Creating Campus Digital Twin for Studying Transportation and Infrastructure

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Acknowledgement

What is a Digital Twin?

A digital replica of a physical entity or system

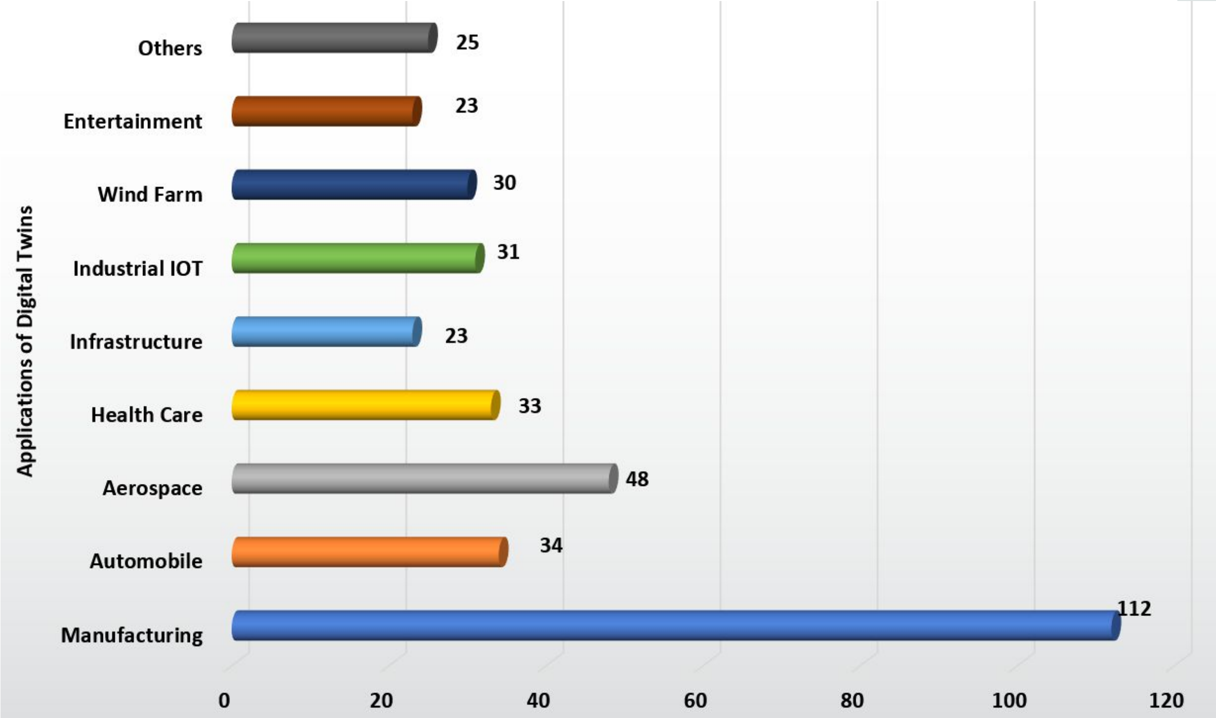
Integrates real-time data and simulations

