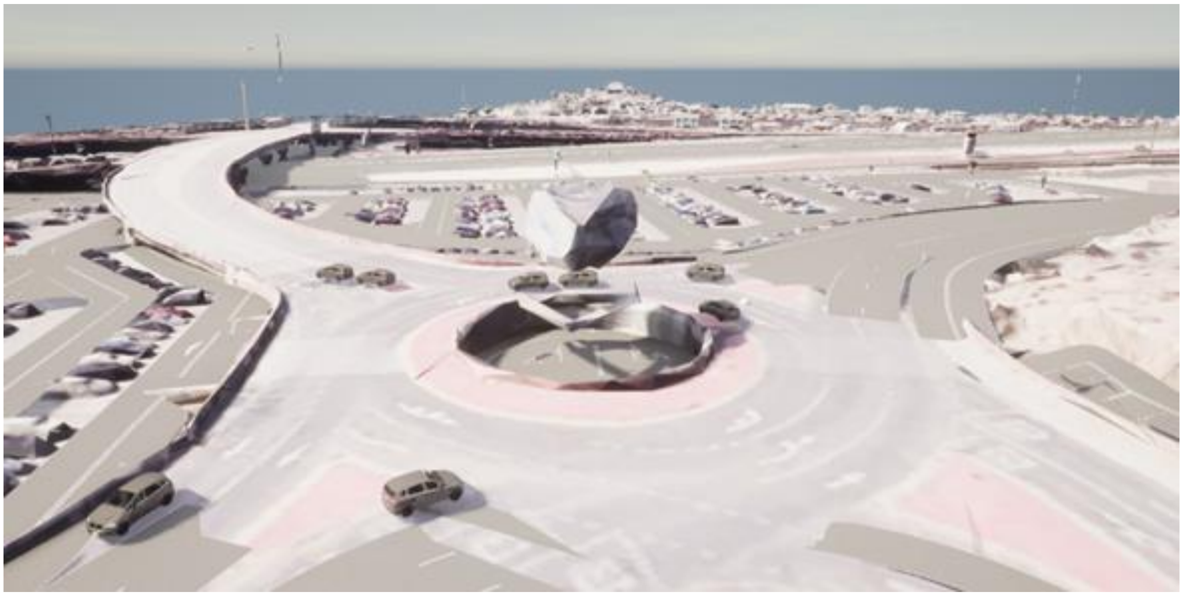

Figure 20. Cars from video projected onto digital model

The digital campus model was built in the compiled from source CARLA project of Unreal Engine using 3d terrain data from Google maps using Renderdoc and Blender, and road network exported from Openstreetmap. Roadrunner software from Mathworks was used to project the road onto the height map obtained from the US Geological Survey. The model is composed of 1.59 million triangles running on an Intel Core i9-10900X CPU, 256 GB RAM, and NVIDIA A6000 GPU. With this configuration the model can load and update the vehicles at 50 fps. Of the 21 vehicles that entered the roundabout, all of them were detected, tracked, and displayed correctly on the digital model. A screenshot of the roundabout with detected cars projected into the digital replica is shown in Figure 20. However, due to some cars disappearing from view behind other vehicles, there were 3 cases of multiple detection, which were subsequently cleared when the list of active vehicles was refreshed. Vehicles far from the center of the frame had a higher error in position on the virtual model owing to the camera lens distortion. This can be remedied by inverting the distortion during preprocessing or by using a higher degree polynomial for regression. An attempt to fix this by using separate linear transforms for different parts of the frame solved part of the problem but the boundaries between the regions did not provide a smooth transition.

Extending the previous work on the digital model, the flow rates obtained from the video detection were used for co-simulation in CARLA and SUMO. Team members have developed an approach to incorporate vehicle detection results via edge computing on the campus DM. One major step towards a true campus digital twin is the integration of real-world data into the virtual model. Vehicle detection can be carried out automatically using many computer vision algorithms, but for real world practical implementation, the challenge lies in performing this detection on a low power edge device in real time.

Previously, this method was used to display the vehicles on the DM, and now this has been extended to extract traffic parameters such as flow rate from the video detection. The raw detection data containing the bounding box coordinates is hosted on an HTTP server on the edge device and accessed by the computer running the DM over the UTEP network.

