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# Digital Twin Technologies Towards Understanding the Interactions Between Transportation and Other Civil Infrastructure Systems

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16. Abstract Digital Twin (DT) technology is the next step in the gradual shift from physical to digital models in civil engineering. Computer-Aided Drafting (CAD) revolutionized the industry by reducing the time and costs associated with documenting design. Building Information Modeling (BIM) has eliminated the need for physical design descriptors (i.e., drawings or physical models). DT models build off CAD and BIM but are utilized over the operational life of the infrastructure as a management tool. A DT is a relevant abstraction of the physical asset; it is most frequently used to model, improve, and control manufacturing systems. Civil engineering applications using DTs have been emerging, but transportation infrastructure represents a challenging extension of DT technology because of its spatial scale, as well as its voluminous and time-varying data. However, DT is a powerful decision support tool for the design, maintenance, and management of transportation infrastructure, particularly for studying its interdependencies with other infrastructure systems, which is of relevance to smart cities. The primary objective of this research was to explore the effectiveness of DT technology as a tool to visualize and understand interactions between transportation and other related civil infrastructure systems.			
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# Digital Twin Technologies Towards Understanding the Interactions Between Transportation and Other Civil Infrastructure Systems

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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:



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## Executive Summary

Digital Twin (DT) technology is the next step in the gradual shift from physical to digital models in civil engineering. Computer-Aided Drafting (CAD) revolutionized the industry by reducing the time and costs associated with documenting design. Building Information Modeling (BIM) has eliminated the need for physical design descriptors (i.e., drawings or physical models). DT models build off CAD and BIM but are utilized over the operational life of the infrastructure as a management tool. A DT is a relevant abstraction of the physical asset; it is most frequently used to model, improve, and control manufacturing systems. Civil engineering applications using DTs have been emerging, but transportation infrastructure represents a challenging extension of DT technology because of its spatial scale, as well as its voluminous and time-varying data. However, DT is a powerful decision support tool for the design, maintenance, and management of transportation infrastructure, particularly for studying its interdependencies with other infrastructure systems, which is of relevance to smart cities.

The primary objective of this research was to explore the effectiveness of DT technology as a tool to visualize 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 a DT model of part of the campus. While a substantial portion of the campus was included in the reality capture model, the model focused on a single building and the surrounding transportation network. The DT was approximated with a digital shadow model. We leveraged existing data sources on campus and supplemented them with synthetic data to simulate the DT. Specifically, the research focused on:

- Summarizing the existing literature around DT in transportation and providing an overview of the state of adoption;
- Creating a baseline digital shadow of a selected infrastructure at the UTEP campus;
- Studying the impact of construction-related activity on the surrounding transportation infrastructure;
- Developing a visualization of the impact analysis.

The team integrated the project with the Senior Design Capstone course at UTEP to expose civil engineering seniors to emerging technologies like LiDAR for reality capture, BIM modeling, Traffic Simulation, and DT. Given the limited time frame of the project, the team conducted a gap analysis based on our study and prepared a future roadmap to create a fully functional digital twin of campus, including identification of the physical and financial resources required to create a full DT model of a large-scale civil infrastructure system of systems like a campus. The project concluded with a stakeholder engagement workshop focused on the El Paso region.

## Table of Contents

Executive Summary .....	v
Table of Contents .....	vi
List of Figures.....	vii
List of Tables.....	ix
Introduction.....	1
Report Organization .....	2
Project Overview .....	3
Challenges and Assumptions .....	5
Phase 1 .....	7
Task 1 – Literature Review and Data Collection .....	7
Task 2 – Reality Capture of Existing Conditions .....	14
Phase 2 .....	31
Task 3 - Integrate Simulation and Information Models with Reality Capture.....	31
Task 4 – Develop a Digital Shadow Model of Campus .....	32
Phase 3 .....	35
Task 5 - Simulation of Campus Digital Twin and Visualization Demonstration.....	35
Task 6 - Gap analysis and Roadmap to Full Digital Twin Model.....	38
Phase 4 .....	45
Task 7 – Community Engagement Workshop .....	45
Task 8 – Reporting and Dissemination .....	55
Czech Technical University Collaboration.....	59
Conclusions and Future Work .....	60
Overview .....	60
Conclusions Regarding DT for Civil Infrastructures .....	60
Future Work.....	62
References.....	63

# List of Figures

- Figure 1. Diagram. Conceptual Project Digital Twin .....1
- Figure 2. Diagram. Project structure by phase .....2
- Figure 3. Map. Aerial View of Area of Interest on Campus .....4
- Figure 4. Document. Survey for Campus Stakeholders .....13
- Figure 5. Image. Campus building rendering extracted from TNRIS LiDAR data .....15
- Figure 6. Image. Signal group for ramp at Gateway East and Schuster .....16
- Figure 7. Image. Signal input for Sun Bowl and Schuster intersection.....16
- Figure 8. Image. Leica BLK 360 Terrestrial Laser Scanner (left) and sample set-up (right).....18
- Figure 9. Image. Aerial-View of Scanner Location Placement.....19
- Figure 10. Image. IDRB building BIM model .....20
- Figure 11. Image. Point Cloud of IRDB .....21
- Figure 12. Image. West-view of Point Cloud IDRB and Surrounding Transportation Network .....22
- Figure 13. Image East view of IDRB building .....22
- Figure 14. Image. RANSAC Reconstruction for Subsampled Data (a) 1%, (b) 2%, and (c) 3%.....24
- Figure 15. Image. RANSAC Model Imported to Revit .....25
- Figure 16. Image. OPS Algorithm Subsampled Reconstruction.....26
- Figure 17. Image. Vehicle as it approaches the sign (left) and vehicle as the sign is just out of the frame (right) .....29
- Figure 18. Image. Dropdown menu of object code and description.....30
- Figure 19. Image. Comparison of two CSV files to match timestamps .....30

Figure 20. Image. Traffic sign Properties input via MUTCD specifications.....	32
Figure 21. Diagram. Target Digital Shadow System.....	33
Figure 22. Diagram. Achieved Synthetic Digital Shadow System .....	33
Figure 23. Diagram. Digital Shadow using Vissim Models.....	34
Figure 24. Image. Traffic simulation overall layout with satellite view.....	35
Figure 25. Image. Close view to alternative route for construction scenario .....	36
Figure 26. Image. Simulation of IDRB Construction Scenario.....	40
Figure 27. Diagram. Conceptual Digital Twin Diagram .....	41
Figure 28. Diagram. Full Campus Digital Twin .....	42
Figure 29. Image. Community stakeholder sign-in.....	47
Figure 30. Image. Opening remarks in visualization lab.....	48
Figure 31. Image. C2SMART introduction and UTEP collaboration history. ....	49
Figure 32. Image. Digital Twin technology introduction and overview. ....	50
Figure 33. Image. Project overview presentation. ....	51
Figure 34. Image. Year 2 lookahead discussion.....	51
Figure 35. Image. Operations and Management breakout group. ....	52
Figure 36. Image. Use case report out discussion. ....	53
Figure 37. Image. Student Presentation at ASCE ICTD Conference.....	56
Figure 38. Image. Digital Twin and Applications Podium Presentation .....	57

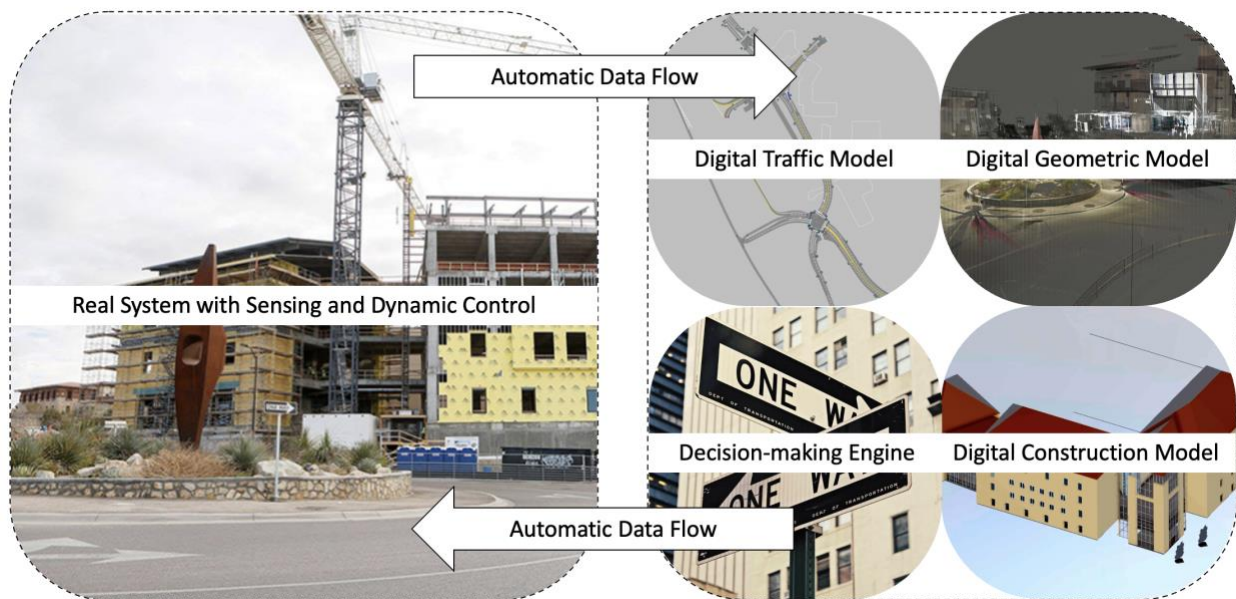


# List of Tables

- Table 1. Data Collection Details .....19
- Table 2. Scan-to-BIM Reconstruction Time .....20
- Table 3. RANSAC Processing Time .....25
- Table 4. OPS Subsampling Time.....28
- Table 5. Campus Infrastructure Systems compatible with DT .....44
- Table 6. Attendees and their organizations and positions .....45
- Table 7. Level of attendees’ DT experience.....46
- Table 8. Desired goals Based on Attendee Survey .....47

## Introduction

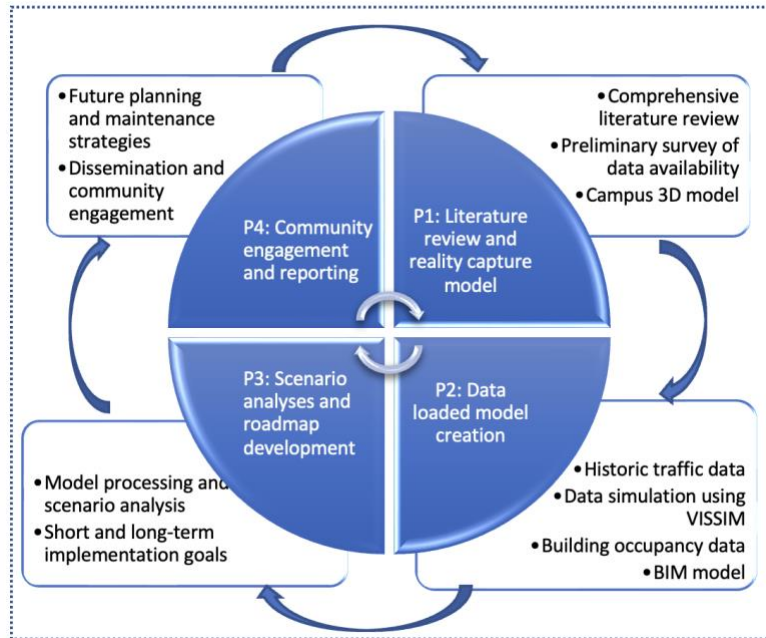
Digital Twin (DT) technology is a cyber-physical system including a real system with some capacity for dynamic control, a real-time data stream from the real system, a digital model of that real system capable of ingesting data from and simulating behavior of the real system, some sort of decision-making intelligence, and a feedback loop to induce change in the real system. This project explores DT as a tool for management of civil infrastructure. More specifically, this project focuses on DT as a tool to manage transportation and construction. A conceptual schematic of a DT for the systems selected for this project, namely a partial campus transportation network and building under construction, is shown in Figure 1.



**Figure 1. Diagram. Conceptual Project Digital Twin**

The real system for this concept is a partial campus transportation network and adjacent infrastructure, inclusive in this case of a campus building under construction. This is depicted in the left-hand portion of Figure 1. The right-hand portion depicts the digital half of the DT. For this concept, the digital system includes a traffic model, a geometric model of the built environment, and a digital model of building construction, plus some decision-making intelligence. Data flow between the two systems is bi-directional. Achieving this level of DT technology is outside the scope of this project. This project serves as the foundation on which the type of DT depicted in Figure 1 will eventually be built.

The project was broken into four phases (P1 to P4) and a total of eight tasks. The Phase breakdown and some tasks and deliverables per phase are shown in Figure 2.