Used to analyze, simulate, and predict real-world scenarios

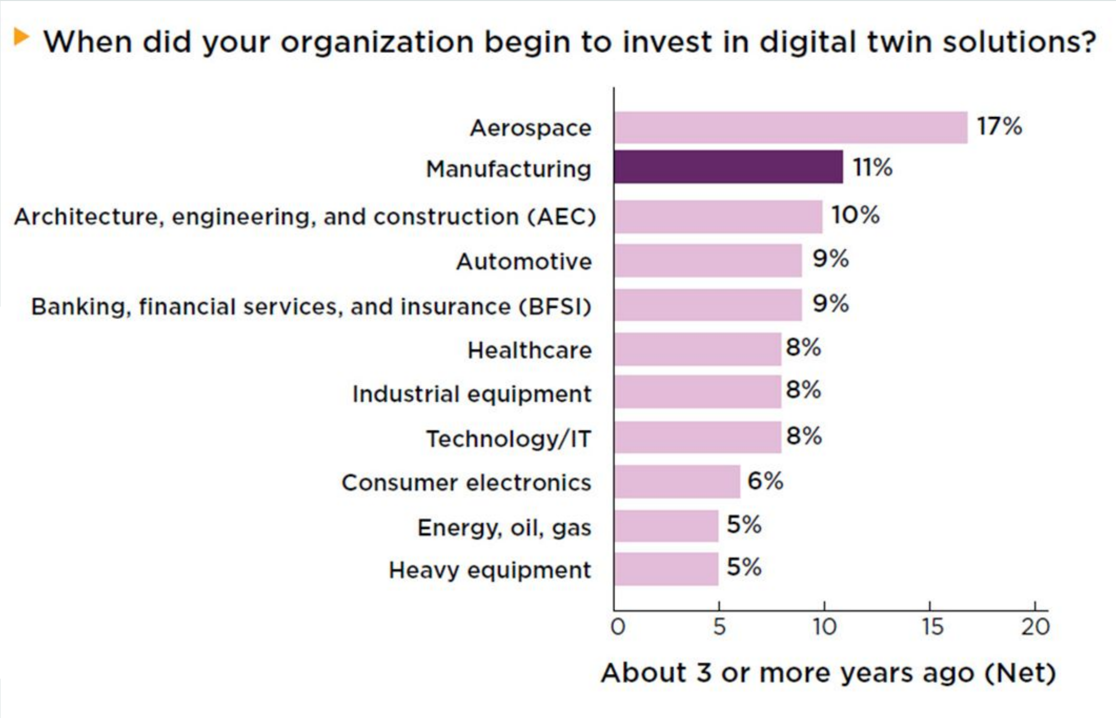
Benefits of Using Digital Twin

1. Efficiency
   - Reduce time and cost in planning and maintenance.
2. Accuracy
   - More precise predictions and analysis.
3. Safety
   - Identify potential issues before they become critical.
4. Innovation
   - Experiment with new ideas in a risk-free virtual environment.

Market Share of Digital Twin



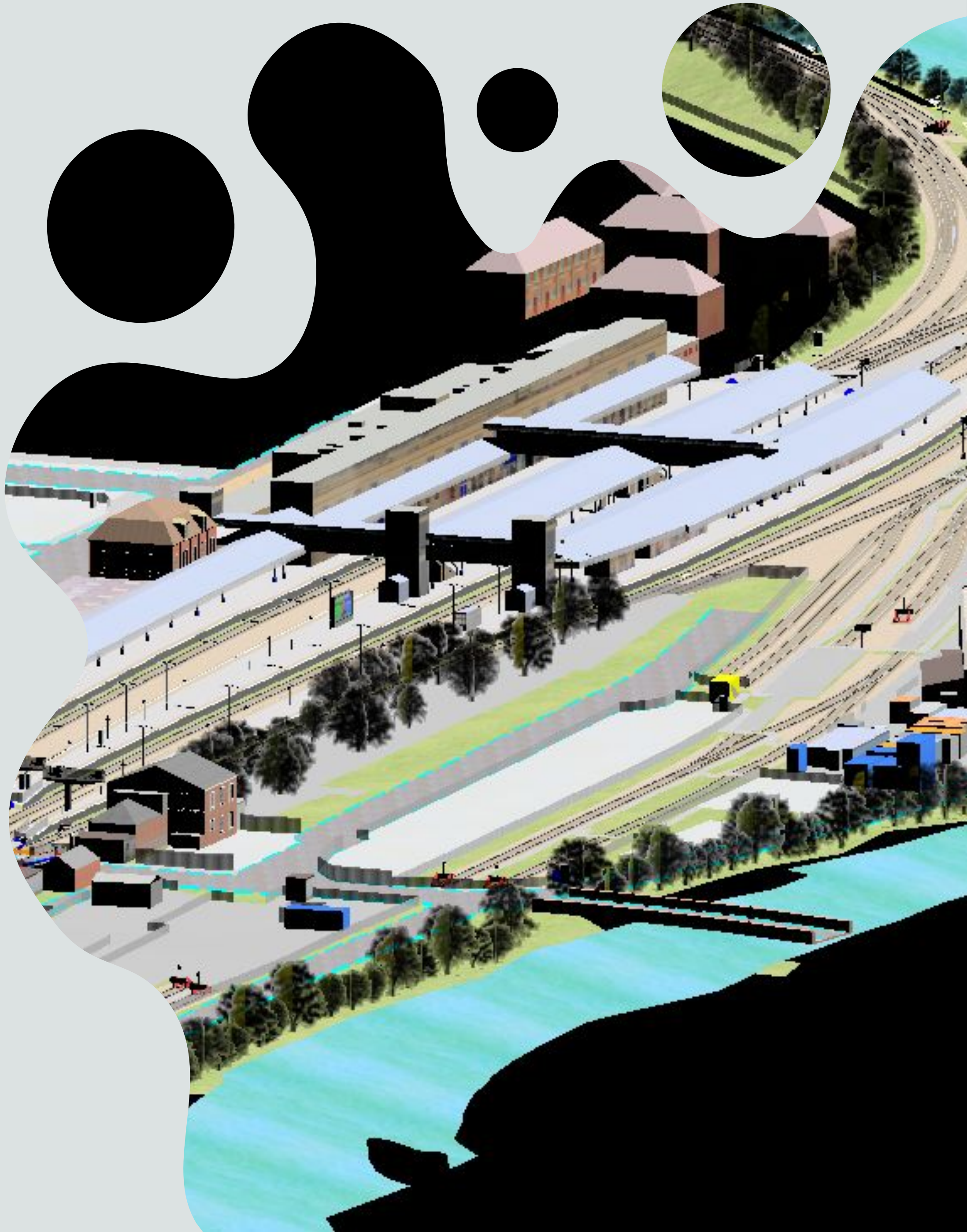
IIPR, 2018



https://altair.com/resource/digital-twin-summary-report (2022)