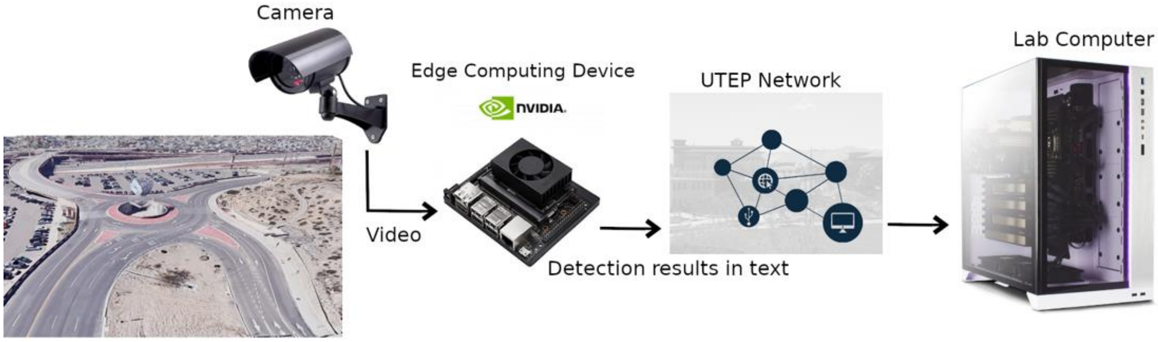

Figure 21. Layout of the video detection architecture

The detection results are then shaped into a Pandas Dataframe and the vehicles are tracked across the image. If the bounding box of a certain vehicle crosses a predefined zone (see Figure 22) on the approach of the roundabout, it is counted as having entered the roundabout. If the same vehicle appears again on one of the other approaches, or the same approach, it is counted as having left the roundabout. Then the value of the corresponding element of the origin-destination (OD) matrix is incremented by 1. This matrix is then used for scenario analysis.

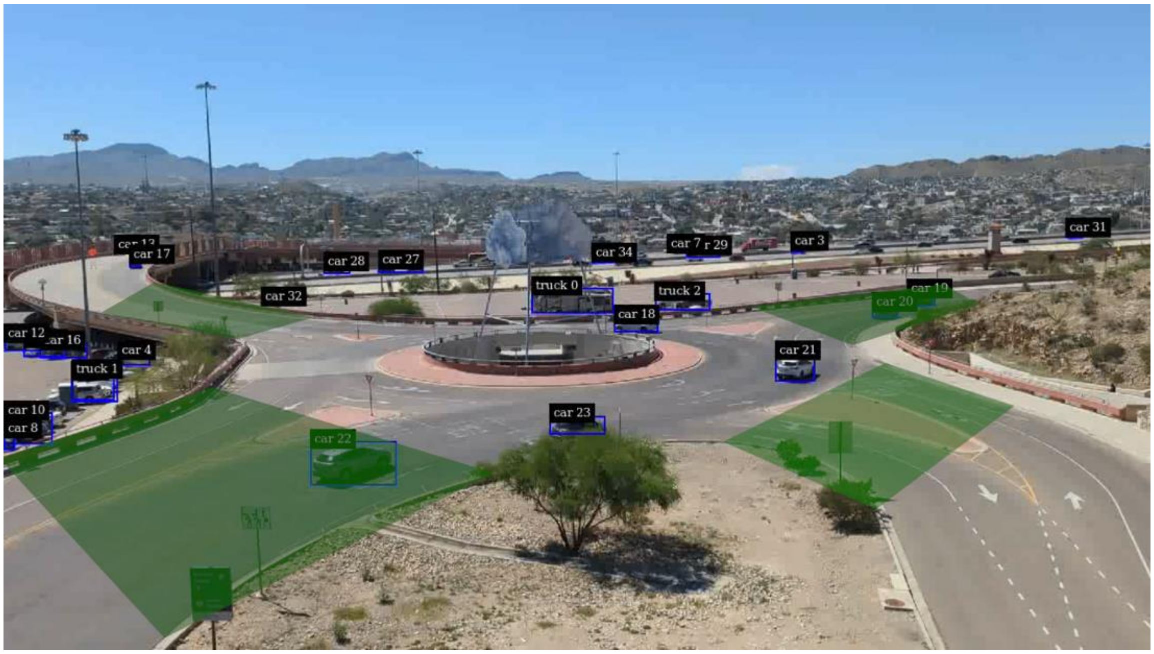

Figure 22. Approach regions of the roundabout marked green

Pedestrian Bridge

A simple bench test was performed to ensure the sensors were functioning properly. The test focused on ensuring the movement from the sensors was recorded on the VWIRE 300 and can be displayed on a laptop in real time. We are in the process of writing a program that can record and store data on the CR6, and then export it onto a laptop at a later time. The installation of the sensors onto the pedestrian bridge is still in progress.

The project's current stage is ensuring that the structural model of the pedestrian bridge is analyzing test loads correctly. Some issues were observed using Autodesk Structural Analysis. The first problem was the option of using offsets or rigid links in the structure. The first method was used but the results of the analysis indicated that there exist various separate structures within the model. The solution to this problem is to move to the second option of using rigid links in the structure to eliminate the problem of having separate structures. The team is currently working on creating an accurate model using only rigid links as part of the model design.