**Figure 2. Diagram. Project structure by phase**

## 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
- Phase 1: Discusses Task 1 – Literature Review and Data Collection and Task 2 – Reality Capture of Existing Conditions
- Phase 2: Discusses Task 3 - Integrate Simulation and Information Models with Reality Capture and Task 4 – Develop a Digital Shadow Model of Campus
- Phase 3: Discusses Task 5 - Simulation of Campus Digital Twin and Visualization Demonstration and Task 6 - Gap analysis and Roadmap to Full Digital Twin Model
- Phase 4: Discusses Task 7 – Community Engagement Workshop and Task 8 – Reporting and Dissemination
- Conclusions: Summarizes the conclusions and future work

## Project Overview

This project seeks to make incremental progress towards a true DT system for civil infrastructure. Notably, this means that the project team was not trying to create a full DT, which was beyond the scope of the project. 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 key components of a DT designed to explore the interaction of a campus transportation network and an on-campus construction site.
- Identify data and data collection practices for reality capture of existing infrastructure.
- Create a Digital Shadow (DS) model of the selected civil infrastructure systems.
- Explore scenarios with real or synthetic data in the DS to understand how DT may affect operations of the selected civil infrastructure systems.
- Identify gaps and needs to facilitate a broader adoption of DT for a college campus, and to qualify the potential of DT.
- Disseminate the results and educate local public stakeholders about DT technology.

The case study for this effort was the campus of UTEP. In particular, the project team focused on the western edge of campus where the recently completed Interdisciplinary Research Building (IDRB) was located. Born out of anecdotal experience, the team elected to explore the interaction of the construction (of IDRB) and the neighboring transportation network. This area of campus, shown in Figure 3, tends to be congested at peak hours. This is particularly noticeable at the beginning of the semester when students and faculty are not yet in a travel routine and when there is any change or interruption to the network, such as lane closures for construction.

The area of interest is from the intersection of Sun Bowl Dr. and Schuster Ave. to the south, the ramps that connect University Ave. to/from the I-10 Freeway to the west, the entrance to the inner campus to the east, and the entrance to the Sun Bowl garage to the north, with the Mining Minds roundabout in the center of the area of interest. The IDRB is located on the southeastern corner of the Mining Minds roundabout. The northeast corner is the university bookstore, the northwest corner is barren land adjacent to a small surface parking lot, and the southwest corner is the Sun Bowl 2 surface parking lot.



**Figure 3. Map. Aerial View of Area of Interest on Campus**

During construction of the IDRB, which occurred from 2016 to 2020, a portion of the Sun Bowl 2 parking lot was fenced off and dedicated for construction trailers and material staging. Two large tower cranes served the site, frequently picking materials from the Sun Bowl parking lot and transiting them over Sun Bowl Ave to the construction site. Whenever these moves were required, Sun Bowl Dr. was closed for safety of the traveling public. This was the primary idea behind the transportation and construction scenario that was developed as part of the project.

Ideally, the team would have had access to real-time monitored data from both the construction site and the local transportation network, the two of which comprise the “real system” components of a theoretical DT. The monitored data would feed into the “digital system” half of the DT where analysis would occur resulting in some adjustment or change to the real system to improve behavior or functionality.

As construction of IDRB was already completed, there was no current campus construction at the start of the project, and there were no readily available data streams from campus, immediately the team began exploring ways to recreate the scenario above using exclusively simulation models. More specifically, both components of the DT (real and digital) would have to be digital. This allowed the team to explore and understand the components and functionality of the DT without the burden of sensor procurement, installation, networking, maintenance, and troubleshooting.

The original intention was to utilize the contractor-built Building Information Model (BIM) of the IDRB which was a full 4D model inclusive of all construction staging and work zone traffic control. This would have allowed the research team to identify the scenarios experienced by campus stakeholders during the actual construction of IDRB with accurate semantic data and construction progress for visualization purposes. These snapshots in time would serve as inputs to the transportation network model, mimicking as the real system.

The transportation network was to be modeled using a traditional, industry standard traffic simulation tool. The project team considered SUMO, VISSIM, and AnyLogic, eventually settling on VISSIM because of the team's familiarity with the software, and the nuanced flexibility of the software to create detailed microsimulations. Based on the behavior of the perturbed transportation model (the real system), the research team could track a performance indicator (i.e., queue length) and use a duplicate of the transportation model as a digital system to development system interventions that may improve performance both acutely and over the full construction project. These interventions could then be implemented in the real system, completing the DT. At the outset, the intention was to utilize a third, as-of-yet unidentified software to combine, analyze, and visualize the DT.

All these models were to be augmented through reality capture of the existing conditions to create a visualization base layer on which the DT could be laid. The reality capture effort would include existing data sources and some new data collection.

As the project progressed, innovative solutions were improvised from the intended approach, by necessity, but the stated goals of the project were nonetheless achieved. Challenges to the project and required assumptions are listed below.

## Challenges and Assumptions

The following challenges were faced and accounted for in this project:

- The COVID-19 Pandemic hampered the research team’s ability to start the project in a timely fashion, recruit students, meet and collaborate regularly, engage with public stakeholders, and disseminate early results.
- The contractor for the IDRB was not willing to provide the full BIM model of the building to UTEP because the project was not yet closed out. Therefore, UTEP Campus Facilities and Services was unable to provide the BIM model to the project team.
- The selection of VISSIM limited the research team’s ability to integrate the transportation model component with the construction component in any third-party software. VISSIM is a proprietary software with little programmatic control flexibility. The software does have an Application Programming Interface (API) but the functionality is limited and the language required (COM) is unique.
- VISSIM did not have the capability (nor would most traffic simulation software) to exactly replicate the scenario desired.
- The network selected has limited options for interventions for the scenario created. There is no clear alternate route that could serve as a detour route.

The following assumptions were made to address challenges as required:

- The team assumed that replicating the scenario through which traffic was interrupted was more important than visualizing construction (i.e., incomplete building, tower cranes, etc), sacrificing the latter when it became clear that the 4D BIM model was unavailable.
- The team pivoted to VISSIM as the primary software platform for simulation, abandoning a third software to combine the VISSIM and the BIM. This was due to the challenges posed by a lack of interoperability of VISSIM.
- The team identified a single trigger and intervention, namely a reroute of traffic on Sun Bowl through the Sun Bowl 2 parking lot, as opposed to numerous options between which the DT may choose.

## Phase 1

Phase 1 includes two preliminary tasks. They are Task 1: Literature Review and Data Collection and Task 2: Reality Capture of Existing Conditions. The results of each task are described below.

### Task 1 – Literature Review and Data Collection

Task 1 contained two main subtasks. The subtask was the literature review as described in Task 1.1 – Literature Review. The second subtask was data collection via a survey as described in Task 1.2 – Data Collection.

#### Task 1.1 – 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.

##### Task 1.1.1 - 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).

#### Task 1.1.2 - Review of Digital Twin application for Civil Infrastructure

DT for static processes in structures and transportation infrastructure present 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).

#### Task 1.1.3 - 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).

#### Task 1.1.4 - 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.

#### Task 1.1.5 - 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 1.2 – Data Collection

The goal of this subtask was to create and distribute a survey to campus stakeholders. The survey, as it was distributed via email, is shown below in Figure 4.

C2SMART: Survey Regarding Campus Data |

I am writing to ask for a few minutes of your time to support a project on campus by completing a brief survey regarding the types of data that campus stakeholders collect and use on a regular basis.

Recently, Drs. Jeffrey Weidner, Adeeba Raheem, and Kelvin Cheu from the Department of Civil Engineering at UTEP were awarded a USDOT grant titled “Digital Twin Technologies Towards Understanding the Interactions between Transportation and other Civil Infrastructures.” The goal of the project to begin to create a Digital Twin (DT) model for the UTEP campus. A DT model is a simulation model or models that replicate a real system which utilize data from sensors within the real system. DT models are frequently used in closed systems in manufacturing to help optimize and improve the process.

Our project aims to explore how this technology would apply to a complex system like a university campus. Our initial focus is on civil infrastructure systems on campus (broadly inclusive of transportation and buildings/construction at this time) but one of the tasks in this project is to explore the availability and applicability of existing data sources on campus that can be added to the DT model in the future. That is the purpose of this survey.

The subsequent questions are an informal survey about your department and the data that you use on a regular basis. The survey does not require IRB approval because it is not human subject research. There are no obligations to participate or otherwise commit any time outside of the survey. We are just trying to understand the complex campus system on campus and the data that drives it. We are hoping to generate future research ideas based on your input.

Survey

A key aspect of a Digital Twin model is data collection, analysis, and feedback to the simulation model. The following questions relate to campus-specific data and are for information purposes only. Feel free to answer in whatever form you desire. Note that we may follow up for clarification purposes.

1. What data do you collect?
2. How do you use the data you collect?  
How long do you keep this data, and are there requirements for retention?
3. How frequent do you use the data (i.e., up to the minute, daily, weekly, monthly, term to term, or annual)?
4. What data do you wish you had?
5. Who are your stakeholders?
6. Do you share your data? If yes, with whom?
7. Is there anyone else on campus to whom we should send this survey?

Thank you for your time. If you prefer us to contact you in a mode other than through your UTEP email, please let us know.

**Figure 4. Document. Survey for Campus Stakeholders**

The survey was distributed to a list of 12 targeted campus stakeholders, whose names are withheld for privacy. Unfortunately, despite several reminders, we did not receive any feedback. Rather than continuing to pursue this avenue of stakeholder engagement, the research team elected to establish a relationship with campus stakeholders at the workshop (Task 7 – Community Engagement Workshop) and work from there moving forward.

## Task 2 – Reality Capture of Existing Conditions

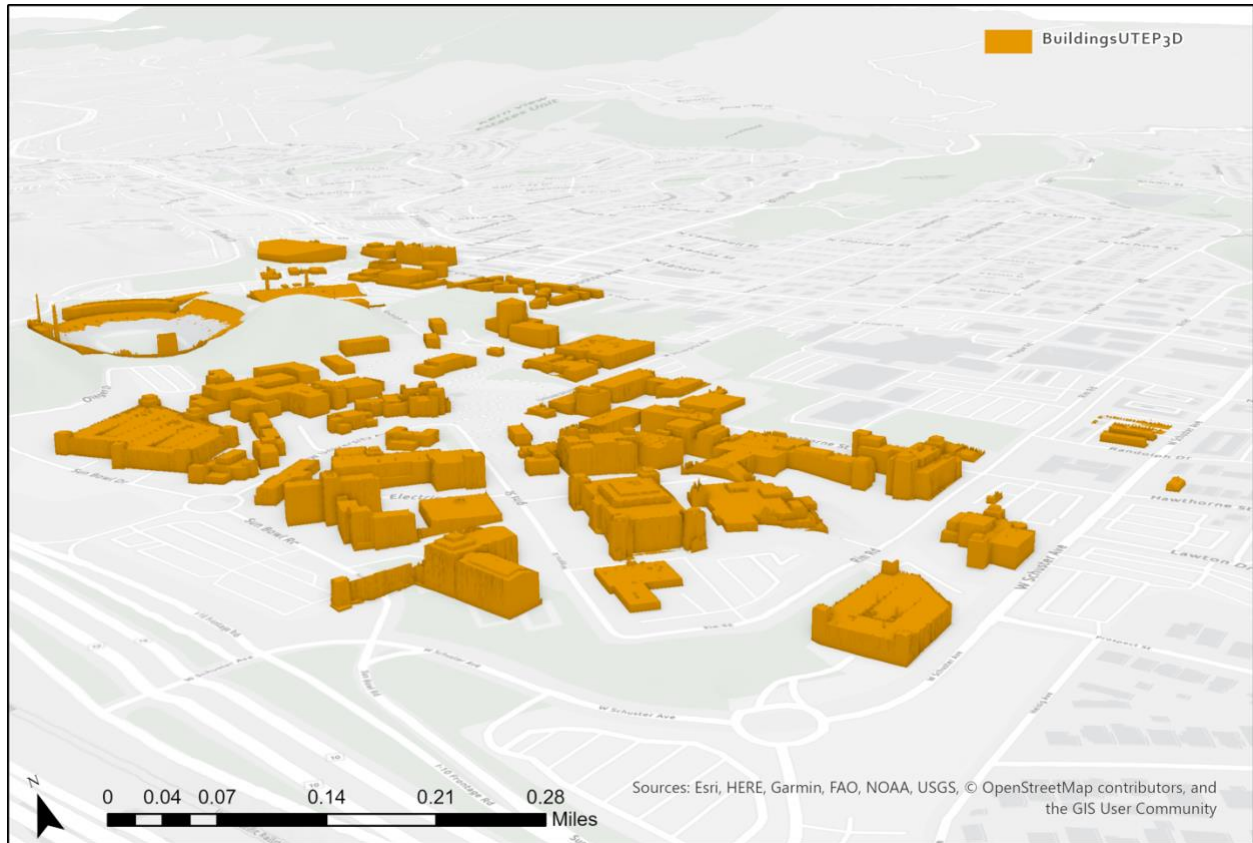
This task included three subtasks. Task 2.1 was to create a base layer model using existing data as described in Task 2.1 – Base Layer Creation from Existing Data. Task 2.2 included reality capture of the IDRDB as described in Task 2.2 – Reality Capture of Campus Building using LiDAR. Task 2.3 focused on the transportation network as described in Task 2.3 – Reality Capture of Existing Transportation Signage Data.

### Task 2.1 – Base Layer Creation from Existing Data

An important component of DT is visualization capacity. While not necessary to achieve the pure functionality of a DT, visualization supports deeper understanding and intuition of DT by humans, and serves to support stakeholder outreach, education, workforce development, and dissemination. Our case study included two primary simulation capacities – namely a BIM model and a transportation network microsimulation. To help connect the two and create a rich environment to visualize the scenario, a base layer was required.