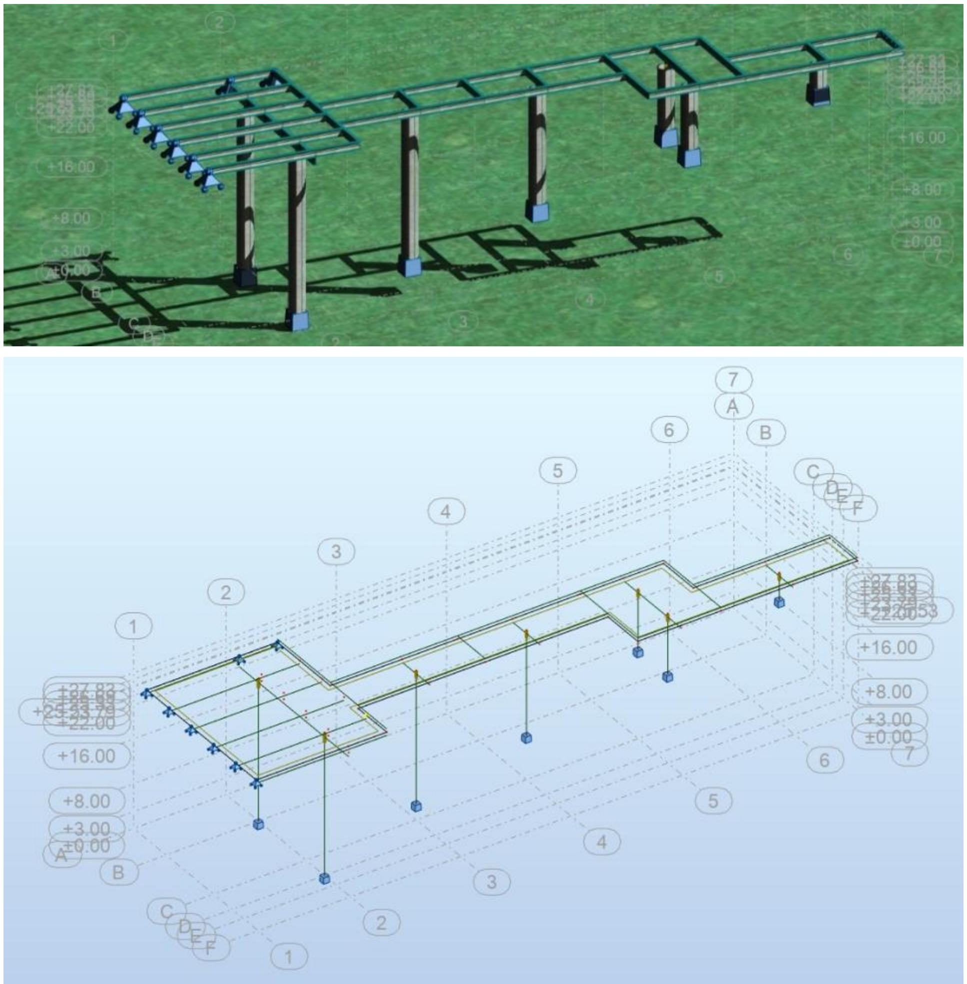

Figure 23. Pedestrian Bridge model using offsets

Extended Reality

Currently there is no digital shadow model of the locations that were LiDAR scanned and visualized in the lenses. Doing so will require a camera positioned at each location to track changes and automatically update the virtual model. Since most of the structures that are scanned do not change such as buildings, parking garages and other structures there is no need for a digital shadow model. As it relates to laboratories and other classrooms within the campus it would be helpful to keep track of hardware, office equipment, computers, and more yet it then creates a privacy issue. Hence, the reason why the models used in the extended reality component of digital twins uses the applicability of LiDAR scanning. Furthermore, if there are any changes in the future, scans can be completed to adjust for any modifications.

After scanning both of the labs labels were created to identify locations and objects to include cabinets, a whiteboard, TV, door, 3D printer, computers, and the scanner location. Labels were created to provide the user with a better understanding of their perspective with the room when combining the virtual and physical room. With further development users will be able to click on an object within the point cloud or physical object to obtain the object properties.

Figure 24. Labeled PASS Lab

Figure 25. Labeled Infrastructure Lab

Task 6: Scenario Analysis

Bridge Prototype

We are developing a scenario related to standard bridge movement threshold exceedance. Structures tend to move relative to temperature and position of the sun due to expansion and contraction of the bridge materials. Depending on the structure type, this can cause large deformations or forces. The sensing system will be able to measure some of these behaviors over time to establish bounds of normal operations. The scenario of interest would be a situation that would exceed those bounds. Given the relatively low level of pedestrian traffic, the primary scenarios that could cause this type of threshold exceedance would be a vehicle on the bridge or a fundamental structural change (e.g., scouring of a pier during a rain event). We are unlikely to run into this scenario, so the Digital Twin scenario will be demonstrated with a model leveraging the real thresholds.

Six proposed strain gauge locations are demonstrated in Figure 26, denoted in red. Gauge locations are placed away from the ends of struts where it is influenced by localized clamping or bolting distortions. Each location will have two strain gauges placed about the y-y axis to measure the axial strain of the member. The number of locations and number of strain gauges per location were selected to provide an adequate amount of data along the length of the pedestrian bridge. The sensors will measure strain every 20 min to reduce the amount of data collected.

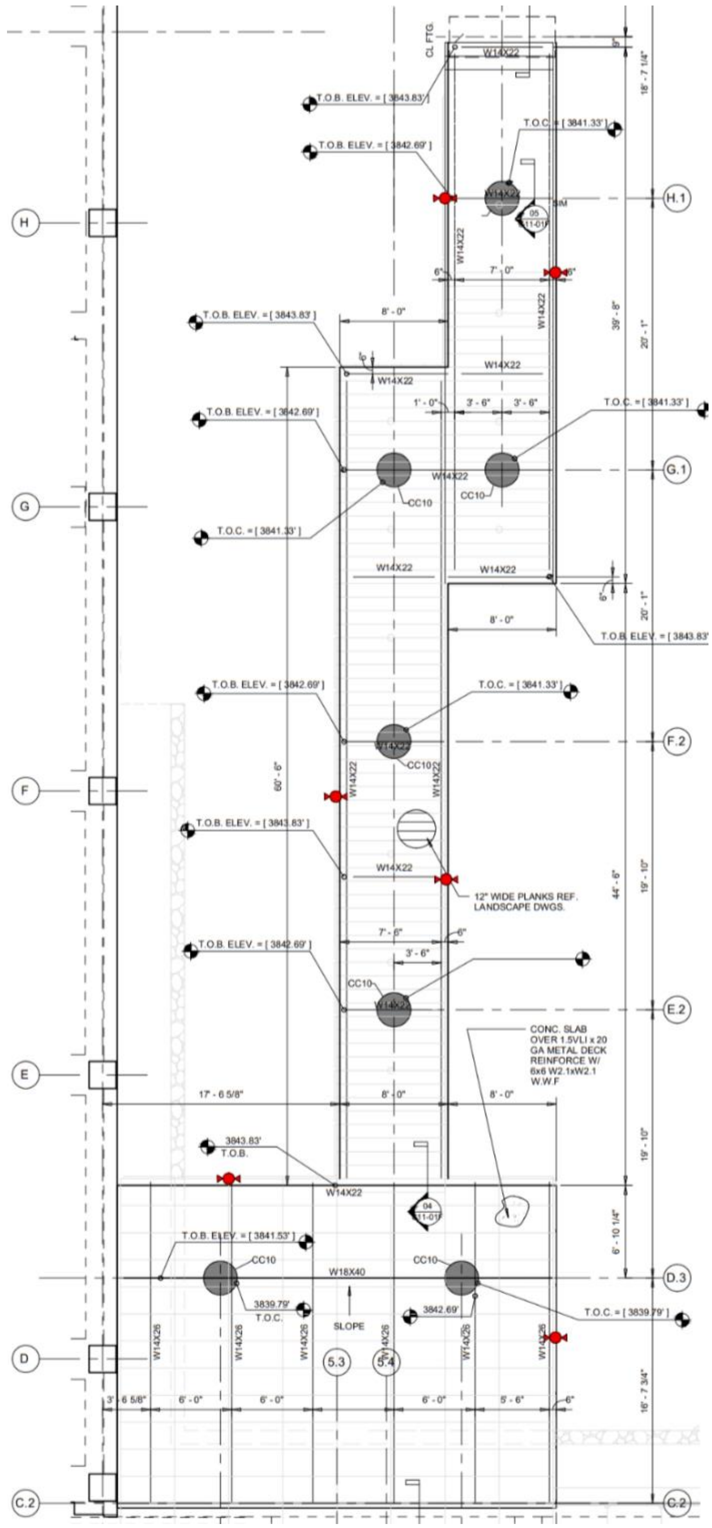

Figure 26. Bridge Strain Gauge Sensor Locations

Roundabout analysis

According to the Highway Capacity Manual (HCM 2010), level of service is calculated from the estimated delay and is used as the main indicator of efficacy for both signalized and unsignalized intersections. The Highway Capacity Manual, however, currently only contains control delay—the delay caused by the control device. Control delay is the amount of time a motorist must wait while in line before finding a suitable opening in the flow of traffic. The equation to calculate the delay is mentioned below:

Delay (d) = $\frac{3600}{c} + 900T\left[x - 1 + \sqrt{(x-1)^2 + \frac{\frac{3600}{c}}{450T}}\right] + 5 \cdot \min(x, 1)$

Where;

C = capacity of lane
T = 0.25 for 15 min time-period analysis
X = v/c = traffic flow/capacity

It is assumed that in case of a two-lane approach and a two-lane roundabout the capacity of both the lanes differ which is calculated by following equations:

$cr = 1130 \cdot e^{-0.0007Vc}$: Capacity of right lane

$cl = 1130 \cdot e^{-0.00075Vc}$: Capacity of left lane

Where *Vc* is Conflict flow.