#### Task 2.1.1 – TNRIS Aerial LiDAR Data

The base layer is primarily a geometric replica of the as built environment. The first effort to create this utilized aerial LiDAR data captured in 2014 by the Texas Natural Resource Information System (TNRIS) for the purposes of flood planning by FEMA. The dataset is publicly available from the TNRIS website (<https://tnris.org/>). The data includes 77 individual files in .LAZ format. The data is point cloud data, including three dimensional coordinates for each point, with the vertical component referenced to sea level. The data is in meters. The raw data was processed to create a digital surface model and digital terrain model. The former includes all vertical appurtenances (i.e, buildings, trees, etc) and the latter is simply the ground elevation. Through comparison of the two, buildings were identified on the university campus, as shown in Figure 5.



**Figure 5. Image. Campus building rendering extracted from TNRIS LiDAR data**

As this data set was created in 2014, there have been some changes to campus. Most notably, the IDRB was not yet built in 2014. In fact, the former building, Burges Hall, is still visible in the data. This building was manually removed from the base layer. However, this required the team to create a new model of the IDRB, as described in Task 2.2 – Reality Capture of Campus Building using LiDAR.

#### Task 2.1.2 – Transportation-related Data

The transportation network was built initially off two existing data sources. The first was a shapefile of roadway centerlines provided by the City of El Paso. The second was origin and destination data for the campus network from a prior research project (Cheu & Ruiz, 2021).

The existing transportation network was input into VISSIM, the selected simulation platform for transportation data. In terms of the physical infrastructure, this base model included travel lanes, signal heads and signal timing, and signs (i.e., stop and yield). This model was later updated with the data collected in Task 2.3 – Reality Capture of Existing Transportation Signage Data.



The synthetic data for the intersections of interest (Schuster Ave. and Sun Bowl Dr., and Schuster Ave. and the freeway ramps) was provided by the City of El Paso Street and Maintenance Department; this data includes traffic volumes per turning movement and traffic signal timings. Figure 6 shows the signal timing plan in VISSIM, for the Schuster Ave. and eastbound I-10 intersection; Figure 7 shows the signal timing for the various phases at the Schuster Ave. and Sun Bowl Dr. intersection.

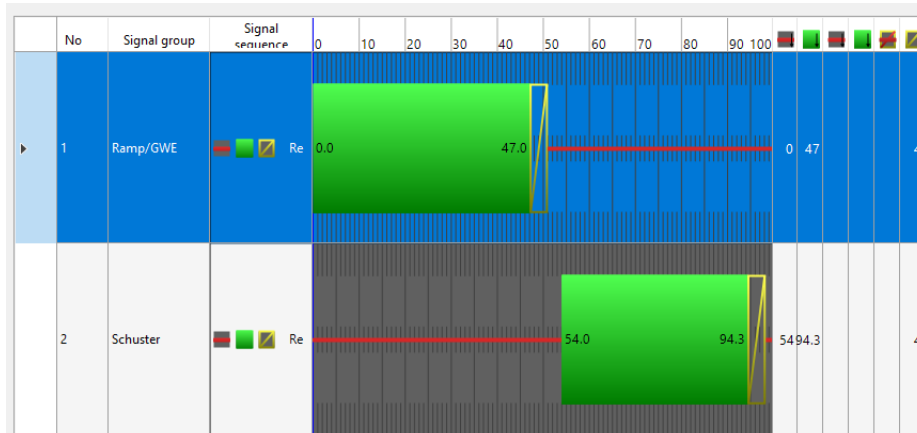


Figure 6. Image. Signal group for ramp at Gateway East and Schuster

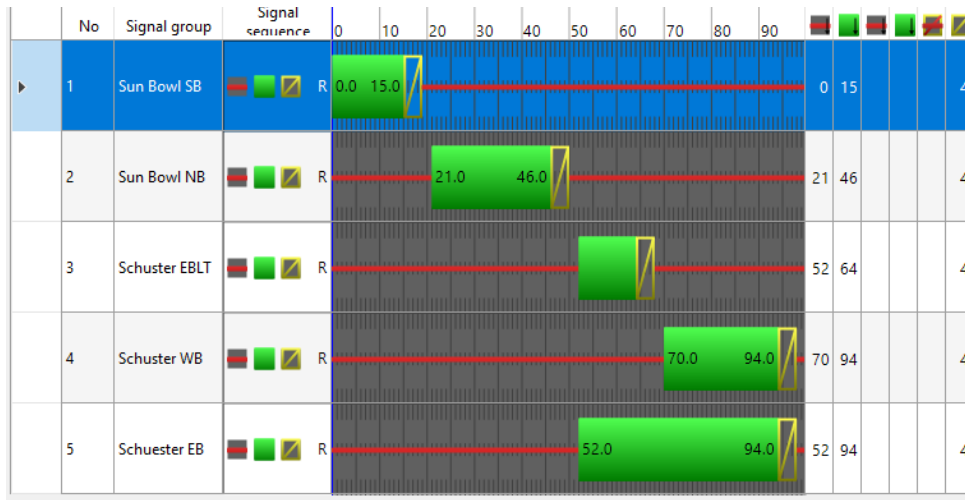


Figure 7. Image. Signal input for Sun Bowl and Schuster intersection

The peak hour turning movement data for the intersection at Schuster and eastbound I-10 was collected in September 05, 2012. The peak hour turning movement data for Schuster and Sun Bowl intersection was taken on Thursday October 04, 2021. The data includes the count for left turns, straight, and right turns from each approach.

The total vehicle counts for the turning movement at the peak hour was determined as between 8:00 a.m. and 9:00 a.m. The values used for the simulation input in VISSIM for the total vehicle count are shown in appendix.

*Model Input:* Static routing decisions were used in the model to represent how vehicles flowed through the transportation network (i.e. how many vehicles chose to go straight versus turn). The relative flow values for the vehicle inputs were based on the traffic turning movement counts from data provide by the city and also obtained from previous research. The relative flow values for the intersections in this network (Schuster Ave. and Gateway East Ramp, Schuster Ave., and Sun Bowl Dr.) were obtained from documents provided by the City of El Paso. The vehicle input for Sun Bowl Southbound was retrieved from previous publicly available research conducted by the university.

Vehicle routing decisions for roundabouts and inlet ramps to interstate highway (I-10) have equivalent distribution turning movements due to limited availability of data. The roundabout next to the campus entry point was not assigned equivalent distribution for vehicle decision. Adjusted data from previous research was included for roundabout routing decision values (Cheu & Ruiz, 2021). The traffic decision heading into campus is less because of the controlled entry point.

## Task 2.2 – Reality Capture of Campus Building using LiDAR

### Task 2.2.1 – LiDAR Data Collection

A 3D model of the IDRIB was created using a BLK 360 laser scanner from Leica Geosystems (Figure 8). The laser scan was used to create a point cloud of the infrastructure system (without the need for design drawings) for externally exposed components. To perform the scans, the Field Cyclone 360 app on any mobile device was used on-site to remotely control the scanner and to view the raw 3D point clouds immediately after scanning. The app was essential on-site for quality control of field scans, to keep track of the scans, and to piece together the point cloud data using edge computing technology. The software was used to manually select the general position of each individual scan to align and combine the scans. The allowed the project team to verify quality of the scan and area of interest and rescan if needed.



**Figure 8. Image. Leica BLK 360 Terrestrial Laser Scanner (left) and sample set-up (right)**

The scanning took approximately three to six minutes per scan depending on the quality and the detail of the scan. The scanning process for the building took 12 individual scans to generate the point cloud needed to reconstruct the building. An additional seven scans were made to capture the surrounding transportation network, roundabout, adjacent parking garage, and Sun Bowl Dr. The scanning locations and pattern can be seen in Figure 9. In addition, the second floor of the interior of the building was scanned to include the lobby area and hallways. The full interior of the building could not be scanned because of access restrictions. The interior that was scanned was not included BIM model because the scenario adopted was focused on the building exterior and transportation network.



**Figure 9. Image. Aerial-View of Scanner Location Placement**

After gathering the necessary scans around the area, Cyclone Register 360 was used for on-site tagging of measurements, videos, images, text, or voice files to the point cloud. When the scans were not well aligned, the software was used to adjust the point cloud or rescan. After creating the point cloud and aligning the scan accurately, the file was shared to Autodesk Recap for conversion to a file type compatible with Autodesk Revit (i.e., .rcp). In this case, point cloud data was imported into Revit to manually use a point-to-point tracing method to generate the three-dimensional model for the external characteristics of the building (i.e., walls, doors, windows, and roof). Table 1 summarizes the number of scans, time taken for those scans, and the number of points collected for the point cloud.

**Table 1. Data Collection Details**

	Scanning	Registration	No. of Points
<b>Data Collection</b>	19 scans	4 hours	142,145,570

#### Task 2.2.2 – Manual Construction of BIM Model

The material sections were identified and assigned using the design drawings (provided by UTEP) and then manually applied. The walls were traced, extruded, and assigned a material section. A similar process was

followed to include windows and doors at the correct position. The roof was approximated using the design drawing since the terrestrial laser scan was not able to capture any point above the roof ledge. Table 2 describes the number of elements per component category and the time spent adding those elements to the IDRB BIM model; Figure 10 shows the completed BIM model.



**Figure 10. Image. IDRB building BIM model**

**Table 2. Scan-to-BIM Reconstruction Time**

	Component	Count	Total Time (hrs)
<b>Scan-to-BIM</b>	Windows	80	5
	Doors	8	2.5
	Walls	10	3
	Roof	7	3

Since the laser scan captures only the external exposed geometrical information, the material sections were selected and assigned based on the specifications from the design drawings and visually identifiable

material (e.g., glass windows and doors, walls, etc.). The entire model must be done manually and is, therefore, more time-consuming.

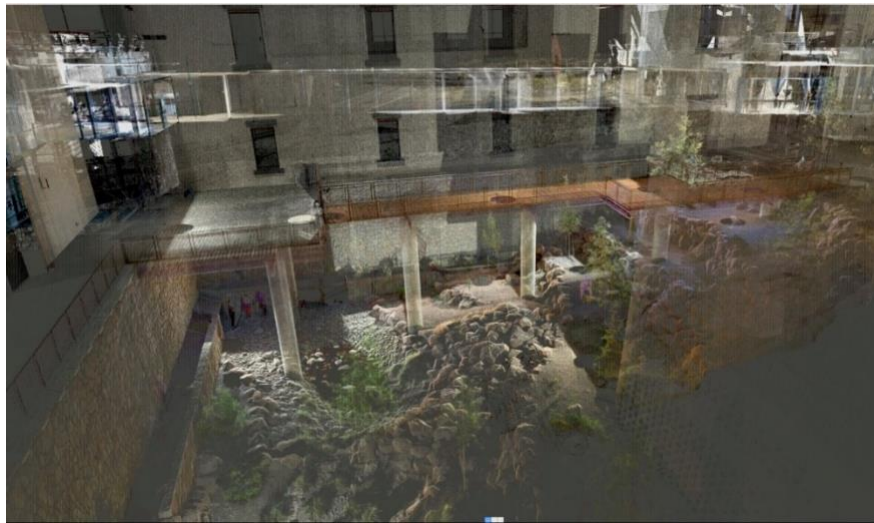
The point cloud generated from the scans can be seen in Figure 11 for the IDRB building at UTEP created using the Leica BLK360 laser scanner. This 3D model can be scanned in black and white to compensate for big data storage, to decrease individual scan duration, and to optimize laser scanner battery life. The Leica BLK 360 allows for not only color but thermal readings at the time of the scan. Figure 12 shows the surrounding transportation system, including a roundabout, near the IDRB building. Figure 13 shows the east side of the IDRB and a pedestrian bridge.



**Figure 11. Image. Point Cloud of IRDB**



**Figure 12. Image. West-view of Point Cloud IDR B and Surrounding Transportation Network**



**Figure 13. Image East view of IDR B building**

The following steps outline the general methodology used for the creation of a LiDAR to BIM model:

- I. Laser scanning of the building

- a. Place laser scanner at key point to capture detail scan building (number of scans depends on building size, shape, and access)
  - b. Check the scans on-site using mobile device application
  - c. Rescan if needed
  - d. Automated update of point cloud to storage
- II. Transfer point cloud data from cloud storage to computer (software manipulation)
  - a. Large data files become time consuming at data transfer and manipulation
- III. Align scans in Cyclone Register
  - a. Check all scans are aligned correctly
  - b. Manual approximate adjustment
  - c. Artificial Intelligence finished alignment
- IV. Classification of the files (compatibility with BIM model software)
  - a. Convert file depending on the software that is going to be used
- V. Open the file in the BIM software
  - a. Import as point cloud file
  - b. Choose the point cloud file as .rcp

#### Task 2.2.3 – Automated Approaches to Model Reconstruction from Point Cloud Data.

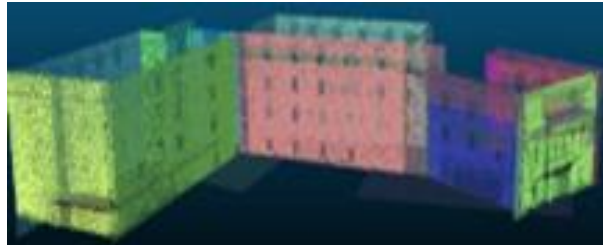
To improve the time to reconstruct a virtual model directly from the point cloud of the IDRb, various three-dimensional reconstruction algorithms were explored. The two methods selected were Random Sampling and Consensus (RANSAC) algorithm and the Oriented Point Sampling (OPS) algorithm. These methods were selected based on 1) the ability to reconstruct a virtual model directly from the captured point cloud data, 2) the reduction in time to reconstruct the model, 3) the computational efficiency of the reconstruction, 4) the ability to detect planes for the plane-like nature of the exterior walls of the building, and 5) to automate the reconstruction process of the building. These methods were investigated to determine the level of detail (LOD) for which the automated approaches reconstruct the virtual model.

The RANSAC algorithm detects planes by computing the normal of the point and assigning a plane to point clusters within the specified input parameters. For this algorithm an open-source software was used for its user-friendly point cloud data management and simple iterative process for various input parameters. In addition, noise filtering, subsampling, normal computation, and file compatibility for export to other modeling software. The point cloud data was subsampled and saved as separate files to record the computational requirements and total time to generate the virtual model. A random subsampling of 1%, 2%, and 3% from the original point cloud were selected. The time to generate the model, number of planes detected, number of inliers per plane, and processing time to detect a single plane was recorded for the original and each subsampled data set. The resultant models for RANSAC can be seen in Figure 14 and the OPS resultant models can be seen in Figure 16.

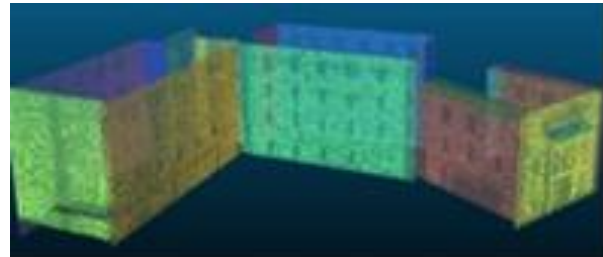




(a)



(b)



(c)

**Figure 14. Image. RANSAC Reconstruction for Subsampled Data (a) 1%, (b) 2%, and (c) 3%**

The point cloud data was subsampled, and the times per subsampling, the number of planes detected, and processing time to generate the RANSAC mode are recorded in Table 3. The model was created under 12 seconds for the external geometry of the building. The algorithm oversimplifies the point clusters to random planes and assigns random orientation. The RANSAC algorithm works best when the point clusters present a clear distinction between the planes to detect. Therefore, a lower subsample yielded a simplified external geometrical replica of the building with clear distinction of the planes (as shown in image C in Figure 14). The plane detection and the convergence of the planes for the best fit model was done within 1.73 seconds with only 19 planes detected. A higher subsample generated random planes with incorrect orientations for various point clusters.

**Table 3. RANSAC Processing Time**

Subsampling	No. of Planes	Processing Time (s)	Subsampling Time (s)
3	264	11.671	34.338
2	36	3.681	33.887
1	19	1.713	34.098

The processing time when compared to manual approaches significantly reduced the time to generate the model for reconstructing the external geometry of the building. This is limited to the external geometry with no material properties of the building when compared to the BIM model. An approach to incorporate material detailing to the RANSAC model was explored by importing to BIM software. The RANSAC resultant model was converted into a point cloud data file type and imported in the Revit as an intermediary step to reconstruct the model using the approximate geometry and assigning material section characteristics. The imported file to the BIM software can be seen in Figure 8. The colors were randomly assigned to generated planes. These were maintained after export into the BIM software.

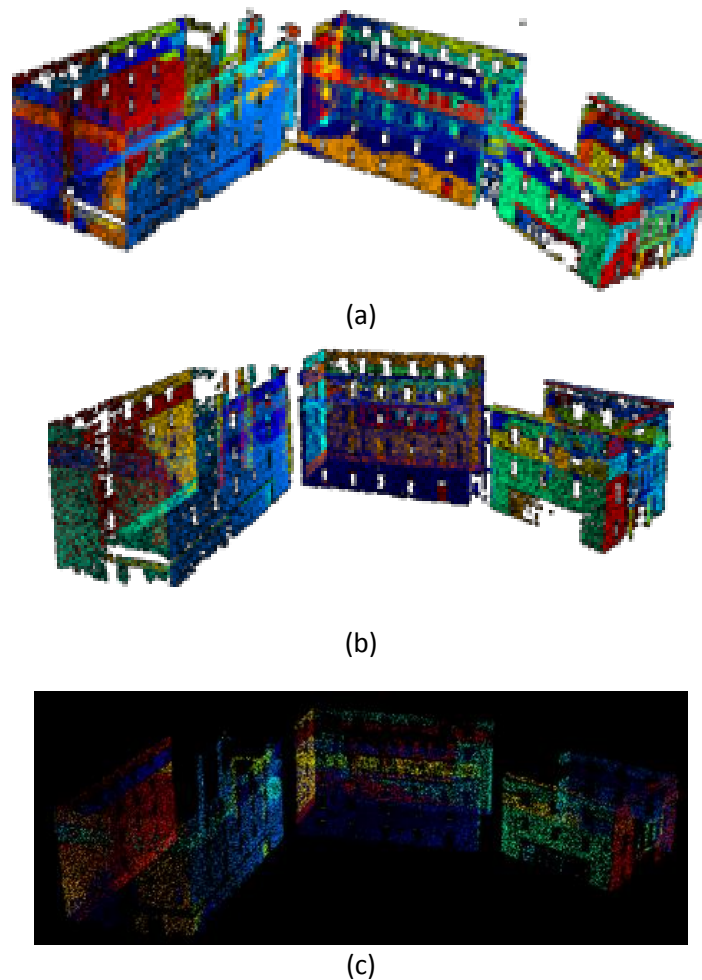


**Figure 15. Image. RANSAC Model Imported to Revit**

The second algorithm model selected was the Oriented Point Sampling (OPS) algorithm. This approach is supposed to reduce the time required to generate a three-dimensional reconstruction from the captured point cloud data. The algorithm uses a single point to detect a plane then converge the point clusters into a plane. The algorithm was developed by Victor Amblard to optimize the computational requirement

when using point cloud data. The requirement to run the algorithm are: 1) Download of point cloud and boost libraries, 2) manual installation and integration of depreciated libraries, 3) generating a cmake file by adjusting the correct paths for the algorithm.

The same randomly subsampled point cloud data files were used (3%, 2%, and 1%). A file conversion from .e57to a file format .pcd was performed using cloud compare open source software. The output file from the file conversion was then used as the input for the OPS algorithm. The resultant models for the OPS algorithm subsampled point clouds can be seen in Figure 9.



**Figure 16. Image. OPS Algorithm Subsampled Reconstruction**

The OPS reconstruction performs best when there are sufficient points to detect and generate the planes. This approach produced an accurate three-dimensional model for a subsample of 3%. Any reduction in the number of points reduces the quality of the model. The best-fit virtual model using the algorithm was produced with 88 planes in approximately 2 minutes (shown in Table 4).

This algorithm-generated model present its own unique limitations. The algorithm is limited to the visualization tool in the point cloud library. This prevents the model from being export to additional simulation software and digital twin platforms. In addition, no material section and material properties can be added to the model.

#### Task 2.2.4 – Summary of Reality Capture of Buildings using Terrestrial LiDAR

These methods each present the individual benefits when reconstructing a virtual model from the point cloud data. To summarize the three-dimensional reconstruction methods each present distinct benefit and disadvantages:

- 1) BIM model using Revit
  - a. A high-fidelity model to include material properties
  - b. BIM model is time consuming when compared to automated methods
- 2) Automated methods using algorithm approaches
  - a. OPS
    - i. Automated the reconstruction process using mathematical calculations
    - ii. Direct import of point cloud data
    - iii. No application to integrate material properties
    - iv. No export of generated file
  - b. RANSAC
    - i. Automated the reconstruction process using mathematical calculations
    - ii. Assign random plane to point clusters based on input parameters
    - iii. Direct import of point cloud data
    - iv. No application to integrate material properties
    - v. Export option available to improve model and include material properties

**Table 4. OPS Subsampling Time**

Subsampling (%)	No. of Planes	Average Iterations	Avg. Inliers/Plane	Total Time (s)
3	88	204	1233	123.267
2	73	311	971	64.295
1	44	375	752	17.204

A paper showing the qualitative comparison of the reconstruction methods was published at the ASCE International Conference for Transportation and Development by Julio Gallegos and Jose Luis Lugo. The resultant model’s algorithm generated BIM lacked certain DT ready qualities. The model is limited by the external characteristics of the building with limited information of additional structural elements, utilities, and hidden components. The DT model reconstruction is dependent on the use of the model and for the serviceability of the surrounding transportation network the visual of the three-dimensional geometric characteristics of the exterior building is sufficient for visualization purposes of the surrounding infrastructure.

The algorithm generated models in specific proved to be useful as an intermediary step to achieve a BIM model of the building to include detailed geometry, windows, doors, and roof. All attempted reconstruction methods can be improved in terms of accuracy of the building characteristics, compatibility with real-time data, and efficiency when creating the model.

### Task 2.3 – Reality Capture of Existing Transportation Signage Data

#### Task 2.3.1 – Data Collection

To determine the transportation signage to include in the DS model, the pre-existing transportation network asset data (e.g., signage, pavement markings, etc.) for the entire campus network was recorded semi-automatically from video footage. The data recorded included signage designation, the orientation of the signage (i.e., which cardinal direction the sign is facing), side of the street where the sign is located (e.g., NE, NW, SE, SW, or the center of the street), latitude, longitude, and altitude. This data was collected using a mounted GoPro (model: HERO8 Black) attached to the exterior windshield of a car. The longitudinal and latitude coordinates for each sign were extracted for each individual transportation asset for a given point in the video recordings. Different portions of the campus were recorded by driving

campus roadways, ensuring to capture the entrances and exits of the parking lots and garages located on and around campus. A total of 30 videos were collected. These videos ranged in length from 37 seconds to nearly 12 minutes.

#### Task 2.3.2 – Data Extraction and Analysis

From these videos, the camera telemetry data was extracted into a CSV file – most importantly, the latitude, longitude, and altitude associated with each timestamp from the videos. To collect the data, the videos were manually reviewed by moving through the different frames of a video until an object of interest was located. The objects of interest considered for data collection are:

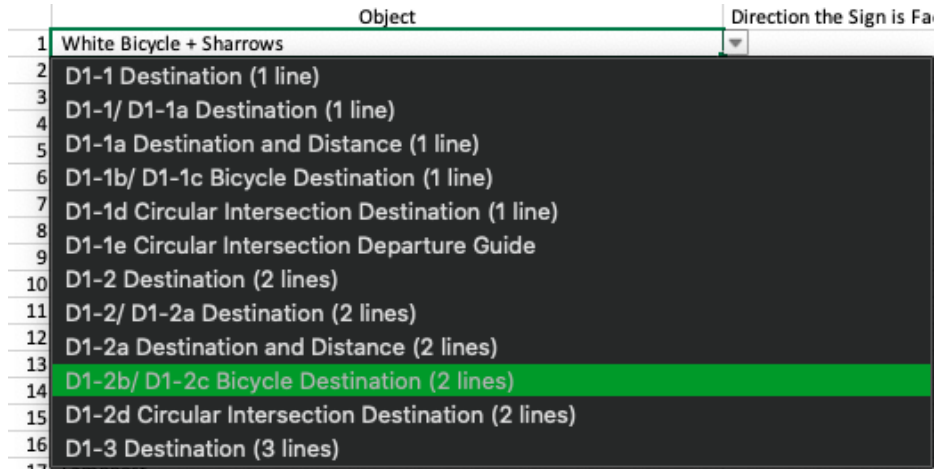
- Traffic signs
- Pavement markings
- Utility access hole covers
- Trashcans
- Lampposts
- Fire Hydrants
- Traffic Control Stations
- Storm Drains

The object of interest was considered as close to the vehicle as possible when the object was just outside of the frame of the video, as seen in Figure 17.



**Figure 17. Image. Vehicle as it approaches the sign (left) and vehicle as the sign is just out of the frame (right)**

At this frame, the timestamp was recorded into a CSV file, as well as the object description with MUTCD code (if applicable; some objects did not have a MUTCD code, such as the pavement markings), the orientation of the sign, and the side of the street the sign is on. The object description with the MUTCD code was organized into a dropdown menu, with the MUTCD code followed by the description – see Figure 11.



**Figure 18. Image. Dropdown menu of object code and description**

A program was developed to associate the timestamps of an object with the corresponding latitude, longitude, and altitude for that timestamp. The program either matched the timestamps exactly (e.g., where both documents had the timestamp 00:42.7), or it matched the timestamp that came immediately before. Figure 19 shows a portion of the output of the program, providing a visualization of the comparison. The program wrote a new CSV file combining the information from the GoPro telemetry data CSV file and the CSV file containing the objects of interest.

```

Home file (Route# CSV):    1 00:03.3
Away file (gryo-gps CSV): 7 00:03.2
Lat: 31.7696763
Long: -106.5083334
Altitude: 1172.996

Home file (Route# CSV):    2 00:04.4
Away file (gryo-gps CSV): 12 00:04.3
Lat: 31.7697159
Long: -106.5083746
Altitude: 1173.026

```

**Figure 19. Image. Comparison of two CSV files to match timestamps**

The dataset includes a total of 1,835 identified assets. Combined with the videos, this provides a valuable, manually created dataset for machine learning applications focused on identification of traffic assets, which was out of the scope of this project.