For the project, a manual 15-minute directional count was performed at the roundabout and the delay for the Westward approach was calculated.

Table 2. Manual directional counts at roundabout; rows are origins, columns are destinations

	N	E	S	W
N	1	5	8	11
E	1	0	66	58
S	1	35	0	16
W	0	28	68	2

Using the data in Table 2, and the above set of equations, the delay in the left lane at the Westward approach was found to be 10.08 seconds/vehicle whereas for the right lane it was 12.48 seconds/vehicle.

Roundabout simulation

Once the OD matrix for the roundabout is obtained, co-simulation is performed on SUMO and CARLA to visualize the state of the traffic in two scenarios based on ongoing construction on Schuster Avenue. The first scenario involves no construction and the second scenario - with construction - involves closing two lanes for about 450m from the roundabout, turning four lanes to two.

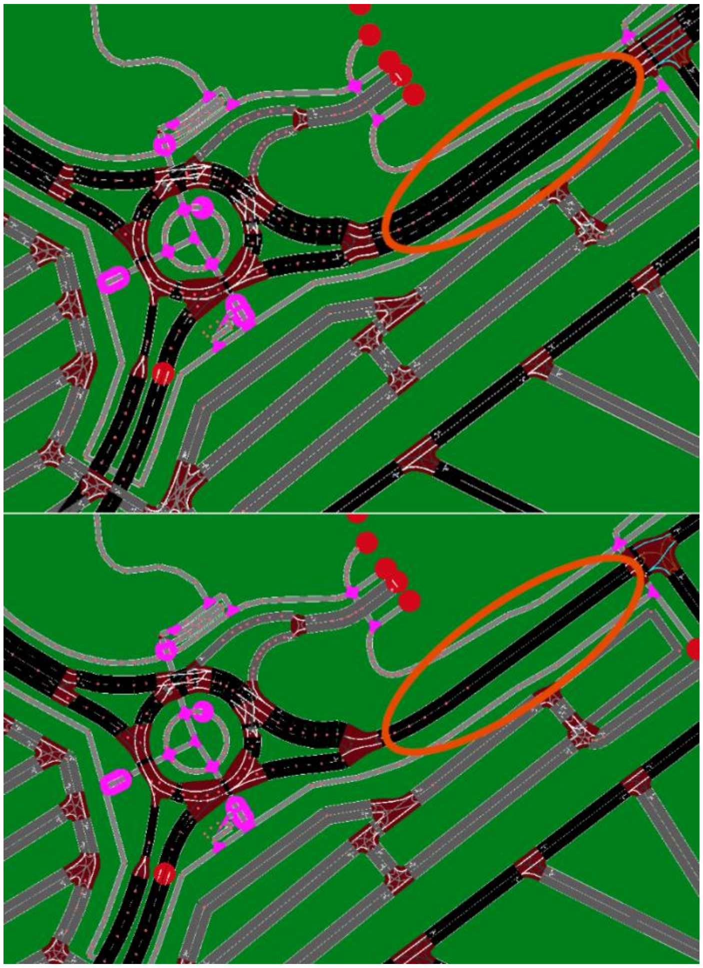

Figure 27. SUMO screenshot of two scenarios: 4 lanes (top), 2 lanes (bottom)

Three videos of around 4 minutes each were analyzed using the aforementioned detection method resulting in the total counts in Table 3. These counts differ from the manual counts significantly due to occlusion, but over long periods of time the model can be calibrated to adjust the errors using comparisons of manual and automatic counts.

Based on the manual counts, the simulation was run in SUMO for the two scenarios. The average Time loss is defined as the extra time the vehicles take on average compared to an ideal time of driving through their routes without stopping. Without construction this Time loss was 31.13 seconds and with construction closing two lanes this loss was 34.54 seconds, meaning an additional average delay of 3.41 seconds.

Table 3. Directional counts from video; rows are origins, columns are destinations

	N	**E**	**S**	**W**
N	0	3	5	13
E	1	0	21	39
S	2	33	1	13
W	1	10	36	5

While the two lanes do create a delay, it is seemingly minor since these demands were based on relatively low traffic. If the demand for each direction is doubled, the four-lane scenario gives only 32.89 seconds loss while the two-lane scenario gives 49.84 seconds, increasing the delay to 16.95 seconds. While this is still not enough demand to build up a meaningful queue in the four-lane scenario, it causes significant buildup in the two-lane scenario as shown in Figure 28.