## Phase 2

### Task 3 - Integrate Simulation and Information Models with Reality Capture

This task focused on integrating the two primary digital models utilized for this project with the reality capture base layer; namely the IDRB BIM model, the VISSIM Transportation Model, and all the data collected in Phase 1. Each are discussed in turn, and the process for combination to create a DS model is discussed in Task 4 – Develop a Digital Shadow Model of Campus.

#### Task 3.1 – Creation of IDRB model for integration into DS

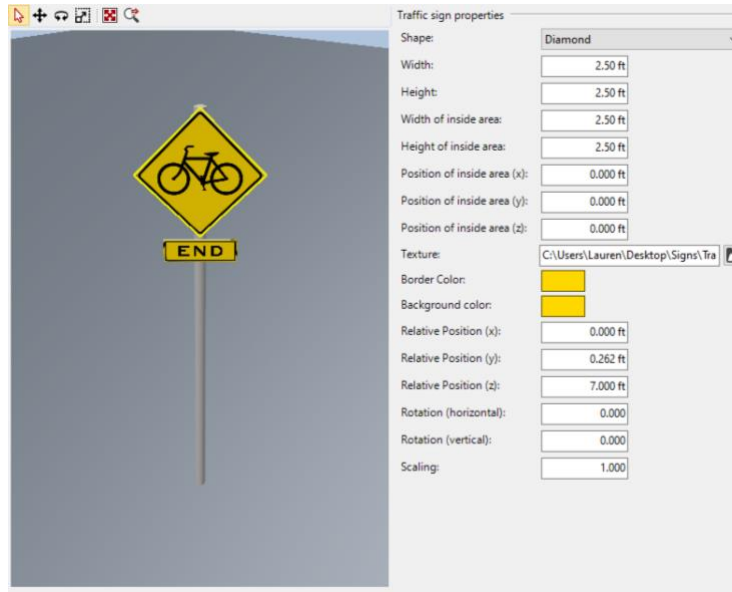
The IDRB BIM model was created as part of Task 2.2 – Reality Capture of Campus Building using LiDAR. However, the proprietary format utilized by Autodesk REVIT was not compatible with any integration tools. As we felt we no longer needed the construction progress for visualization purposes, we elected to convert the REVIT model to SketchUp (.skp) which is a much more ubiquitous file type for integrating with other software. This model maintained LOD 300.

#### Task 3.2 – Addition of Signage to Reality Capture Base Layer for Transportation

The transportation network signage data was input in VISSIM manually. For example, the pole and sign dimensions were retrieved from the Manual on Uniform Traffic Control Devices (MUTCD) standards. Then, an image of the sign was imbedded into the sign linked to the VISSIM software. The traffic signage was added to the model manually by drag and drop tool based on the approximated latitude and longitudinal coordinates extracted from the data collection in Phase 1. An example of a traffic sign input into VISSIM can be seen in Figure 20.

The model includes a total of 83 transportation signage from a combination of signs, traffic signals, and lampposts. Additionally, 71 pavement markings unique to VISSIM (i.e., pavement markings not available in the VISSIM pavement network object sections) were added to the network.





**Figure 20. Image. Traffic sign Properties input via MUTCD specifications**

#### Task 4 – Develop a Digital Shadow Model of Campus

As previously stated, the purpose of this project was to work towards a DT application for a college campus. The goal was to achieve a Digital Shadow (DS) model. A DS model has the same primary components as a DT; namely a real system component (in this case, operational transportation infrastructure and a construction site) with sensors that produce data to support decision-making and a digital replica of the real system with some decision-making intelligence. The primary difference is that the DS includes only communication from real to digital systems. The digital component does not communicate back to the real system. The target DS system for the project is depicted in Figure 21. As stated in Challenges and Assumptions, construction on the IDRBR has completed, and the transportation network is not currently instrumented. Adding instrumentation was out of the scope of this project, meaning we could not create a true DS system inclusive of the operational infrastructure. We pivoted to create a digital shadow where the real system component was also a digital model, as depicted in Figure 22.

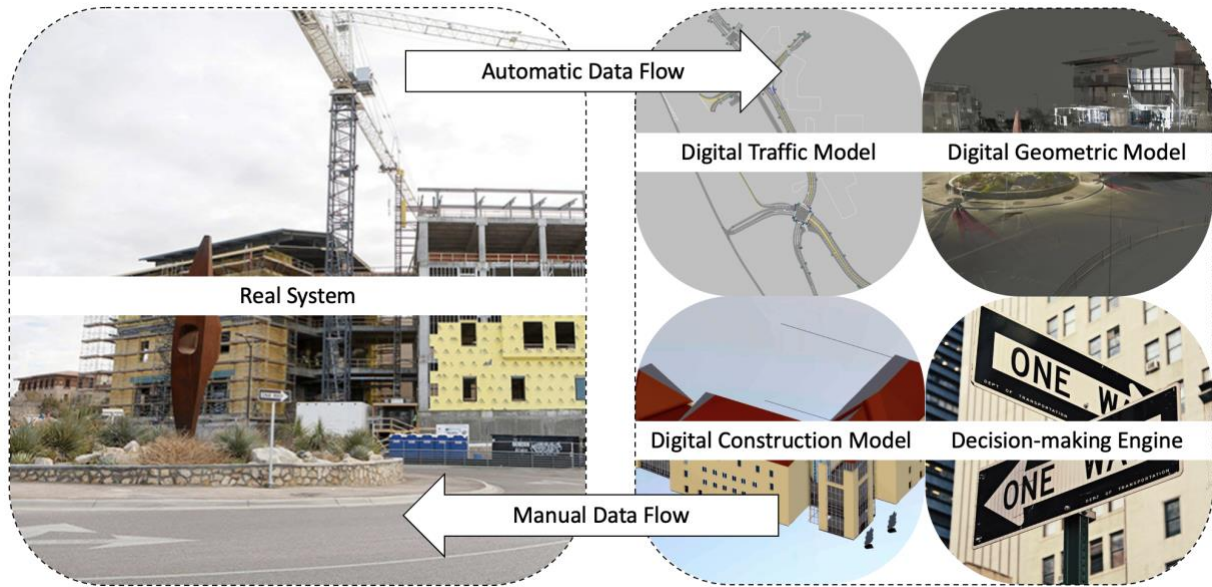


Figure 21. Diagram. Target Digital Shadow System

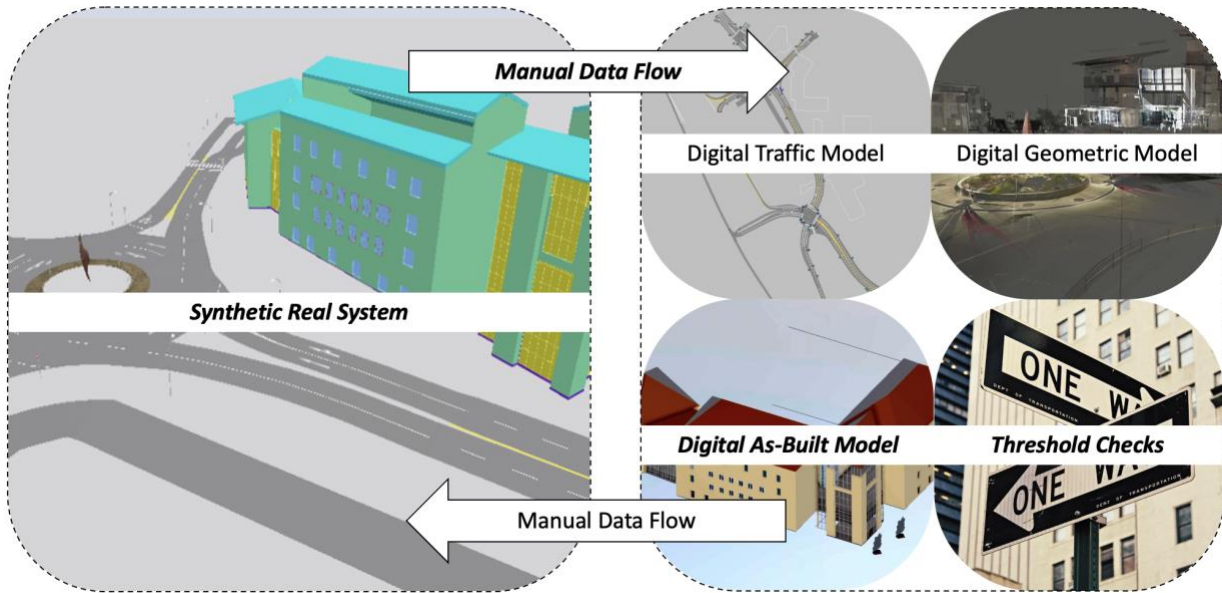
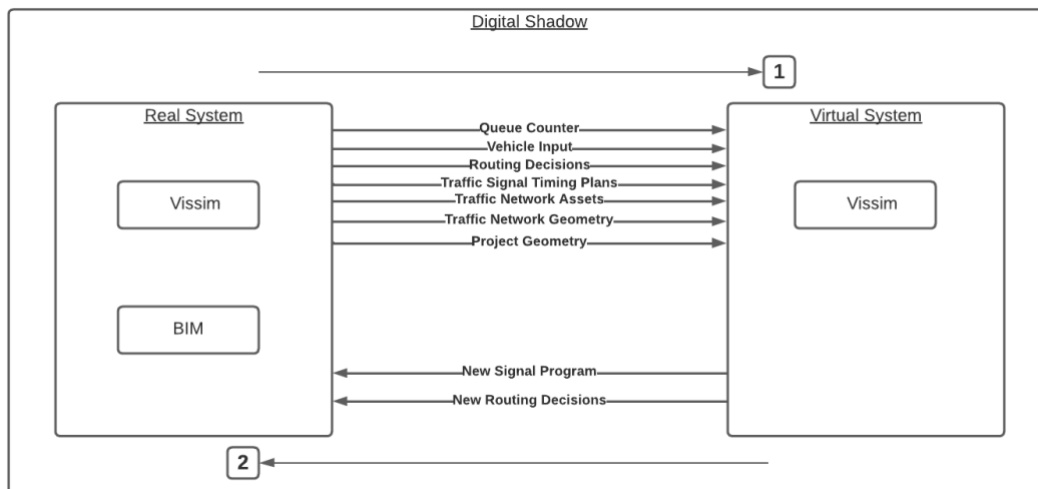


Figure 22. Diagram. Achieved Synthetic Digital Shadow System

The synthetic DS system presented some unique challenges. The primary challenge was that the transportation network model, created in VISSIM, would have to serve as both the real system component (data producer) and the digital replica component (data consumer). However, due to licensing issues, we could not have two instances of the VISSIM model running concurrently. Therefore, the DS model would have to run sequentially. In either capacity, the VISSIM model would have to be dynamic, meaning that it could change mid-simulation. In the case of the replica real system, the VISSIM model would have to be altered from free flow conditions to include an interruption to traffic that represents the system disturbance scenario. In the case of the virtual system component, the VISSIM model would have to take input from the real system and model a change behavior to determine if and when a change should occur. Figure 23 illustrates how the real system interacts with the virtual system to form the digital shadow given the aforementioned limitations.

This simulation change behavior was achieved via an Application Programming Interface (API) and Component Object Model (COM) programming. COM programming allows for dynamic alternation of the VISSIM model, but it is not without some limitations. Model interventions have to be prescribed, but they can be triggered based on certain thresholds. In the case of the DS, the traffic interruption was predefined as described in Task 5 - Simulation of Campus Digital Twin and Visualization Demonstration.

The other notable challenge with the synthetic DS system was inclusion of construction of IDRB. Since the as-built BIM model was not made available from the contractor responsible for the construction of IDRB, we elected to include only an as-built BIM model.



**Figure 23. Diagram. Digital Shadow using Vissim Models**

## Phase 3

### Task 5 - Simulation of Campus Digital Twin and Visualization Demonstration

#### Task 5.1 – Traffic Interruption Scenario Development

The modeling scenario the team wanted to test with a Digital Shadow model is the interruption of the surrounding transportation network due to the construction of the Interdisciplinary Research Building, specifically, having northbound Sun Bowl Dr. traffic be blocked due to a construction vehicle. This scenario was frequently observed anecdotally during the construction of IDRB by the research team. The Sun Bowl 2 parking lot was used for construction staging and traffic was frequently interrupted to allow the tower crane to pick materials from the lot and bring them on site. It was also observed that there was not a lot of redundancy in the transportation network in that vicinity that would allow for rerouting or detours during these short closures. For the purposes of the scenario, an alternative route was proposed through Sun Bowl 2 parking lot to accommodate northbound traffic on Sun Bowl Drive when there is a complete closure of the road. Figure 24 shows the transportation network modeled to analyze this scenario.



**Figure 24. Image. Traffic simulation overall layout with satellite view**

The scenario simulated within VISSIM was a short-term obstruction used at the southernmost entrance of the roundabout at Sun Bowl Drive and W. University Avenue. In lieu of a crane, a construction vehicle would occupy the two northbound (NB) lanes of Sun Bowl Drive. This results in a queue developing in the NB direction. When the queue length exceeded a certain threshold, traffic was rerouted through the SB2 parking lot to the roundabout on W. University Avenue heading eastbound (EB). The two southbound (SB) lanes of Sun Bowl Drive will remain open during this scenario because any rerouting would have required a substantially larger network model. The blockage event was scheduled to last 30 minutes. Figure 25 shows the blockage event and the alternative route vehicles would take to circumvent the blockage. Note that the reroute passed through the portion of the lot that was dedicated for construction. This was done for simplicity's sake.



**Figure 25. Image. Close view to alternative route for construction scenario**

Analysis of the scenario as described above indicates that the proposed reroute of traffic through the Sun Bowl 2 parking lot would have been a feasible solution to the traffic interruptions and a DT model would have been useful in identifying and demonstrating the efficacy of this solution. Moreover, if data was available on queue length and that the network was equipped with sufficient ITS technology, this option could be triggered automatically by a DT system once it was originally established. Additionally, if southbound traffic from the roundabout was blocked as well, the parking lot could have accommodated the portion of southbound traffic approaching from the I-10 exit, but there would still be a requirement to accommodate traffic from southbound Sun Bowl and University Ave. A larger scale and more complete DT model would support developing those solutions as well.

## Task 5.2 - Visualization Scenarios with Senior design students

To facilitate dissemination and workforce development regarding DT technology, the UTEP Civil Engineering Senior Design Capstone course was involved in the project. This term, each senior design team, comprised of between four and six students, worked on a campus improvement project of their own design. As part of their project, each team was invited and encouraged to collaborate with the research team to conduct a terrestrial LiDAR scan of their site. The scan point cloud data was used as a visual to aid in the conception of their design ideas. Some teams used the point clouds to quantitatively determine project requirements like terrain contours for survey purposes. The team projects ranged from building renovations and replacement, pedestrian bridge for improved accessibility to adjacent buildings, and parking space expansion. The scans at each site were added to the reality base capture layer to help support the development of a more detailed campus model. The Senior Design laser scanning includes the following sections of the university campus:

- Advising Center
- Bell Hall
- Benedict Hall
- Centennial Plaza
- College of Business Administration Building
- Schuster Garage (external and Internal scan)

A senior design team was interviewed to briefly describe the project idea, whether they were familiar with the technology before their project, the experience using laser scanning technology, and the applications given to the point cloud data obtained from the scan. The following question were asked to the Desert Design senior design group and the responses were summarized:

1. Describe what your senior design project.

Response: The project was to demolish two currently underutilized buildings on campus (Bell Hall and Benedict Hall) and add a new 4-story academic building. The new building will house the mathematics department. The goal was to expand the office spaces for faculty, graduate researchers, and teaching assistants by allocating space at the top 2 floors (floors 3 and 4). The 2<sup>nd</sup> floor was designated for classroom space and the first floor includes a lobby open to students and includes a convenient store. The team designed the floor plan, building frame structure, and the foundations.

2. What was your experience using LiDAR before senior design?

Response: The team had not used or had any knowledge of what a LiDAR scanner was and the uses of the scan before the senior design application.

3. How did your senior design team use the point cloud data from the laser scan?

Response: The senior design team used the point cloud data to create a model in Revit. This was helpful to understand the measurements of the land currently occupied by the existing buildings. The point-to-point measurements were helpful to identify the height, and to develop a floor plan to optimize the use of the space available after the demolition. The team was able to identify the need to extend the construction of the project north to complete the project.

4. Did the use of LiDAR help in the design of the senior design project using or find any other applications for this technology?

Response: The team was able to import the point cloud into Revit and used to measure the new floor plans created in AutoCAD to the existing building occupied space. The point cloud data was super helpful to know where the building was going to lie, spacing of window floor plan of floor, and to gain perspective of the in the sizing and use of the available space. The construction of the senior design project is inside the university campus with limited space to use for the construction of the new academic building.

5. Did the team plan for a staging yard for the construction and a plan to get material into construction site? If so, did having a LiDAR scan help plan for the space to use in the construction phase?

Response: Yes, the team had a staging yard and the point cloud data from the LiDAR scan was indeed helpful when allocating a large enough space as access point to the construction site and staging yard.

## Task 6 - Gap analysis and Roadmap to Full Digital Twin Model

This project, by design, was focused on creating a DS model as a step towards a full DT model. As described previously, synthetic data was leveraged, and the “real” component of the DS model was created using simulation as well as the digital component. From the perspective of understanding the process of developing a true DT model, the execution of this project was invaluable.

Task 6.1 – Gap Analysis for Full DT Model The digital shadow was combination of the data into a digital traffic simulation model. The model simulated a traffic interruption for the construction of the IDR. The construction scenario was the transport of construction material to the construction site across the road.

This process creates a temporary closure of the road. To mitigate the queue build-up, an alternative route was proposed through the parking lot.

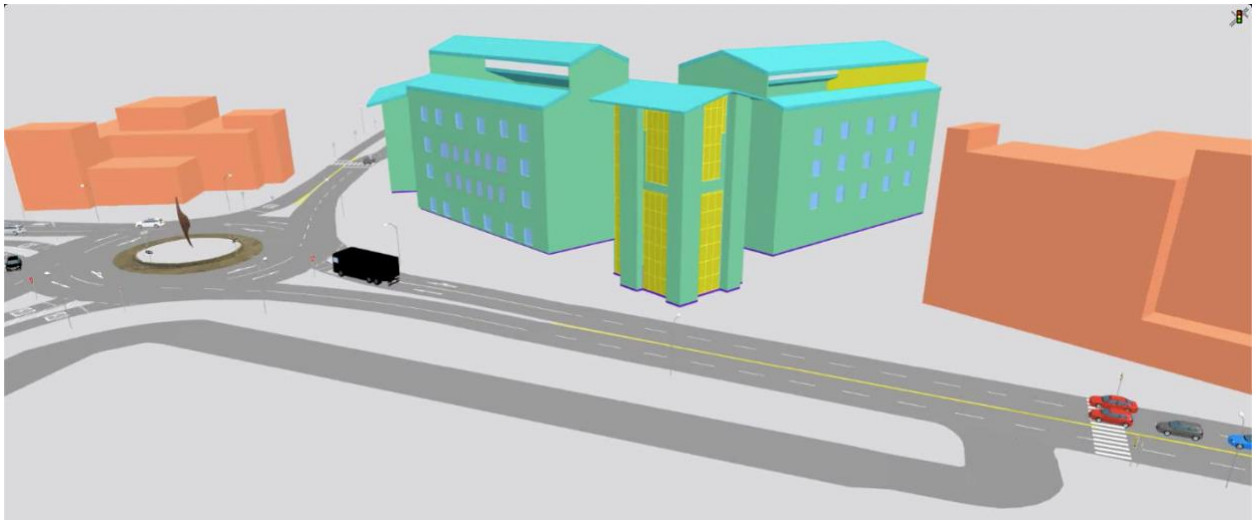
The simulation models the traffic buildup due to the closure and rerouted the vehicles to the proposed alternative route. To visualize the construction building in the simulation software (i.e. PTC VISSIM) a BIM model was created using point cloud data from a terrestrial LiDAR scanner. The scenario simulated was the closure of Sun Bowl Dr. during the construction phase of the building. Since the building is constructed several input parameters were approximated. In addition, existing traffic light data and previously acquired data was used for the input parameters. This includes the vehicle counts at each intersect, the light signal time, and the construction interruption time for the simulation.

The digital shadow produced in this case was an intermediary step to achieve a true understanding of the requirement of a functional DT of the campus. The list of various DT applications for campus systems can be seen in Table 8. Various gaps in the data collection, data processing, and feedback to affect the transportation network were identified.

A digital shadow was achieved for the IDRB's surrounding transportation network (shown in Figure 26). The team defined a digital shadow as a one-way data flow collected from the physical infrastructure. The data was obtained from various sources:

1. Laser scanning for exterior of IDRB
  2. Video footage and manual extraction of highway assets
  3. Traffic light signal timing (provided by city of El Paso)
  4. Peak hour vehicle turning movements (provided by city of El Paso)
  5. Vehicle count from previous research (Southbound Sun Bowl Dr)
- 
1. Real-time data collection methods
    - Sensor installation
    - Private data collection agencies
    - Access to existing local data collection technologies
  2. Decision to affect the simulation scenario
    - Implement threshold to indicate a change in the physical space (automated or semi-automated)
    - Digital LED sign to inform incoming traffic of the decision
  3. Expansion of the application of DT in campus
    - Buildings, pedestrian bridges, parking
    - Based on available real-time data source
    - Acquisition of new sensing methods