Figure 28. SUMO screenshot of buildup in the two-lane scenario

Extended Reality

The process to obtain a working simulation for the HoloLens included the following:

- Scan location or object with LiDAR scanner
- Export file from scanner files as an e.57 file
- Open file in Cloud Compare to adjust color, size, location setups and export as a .ply file
- Upload file to Unity for simulation and game design development
    - Used to develop a project file code that is sent to the HoloLens through Microsoft's Visual Studio
- Run build settings on Unity to export "Build" file code for Visual Studio
- Obtain HoloLens IP Address to plug into Visual Studio
- Send to HoloLens by running the code without debugging
- Manipulate model in HoloLens using hand interaction

The world of extended reality continues to grow, further expanding the technology and software that allows us to build virtual environments into the physical world. The current state of the digital twin modeling through extended reality consists of being able to visualize both labs as seen in Figures 5 and 6 on the HoloLens. For the Oculus we are able to visualize the Revit sample model. Both lenses are currently unable to visualize both sets models with the HoloLens focused on point clouds and the Oculus with 3D models. The biggest concern with HoloLens is the connection limits between Visual Studio and the lenses as larger files tend to crash the lenses sooner than later. Similarly, we are unable to clearly visualize the point clouds and 3D models within bright environments. On the other hand, the only model tested on the Oculus has been the test model through a free application Sentio VR to which we have not connected any other scanned models. The ideal future state of these methods of modeling would consist of all types of models, to include 3D models, point clouds and more to be readily accessible on both headsets. To obtain this accessibility the following steps need to be taken:

- Research and test different methods of connections to minimize connection losses
- Test other types of project models on the lenses outside of 3D models and point clouds
- Conduct further testing on the model limitations within both headsets
    - Model size, depth, brightness, color, opacity, etc.
- Utilize the software currently available to upload models in both headsets

Although the biggest gaps within this method of digitization focus on the connection and size following the plan above would lead to the further development of a full digital twin model.

Task 7: Outreach Workshop

On May 05, 2023, the project team hosted a workshop which focused on engaging local transportation stakeholders about DT technology. The organization and outcomes of that workshop are presented in this section.

Identification of Community Stakeholders

The team extended an invitation to individuals from various backgrounds to participate in a community engagement workshop. Attendees came from the University of Texas at El Paso (Operations Division), SunMetro (a local public transportation provider), the City of El Paso (Parking and Streets Divisions), and the El Paso Metropolitan Planning Organization. These attendees and their respective organizations are found in Table 3.

Figure 29. Introductory session

Table 4. Attendees and their organizations and positions

Name	Organization	Position
Claudia K. Garcia	City of El Paso	SunMetro
Clifton Walsh	UTEP	Police
Eddie Valtier	TxDOT	Transportation Planner
Eduardo Adame	TxDOT	Transportation Engineer
Jared Cryer	UTEP	Facilities
Jerri Herrera	UTEP	Parking
Jiann-Shing Yang	City of El Paso	Streets
Joaquin Rodriguez	City of El Paso	Transportation Planner
Jon Feind	UTEP	Planning & Construction
Kyle Ibarra	City of El Paso	Streets
Lindsey Adams	City of El Paso	Legislative Liasion
Marty Boyd	TxDOT	Transportation Planner
Omar Martinez	City of El Paso	Grants & Strat Initiatives
Raymond Telles	CRRMA	Executive Director
Rob Parker	UTEP	Facilities
Salvador Gonzalez-Ayala	El Paso MPO	Transportation Research

Workshop Agenda

The workshop was hosted in the Interdisciplinary Research Building (IDRB) titled "Digital Twinnovation Workshop", where community stakeholders were welcomed to the venue to sign in and enjoy complementary pastries and coffee. The venue offered the opportunity for the community stakeholders to introduce themselves to the team and each other. After the initial introductions, there was a brief overview of the project and the three directions of DT that the team had worked on.

Figure 30. Presentation of an overview of the Digital Twin project

Following this session, the project team set up three demo stations for the transportation network digital twin of the roundabout, the structural digital twin of the pedestrian bridge, and the VR/AR demonstration for DT. After a short break, there was a presentation on the Innovation Invitational by the Texas Innovation Alliance, followed by lunch and breakout discussion sessions.

This workshop played a role for the community and stakeholders to gain a further understanding of digital twin development. Attendees comprised of representatives from the City of El Paso, Texas Department of Transportation, and the Texas Innovation Alliance. Apart from a showcase of the Digital Twin project, the workshop discussed emerging technologies, grant readiness, and knowledge sharing between institutions.