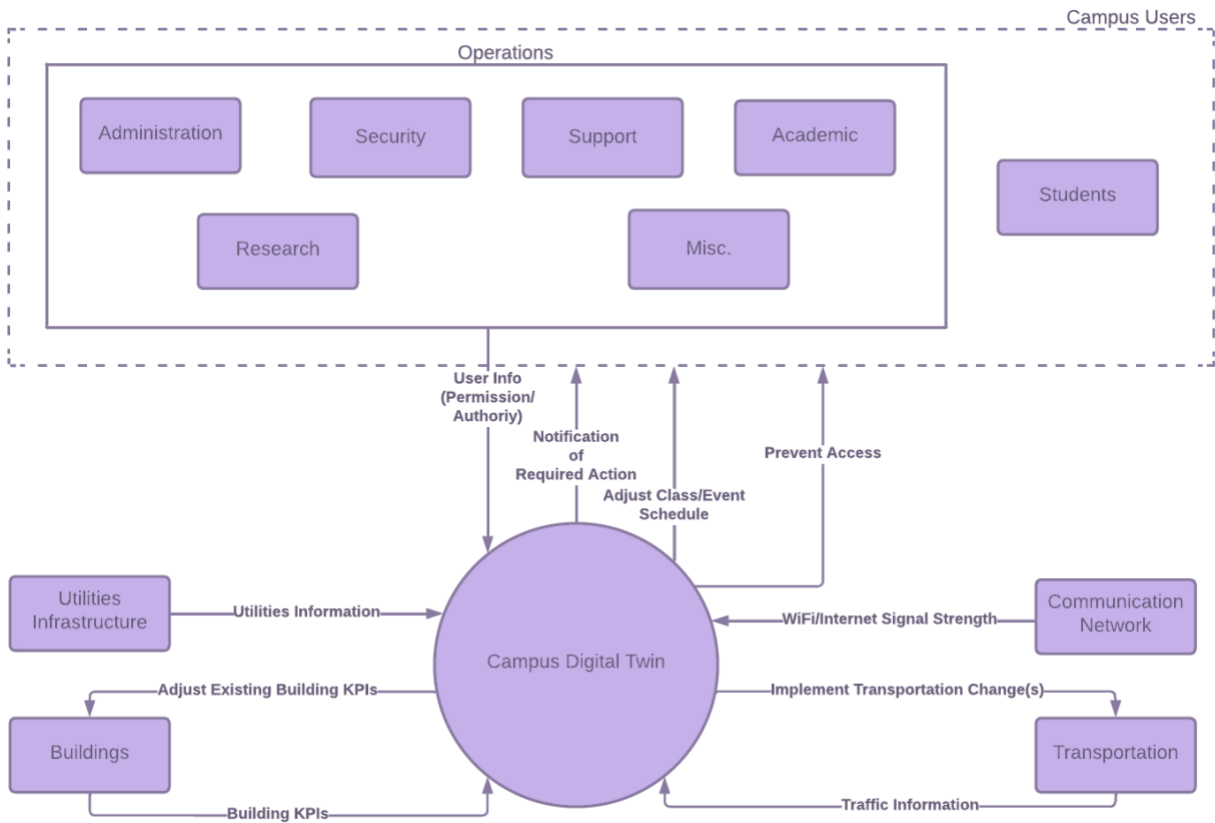




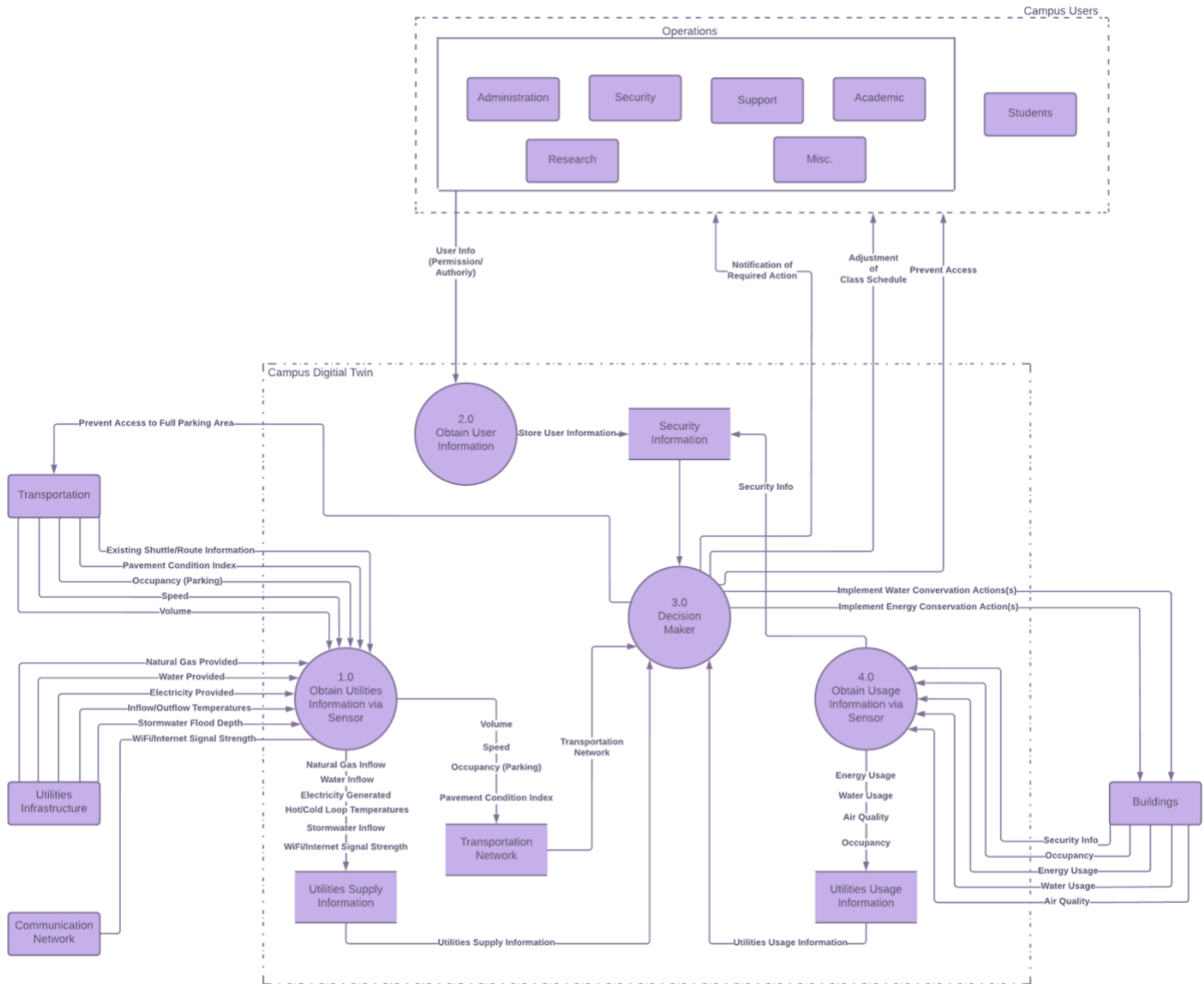
**Figure 26. Image. Simulation of IDRB Construction Scenario**

The simulation model using synthetic data proved to effectively model the traffic scenario with a need to improve on the data input and simulation visualization. Several assumptions were made for the simulation. For example, the weight of the vehicle decision. This affects the routes each vehicle will choose when approaching the area of interest. The collection of the data for identifying and predicting the decision vehicles make needs additional research to improve the accuracy of the daily driving behavior in the simulated transportation network.

A DT for campus can be expanded to include information from campus user, buildings, access, security, utilities, communication network, transportation behavior, and parking (as shown conceptually in Figure 27 and in more detail in Figure 28). This is a matter access to the current available data sources already monitored by the campus officials. A potential partnership for access to these data sources was discussed in the workshop session. The schematic shown in Figure 28 presents a campus digital twin that includes the flow of data and information that is currently collected from campus operations across several domains.



**Figure 27. Diagram. Conceptual Digital Twin Diagram**



**Figure 28. Diagram. Full Campus Digital Twin**

Task 6.2 – Roadmap to Full DT Implementation

The vision for a campus DT as depicted in Figure 28 includes numerous campus systems outside of transportation and construction. Inclusion in DT requires certain components be present. Table 5 lists out specific campus systems that could be included in a DT application. The table is broken down as follows:

- Domain – which part of campus in which the systems falls (i.e., physical, human, natural)
- System Category – a general system type (i.e., building, transportation)
- System – a specific description of the system to be included

- Measure – a system parameter that is measurable and of interest
- Sensor – how the measure can be tracked
- Trigger – a threshold of the measure from the sensor that would indicate action is required
- Action – the event which would happen when the trigger is exceeded
- Timescale – the scale of time over which action would occur

It is worth noting that the timescales range from nearly instantaneous to months. This differs from traditional applications of DT where real-time action is critical. Civil infrastructure requires action over large time scales.

**Table 5. Campus Infrastructure Systems compatible with DT**

Domain	System Category	System	Measure	Sensor	Trigger	Action	Timescale
Physical	Utls. Infra.	Hot/cold loop	Inflow/Outflow temperatures	Thermistors	Threshold exceedance (Hi/Lo)	Facilities takes corrective action	Near real-time
			Pressure	Pipe pressure gauge	Pressure out-of-bounds		Near real-time
		Power plant	Energy produced/day	Energy meter	Capacity met	Notify operations (support) to adjust consumption	Daily
			Annual energy produced	Energy meter	Storage capacity met	Suggest creation of additional storage to operations	Prior to next year
		Storm water	Gallons/minute	Liquid level sensor	Capacity met	Notify operations (support) to adjust consumption	Daily
			Flood depth (elevation)	Ultrasonic Flood Sensor	Nuisance flooding presence	Transportation notification to campus users Add additional stormwater capacity	Near real-time Six months - year
		Electricity	Watts/day	Electricity meter	Capacity met	Notify operations (support) to adjust consumption	Daily
	Water	Gallon/day	Water meter	Capacity met	Notify operations (support) to adjust consumption	Daily	
	Gas	Gallon/day	Gas meter	Capacity met	Notify operations (support) to adjust consumption	Daily	
	Buildings	Energy	Consumption/day	Energy meter	Threshold exceedance	Adjust HVAC	Hourly
						Dim lights	Hourly
						Adjust humidity	Hourly
						Add shades	Monthly
		Water	Annual consumption	Energy Meter	Threshold exceedance	Implement energy conservation plan	Prior to next year
			Consumption/day	Water meter	Threshold exceedance	Turn off unnecessary water usage entities	Daily
		Occupancy	Annual consumption	Water meter	Threshold exceedance	Implement water conservation plan	Prior to next year
			Persons/hour	RFID scanner	Occupancy exceeded	Find alternative location; notify operations (administrative)	Prior to next event
		Security	Per use basis	RFID scanner	Unauthorized attempt	Prevent access	As accessed
			Hack attempt	?	Unauthorized attempt	Notify operations (support)	As accessed
		Air quality	Air Quality Index/hour	Air quality monitor	Threshold exceedance	Turn on ventilation system	Near real-time
	Evacuate affected area(s)					Near real-time	
	HVAC	Temperature	Thermometer	Predetermined outside condition met	Notify operations (support)	Near real-time	
					Set new temperature	Daily	
	Transportation	Parking (garage)	Occupancy rate/hour	Automatic barrier count	Capacity met	Deny access to new individuals	As accessed
			Average occupancy/semester	Automatic barrier count	Capacity met	Adjust class schedule for next semester to spread out users	Prior to next semester
		Parking (surface)	Average occupancy/semester	Automatic barrier count	Capacity met	Adjust # of permits sold (oversold ratio)	Next permit sale cycle
			Occupancy rate/hour	Parking lot sensor	Capacity met	Deny access to new individuals	As accessed
		Pedestrians	Average occupancy/semester	Automatic barrier count	Capacity met	Adjust class schedule for next semester to spread out users	Prior to next semester
Average occupancy/semester			Automatic barrier count	Capacity met	Adjust # of permits sold (oversold ratio)	Next permit sale cycle	
Shuttle		Volume/hour	Tube counter	Capacity met	Adjust class schedule for next semester to spread out users	Prior to next semester	
		Occupancy rate/hour	Automated Passenger Counter (APC) sensor	Capacity met	Deny access to new individuals	As accessed	
		Occupancy rate/hour	Automated Passenger Counter (APC) sensor	Capacity met	Add additional route	Hourly	
Streets		Occupancy rate/hour	Automated Passenger Counter (APC) sensor	Zero capacity	Temporarily remove route	Hourly	
	Volume	Tube counter	Capacity met	Adjust class/event to spread out users	Prior to next event/next semester		
	Density	Tube counter	Capacity met	Adjust class/event to spread out users	Prior to next event/next semester		
	Speed	Radar	Speed met or exceeded	Warn of speed/flashlights	Near real-time		
Scooters/Bikes	Pavement Condition Index	Visual survey	PCI = unacceptable standard	Notify operations (support) so that pavement can be fixed/replaced	Near real-time		
	Volume/hour	Tube counter	Capacity met	Adjust class schedule for next semester to spread out users	Prior to next semester		
Communication Network	Wi-Fi	Signal strength	Router	Allowance exceedance	Notify operations (police/security)	Near real-time	
				User allowance exceedance	Optimize users connected	Near real-time	
				Loss of signal	Notify operations (support)	Near real-time	

## Phase 4

### Task 7 – Community Engagement Workshop

On May 20, 2022, the Project team hosted a workshop focused on engaging local transportation stakeholders about Digital Twin technology. The organization and outcomes of that workshop are presented in this section.

#### Task 7.1 – Identification of Community Stakeholders

The team invited individuals from a variety of 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 5.

**Table 6. Attendees and their organizations and positions**

Name	Organization	Position
Brian Lake	City of El Paso	Parking
Claudia K. Garcia	City of El Paso	SunMetro
Claudia Valles	El Paso MPO	Transportation Planner
Eddie Valtier	TxDOT	Transportation Planner
Eduardo Adame	TxDOT	Transportation Engineer
Emilio Jr. Rodriguez	UTEP	Env. Health & Safety
Jiann-Shing Yang	City of El Paso	Streets
Jon Feind	UTEP	Planning & Construction
Leonardo J. Aguirre	UTEP	Parking
Sonia Perez	El Paso MPO	Transportation Planner

## Task 7.2 - Preliminary Survey

Prior to the workshop, a short, anonymous survey was sent to attendees to gauge their prior knowledge of Digital Twins for infrastructure. Three questions were asked in total and these responses were used to gauge the focus of the workshop:

1. My level of DT experience is:
2. In a few short sentences, please describe your understanding of digital twins:
3. What would you like to get out of this workshop? Select all that apply

This survey had seven respondents who partially answered the survey (i.e. questions two and three) – of these, five completed the entire survey. Table 6 shows the responses of how attendees felt about their current level of DT experience, three who had no prior experience and two who have heard about it. The responses to question two were all a single sentence or less – two attendees gave their own definitions of what they thought about digital twins, two said that they had heard it in the context of another organization (e.g., NASA and a simulation company), and the last three said that they had no knowledge or experience. Table 7 shows the results from question three, of which attendees could select as many options as possible that best represented what experiences or outcomes they wanted out of the workshop. Most attendees wanted to develop a better understanding of DT technology and learn how to apply it to their projects, and more than half of all attendees would like to develop professionally, network and exchange information, and foster partnership opportunities with UTEP Civil Engineering on future DT projects. Some of the attendees listed in Table 5 did not complete the survey, as they decided to attend the workshop after the survey had been sent out.

**Table 7. Level of attendees' DT experience.**

Experience Level	# of participants
No prior experience	3
I have heard of it	2
I have read about it	0
I am planning to use it	0
I am using it currently	0

**Table 8. Desired goals Based on Attendee Survey**

Goals	No. of participants
Develop a better understanding of DT	6
Learn how DT could be applied in my projects	6
Foster partnership opportunities with UTEP Civil Engineering on future DT projects	4
Networking and information exchange	4
Professional development	4

Task 7.3 - Workshop Agenda

The workshop was hosted in the Interdisciplinary Research Building (IDRB), where community stakeholders were welcomed to the venue (Figure 18), signed-in, and offered complimentary coffee and pastries while they introduced themselves to each other and to the team. During this time, the full color point cloud of the IDRB, Mining Minds roundabout, and some of surrounding transportation network were available in the visualization lab for viewing.



**Figure 29. Image. Community stakeholder sign-in.**



The workshop started with opening remarks and workshop objectives by Dr. Kristie Chin of the Texas Innovation Alliance (Figure 19) – results from the initial survey influenced the goals of the workshop, as community stakeholders indicated that their existing knowledge level on Digital Twin was minimal. Workshop goals were as follows:

- Disseminate the results of the first year of the C2SMART-sponsored research project focused on Digital Twin being conducted at UTEP
- Educate local stakeholders on digital twin technologies and how it may affect their operations and processes in the future
- Identify potential partners for future collaboration under C2SMART or outside of it
- Identify potential pilot projects for digital twin in the region in three specific use case areas; planning, construction and sustainability, operations management, and parking and curbside management



**Figure 30. Image. Opening remarks in visualization lab.**

Dr. Kelvin Cheu introduced attendees to C2SMART (Figure 20) and highlighted UTEP's prior history working with the organization since 2016.



**Figure 31. Image. C2SMART introduction and UTEP collaboration history.**

Dr. Adeeba Raheem introduced attendees to the DT technology, highlighting its importance as an emerging technology in research and industry (Figure 21). As previously mentioned, attendees felt minimally knowledgeable on the topic prior to the workshop – Dr. Raheem defined what a DT is and differentiated it from BIM, a practice established and common in some stakeholders’ professional experiences. This portion of the workshop aimed to communicate DT benefits to stakeholders and its future applications, establishing a baseline for discussion amongst stakeholders for the breakout session component of the workshop.