Figure 31. Showcasing the roundabout transportation DT

Figure 32. VR demonstration of DT

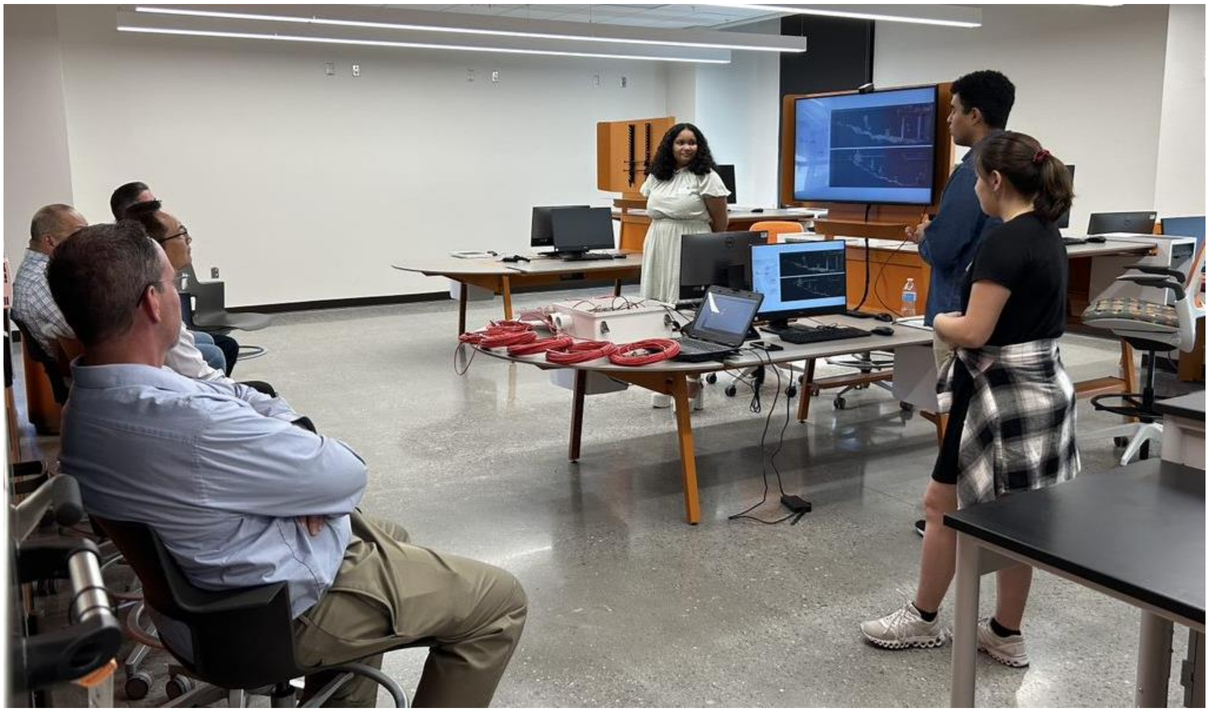

Figure 33. Demonstration of bridge sensors

Observations and Results from Breakout Sessions

One of the breakout sessions focused on the development of digital twins through extended reality. Virtual and Mixed reality goggles/lenses to include the Oculus and HoloLens headsets were present for the visualization of a model home, and LiDAR scanned point clouds as represented previously. The LiDAR scanner was also present to show users how the process flow was developed for the models they had observed in the lenses.

Another breakout group focused on ways to make the El Paso region more sustainable and desirable for private companies. A popular topic was innovating the airport regarding the aircraft being used. The group talked about the application of digital twin technologies to make the airport operations more efficient to reduce delays and costs. A participant mentioned the idea of making El Paso a solar center of Texas and having it be the blueprint for other cities to follow. Another idea mentioned was retaining military talent in El Paso. Since Fort Bliss is one of the largest military bases, we receive a lot of soldiers with knowledge and skills that can be useful in the El Paso region. Unfortunately, there is a low retention rate for these soldiers – a lot of them leave to other cities. Keeping this talent in the region would help expand technology since the military engineers and technicians would be able to contribute to the city. The final topic discussed was about how the city can utilize the space surrounding the Global Reach area. There needs to be a connection from Montana street to 601 Spur and to create new businesses and attractions in the Global Reach area. It would also be useful to connect Fort Bliss to the Downtown area through the use of a public transport hub.

The “Bridge 2 Bridge – Physical/Digital Connectivity Model” group focused on applications addressing the vulnerability of road users, transit efficiency, and transit-oriented development on Alameda Ave., a road that connects two US-Mexico border crossings. Pedestrians have the potential to be in an incident near poorly lit transit stops and crossing the road in non-designated zones. One solution discussed was to create a physical/digital connectivity model that detects pedestrians crossing an intersection and midway blocks. This application along with message boards that detect pedestrians on the road can improve pedestrian safety on Alameda Ave.

Some concerns highlighted in the discussion were Alameda Ave. having many utilities that run through the road, affordability challenges to perform this project on a 14.5-mile stretch, stormwater issues, and land use challenges. Three methods of measuring performance on this road were to detect vehicle headway, pedestrian involvement in using designated zones to cross the road, and Wi-Fi use tracking to measure the amount of pedestrian traffic in the area. Currently, there exists granular mobile data that detects pedestrians in different zones that may be implemented in this idea to improve the DT model.