**Figure 32. Image. Digital Twin technology introduction and overview.**

Dr. Jeffrey Weidner built on Dr. Raheem’s presentation by describing the application of DT technology in the team’s project thus far (Figure 22). Dr. Ruimin Ke, who will be the Principal Investigator for the Year 2 phase of this project, bridged this presentation with how it will be expanded upon in Year 2 (Figure 23). Before the breakout sessions commenced, Dr. Chin, joined by Anna McAuley of the Texas Innovation Alliance, gave attendees the breakdown of the three different use cases to be discussed in relation to DT technology for the breakout session. These three use cases were as follows:

- Planning, construction, and sustainability
- Operations and maintenance
- Parking and curbside management



**Figure 33. Image. Project overview presentation.**



**Figure 34. Image. Year 2 lookahead discussion.**

The breakout discussions for the three use cases were led in pairs:

- Planning, Construction, and Sustainability, led by Dr. Adeeba Raheem and Anna McAuley
- Operations and Maintenance, led by Dr. Jeffrey Weidner and Dr. Ruimin Ke
- Parking and Curbside Management, led by Dr. Kristie Chin and Dr. Kelvin Cheu

The “Planning, Construction, and Sustainability” group focused on applications that addressed climate change, resilience, and project delivery, including building construction, indoor air quality, and scenario planning tools to model the relationship between the built environment and transportation systems. The “Operations and Maintenance” group focused on opportunities to model multimodal traffic flow and work zone safety at the intersection, corridor, or neighborhood levels, including techniques that use sensors to monitor the health and predict maintenance needs of bridges, pavement, and other assets. The “Parking and Curbside Management” group focused on systems that can simulate the parking ecosystem, including parking availability and special events management, as well as other applications include optimizing the use of the curb to inform economic development and congestion mitigation policies. Figure 24 shows how the breakout groups were typically arranged.



**Figure 35. Image. Operations and Management breakout group.**

After the groups finished their discussion, the team and attendees reconvened in the visualization lab so that each of the breakout groups could report out what they had discussed (Figure 25). The outcomes of these breakout discussions will be discussed in a following subsection of this section.



**Figure 36. Image. Use case report out discussion.**

## Task 7.4 - Observations and Results for Breakout Session

### **Parking and Curbside Management Group**

During this session a parking availability pilot concept was discussed for the use of digital twin technologies to improve parking information. A specific scenario was presented for the downtown area of El Paso where visitors claim insufficient parking space in the area. It was noted that parking areas are ample to cover current demands in parking space, but drivers do not know where to park downtown (garage or street parking). The “lack of parking” in downtown or lack of knowing where parking is downtown deters travel to the area. A potential solution suggested for this problem was to fully digitize parking in El Paso.

A possible case study on campus was considered to digitize parking by using data currently collected for the Schuster parking garage. This can include the use of the already in place sensors and cameras for optimization of the parking availability in “real-time”. Since there have been calls of no parking for the UTEP parking garages, DT technologies and available data sources can be leveraged for the planning of parking in the garages and to identify underutilized parking space (e.g., university print shop parking lot).

### **Operations and Maintenance Group**

The second break out group focused on the post event planning uses for a DT by MPO and TxDOT. During an accident if there is a fatality the post event planning takes times. A digital capture of streets using LiDAR or DT technology can be used to plan the response after incident. These technologies can be used at high interest locations such as major highways and high incident intersections. An example of the uses is ITS for traffic management, site investigation, and off-site analysis of event.

A DT platform concept was discussed and a potential advisor for the idea was identified (i.e., Eddie) for the project. The idea presented a potential regional partnership for incidence report. In addition, a camera vehicle-mounted extension of the city contract was discussed as a potential data source, data collection collaboration.

### **Planning, Construction, and Sustainability Group**

The last breakout group focused on the impact construction has on street closures and the local transit user. When planning closures of the streets the transit routes are affected with the need to reroute and update the user in real-time of potential delay. Currently there is data collected and available for DT application in transit planning. The data collected/available is from user ridership, transit routes, and expected closure due to construction (reported).

Another application was discussed for the border area to alleviate the congestion in interstate highways (east to west) near international bridges. The data from international crossing points remains inaccessible to the public. In an effort to collect vehicle count at the border crossing a collaboration between UTEP and Mexico to tally the number of users crossing the international border is on-going. The data collection is limited to manual data collection at each end of the border with limited data access and sharing.

Another potential data source for a campus DT was identified for the UTEP facilities management. The data for various buildings is being recorded and available such as occupancy, access, count of people, energy consumption, temperature, lighting, utilities, and emissions (limited). Potential access to these data sources was discussed.

### **Summary breakout session**

Based on the conversations during the breakout sessions, there is a disconnect between the modern technologies, stakeholders, the real-time data sources, and the use given to the data collected. There are cases identified where the data is already being collected and can be used to improve the community in terms of downtown parking planning, transit and street closure coordination and planning, and energy sustainability for smart buildings. Individual pilot concept studies for each of these applications can be performed with university research resources of campus or by leveraging the data collected by the city for further DT application and research. The aim is to improve the community by identifying opportunities for collaboration with the local entities and implementing these modern DT technologies to enhance the El Paso community.

## Task 8 – Reporting and Dissemination

### Task 8.1 ASCE Conference Paper Publications

As a result of the project, three graduate students were selected to present the research experience in the American Society of Civil Engineers' International Conference on Transportation and Development in Seattle Washington. Two separate abstracts were submitted for conference proceedings publication and inclusion in the conference program. The title of the papers is:

1. Using Vision-Based Methodology to Create a Traffic Network Asset Inventory for a University Campus for Integration in a Digital Twin
2. Evaluation of 3D Reconstruction Methods from Terrestrial LiDAR Point Cloud Data to Create Digital Twins of Civil Infrastructure Projects



The first paper, written by Lauren Brown, was selected for the poster presentation session (shown in Figure 26). The paper explained the methodology used to capture the geospatial data for the traffic assets around the university campus. This included the:

1. Asset data collection via a GoPro video footage
2. Assets identification based on MUCTD
3. Generating transportation asset inventory for campus transportation network
4. Input for traffic simulation scenario in VISSIM

This data collection method remains manually intensive therefore a need exists to automate the highway asset inventory data collection process. The paper explained an understanding of the data input for the digital twin simulation and presented a need to improve the current data acquisition methods to automate the detection process for these highway assets and extraction of the geospatial data.



**Figure 37. Image. Student Presentation at ASCE ICTD Conference**

The second paper, co-written by Julio Gallegos and Jose Luis Lugo, was selected for a podium presentation for the Digital Twin and application session (shown in Figure 27). The presentation was delivered by both

authors on the reconstruction methods for existing infrastructure. The application was presented specifically for the reconstruction of the interdisciplinary Research building for a target LOD 300. This paper emphasized the use of laser scanning to reconstruct the geometry of the infrastructure assets surrounding the transportation network of interest. This was done by evaluating both manual approaches and attempted to automate the process by leveraging existing algorithm approaches.



**Figure 38. Image. Digital Twin and Applications Podium Presentation**

The methodology used generate the BIM model integrated into the VISSIM simulation was explained and the process to obtain the geometrical information for the building from the point cloud data. The result of the various approaches was presented and future research in term of visualization for digital twin modeling were identified. The presentation included:

1. Overview of Digital Twin for infrastructure
2. Terrestrial LiDAR data collection procedure and technology
3. Reconstruction methods for LOD 300 visualization
4. Comparison of the various reconstruction methods
5. Limitation towards DT visualization

#### Task 8.2 – Invited Talks in the Community

Stemming from the efforts described in Task 7 – Community Engagement Workshop, the UTEP team has been asked to provide two additional talks for the purposes of dissemination and education, as described below.

#### Task 8.2.1 – Invited Talk for City of El Paso Parking Steering Committee

On June 30, 2022, Dr. Weidner will give a presentation on Digital Twin technology with a focus on implementation for parking. The audience will be the City of El Paso Parking Steering Committee. This is a diverse group of public stakeholders including representation from several departments at the City of El Paso, the Downtown Business District, TXDOT El Paso, the El Paso MPO, and others. The goal is to introduce the concept of Digital Twin to the entire stakeholder group and gauge interest in pursuing this implementation further through a partnership.

#### Task 8.2.2 – Invited Talk for Texas Department of Transportation Technology Task Force

On August 4, 2022, Dr. Weidner will give an overview presentation on Digital Twin technology, then participate in a panel discussion on the subject along with several other experts. The audience for this presentation will primarily be TXDOT staff, but the event will be virtual so it will be far reaching.

## Czech Technical University Collaboration

The University of Texas at El Paso (UTEP) has an extensive history of collaborating with the Czech Technical University (CTU), located in Prague, Czech Republic. The collaboration between these two universities began in 2008 with non-degree seeking student exchanges. Between 2009 and 2010, faculty and professors from UTEP and CTU visited the opposite institution. A Dual-Master's program was established in 2010 in Transportation and Logistics Systems and was offered through 2018. Another Dual Master's program, this time in Smart Cities, was established in 2020 and continues to be offered today.

Specifically for this project, we were introduced to the creation of a digital twin of Prague, Czech Republic by Dr. Miroslav Svitek (a visiting professor from CTU) and his graduate student. This digital twin allowed users to use augmented reality or virtual reality to be able to see the city and its systems, from the transportation network to air quality. These technologies were originally planned to be shared with the UTEP team, but unfortunately this collaboration did not happen.

Additionally, our team worked with one of the exchange students in the Smart Cities Dual-Master's program, Martin Čirkov, whose thesis involved studying Smart Parking technologies applied to the parking lot Sun Bowl 2, located across from our area of interest. Historical data was shared with this student to analyze smart parking technologies and how they influence parameters such as search time.

## Conclusions and Future Work

### Overview

The purpose of this project was to make incremental progress towards a true DT system for civil infrastructure. 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 key components of a DT designed to explore the interaction of a campus transportation network and an on-campus construction site.
- Identify data and data collection practices for reality capture of existing infrastructure.
- Create a Digital Shadow (DS) model of the selected civil infrastructure systems.
- Explore scenarios with real or synthetic data in the DS to understand how DT may affect operations of the selected civil infrastructure systems.
- Identify gaps and needs to facilitate a broader adoption of DT for a college campus, and to qualify the potential of DT.
- Disseminate the results and educate local public stakeholders about DT technology.

A DS model was created for a portion of The University of Texas at El Paso inclusive of part of the transportation network and an as-built BIM model of a campus building. This was built on the base model developed for campus using historic LiDAR data, among other sources. The base model was augmented using terrestrial LiDAR and image capture methods. Since there was no available data streaming from the real campus system (i.e., the transportation network), a synthetic system was developed to represent the real system in the DS model. The DS model was used to explore a specific construction-related traffic interruption scenario to explore how, if implemented in a full digital twin on campus, the interruption may be accounted for dynamically. Based on these results, a gap analysis was conducted to understand the requirements and the potential for a full campus DT. It was found that there is potential for DT to be substantially beneficial, but with specific caveats, discussed below. Finally, a community engagement workshop was held. The workshop focused on educating local El Paso transportation officials about DT technology and seeking their participation in developing future case studies and applications.

### Conclusions Regarding DT for Civil Infrastructures

Several specific observations about the application of DT to civil infrastructure came about through the course of this project. These observations are discussed below.

## The Importance of Scenario

There is a certain appeal to a DT system that is omniscient with the ability to track a wide host of behaviors and performances, and to react creatively to each. The reality, at least currently, is that this is not feasible. Rather, a DT for civil infrastructure should be designed with certain scenarios in mind. This puts a practical limit on the amount and distribution of sensing and communication technologies that makes DT more appealing. It also limits the extent to which the DT system must make changes to the infrastructure in response to the observed behavior. For a DT for civil infrastructure to be successful, a specific scenario should drive the type, amount, and distribution of sensing, the speed and reliability of communication technology, and if any additional technology or infrastructure is required to implement responses of the system based on the output from the digital component of the DT.

## Variation in Time Scale

One of the key characteristics of DT systems in manufacturing applications, and therefore a key characteristic of DT systems in most conceptualizations, is real-time or near real-time functionality. A DT should be able to ingest, analyze and react to information very fast. In manufacturing contexts, this is logical. The system is closed, with very little random input or unexpected behavior. This allows for tight behavioral tolerances, precise movement tracking, and dedicated pathways connecting system behavior to recommended response.

Civil infrastructure systems are much more dynamic and random. More specifically, the infrastructure itself (e.g., roadways, buildings, signage, etc.) are static over relatively short time scales, while the demands upon those infrastructures (e.g., traffic, loads) are dynamic. Moreover, the demands on those systems are often highly variable and sometimes completely random. In turn, the mechanisms to make changes to the infrastructure systems are generally slow. Intelligent Transportation Systems (ITS) can make dynamic changes to traffic flow (e.g., using dynamic messaging signs to close a lane), but they require prior knowledge of how the system may need to change in order to install, connect, and control ITS infrastructure. Outside of that application, changing the infrastructure takes a relatively long time.

A key characteristic of DT for civil infrastructure is, therefore, a consideration of time scale for various scenarios. This is reflected in Table 5 which provides some scenarios that might make sense for a campus DT including time scale, which can vary from real-time to biannually.

## Software and Data Interoperability

The ability of each component of the DT to communicate is critical to the success of the DT, be it civil infrastructure or other. This is not a surprising conclusion, but it is worth highlighting because this requirement will serve as major impediment for broad application in civil infrastructure because most civil engineers do not have the requisite knowledge to account for it. Civil engineers will need to partner with other domains to ensure the success of DT for civil infrastructure.

## Future Work

This project feeds directly into a year 2 project that will attempt to create the physical components of a campus DT using three specific scenarios and connect them to a single server on campus where simulations can be run. The result will be an actual campus DT implementation.

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