The third breakout group focused on the use of connected vehicles as an application for the innovation zone development. Five key points were discussed: Challenge & Vision, Location, Solutions, Partners, and Metrics & Benefits. The location, in this case, would take place in the bridges connecting Juarez and El Paso, since this is a common issue for residents in the area. The Zaragoza and Stanton ports of entry are notorious for their amount of traffic and time spent waiting to cross over. There are crashes due to backup, the amount of traffic waiting to cross adds to the idling emissions and the unhealthy air quality, making this method a nonpractical way of crossing back and forth. Some solutions were discussed to help with this issue: queue length sensing and communications. The queue length sensing will include Bluetooth and a parking reservation system which will be added to data fusion that will show more reliable wait time information. Currently the City of El Paso and CBP websites are involved in the communications, which will include a smart phone app and a web dashboard. Some of the partnerships that will be involved in this would include both El Paso and Juarez City Unions, TxDOT and UTEP. Implementing connected vehicles will improve air quality monitoring, crash reduction, data reliability, congestion reduction, route planning, and improve the economic development.

Conclusions and Future Work

The purpose of this project was to explore DT technologies and make prototype DT systems for civil infrastructure. The project team achieved the following goals:

- Demonstrate what a DT for Civil Infrastructure can look like, the kinds of problems it can solve, and possible use cases.
- Fast and efficient ways to create a transportation DT of a given geographical location with 3D terrain and road network.
- Selected specific sites for different aspects of infrastructure analysis: roundabout, pedestrian bridge, IDRB building.
- Identified the data and data collection practices for reality capture of existing infrastructure.
- Tested a prototype transportation DT pipeline with real-time visualization, and real-world data based analytics.
- Explored scenarios with real and synthetic data in the DT to visualize simulation results that can help with planning and design.
- Identified gaps in university operating procedures to facilitate a broader adoption of DT for a college campus, and other challenges faced specific to each DT approach.
- Disseminated the results and educated local public stakeholders about DT technology, while brainstorming ideas for future collaborations.

A 3D digital model was created for The University of Texas at El Paso inclusive of the road transportation network. This was built using freely available data and free or open source software, with a focus on minimizing the effort on the model creation so that the procedure can be used for other locations. A structural model of a pedestrian bridge was created, and a sensor layout was determined to find the best placement of strain gauges and tiltmeters. LiDAR scans were performed on multiple locations on campus, both indoors and outdoors to determine the point cloud density needed to recreate the locations digitally, allowing for 3D representations in virtual/augmented reality applications.

With these digital models, simulations were performed using synthetic data, then for the transportation DT, real-world data was used in the form of vehicles detected from videos captured at a roundabout. This was used in scenario analysis of the road network with and without construction related lane closures. The object detection and tracking were performed on a low power edge computing device in real-time and transmitted over the network to the desktop running the DT. The method is scalable to multiple locations and multiple DTs.

Digital twin technologies can be significantly beneficial for planning and construction with regards to civil infrastructure where adding more details and functionality provides higher fidelity to simulations and visualization. Extended reality technology can help create an immersive experience for communicating new ideas and changes to existing infrastructures with stakeholders. DTs also provide a platform for experimental research virtually with realistic physics and geometries.

The major limitations to an extensive DT are the scale of the implementation and availability of data. This project faced these hurdles in the early stages since the detailed drawings or BIM models of campus buildings were not available. The installation of sensors was also endlessly delayed due to the bureaucratic nature of permissions and procedures. Therefore, for a successful DT, there needs to be specific scenarios that inform the requirements for sensing, data, visual fidelity, and communication technology. For example, currently the output of the transportation DT would be manual decisions on detours in the construction zone in heavy traffic hours. This is clearly not an autonomous cyber-physical system with closed loop feedback, but it is sufficient to solve the problem. However, if, for example, the traffic management center of the city had a large DT of the transportation network with real-time traffic information, construction and lane closures schedules, and dynamic message signs and traffic signal timings, similar scenario analysis could be performed to ensure congestion free flow during the planned construction.

The integration of extended reality in construction will allow project managers, owners, engineers, and field workers to be able to visualize all phases of a project and their components. For the further development of digital twins in extended reality maximization of models within both the Oculus and HoloLens are crucial to clearly define the impact that both systems have on any industry. Future work includes more scans of structures around classrooms around campus while ensuring the application into the lenses becomes a more fluid and easily accessible process.

Future directions of research can focus on creating an interoperable software platform that can consolidate the heterogenous data and different DT approaches. For example, road network, building occupancy, parking, energy usage, and structural models should have their own modeling and simulation, but at the same time be incorporated into one central DT which provides visualization and control, including VR/AR, to the stakeholders.

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