Application in Transportation

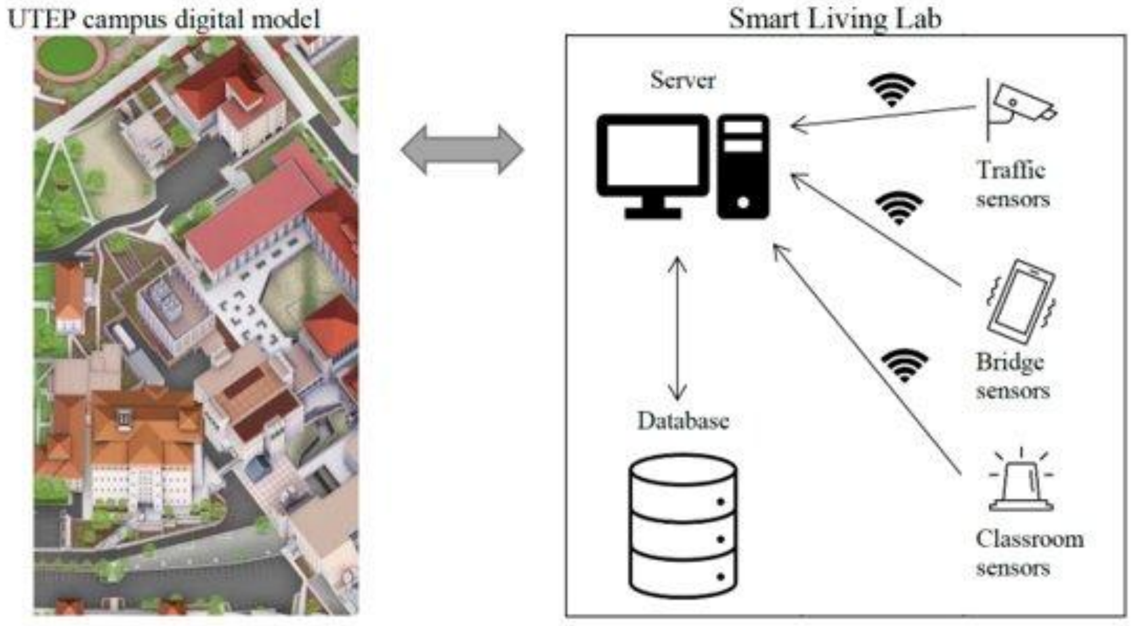
1. Traffic Management
   - Simulate and predict traffic flow.
2. Vehicle Maintenance
   - Predictive maintenance of public transit vehicles.
3. Transportation Planning
   - Design and test new transportation routes.
4. Safety Analysis
   - Simulate crashes to improve traffic safety protocols.



Introduction to the Project

- Project explores DT as a tool for management of civil infrastructure
- Implement a smart living lab (SLL), which may be scaled to a campus-wide DT with a focus on transportation, construction, and planning

- Roundabout at Schuster garage
- Pedestrian bridge
- Extended reality



Tasks and Goals

- Literature review: understand Digital Twin technologies for civil infrastructure, simulation, and intelligent transportation systems
- Digital Model: identify the best ways to create individual digital models and build campus DT
- Site Selection: based on appropriate data to be effective DT use cases
- Implementation of Smart Living Lab: sensing, communication, and algorithms to create the DTs
- Digital Model integration: pipeline of the model, simulation, and analysis with real data
- Scenario Analysis: real and augmented data on different configurations to display analytical capabilities of the DT using real-world data and assumptions
- Outreach Workshop: to fuel future research directions

Digital Model

Challenges in creating Digital Models

- Road networks can be simulated from GIS data but only in 2D (OpenStreetMap)
- Aerial LiDAR data can be used for 3D terrain and building models, slow and costly
- Manual 3D modeling can be used for autonomous driving research in CARLA
- Enterprise services like Microsoft Azure Digital Twins, AWS IoT TwinMaker, and Bentley iTwin support Digital Twin applications

There seems to be no simple solution for University campus digital twin model that supports transportation simulations

Digital Model

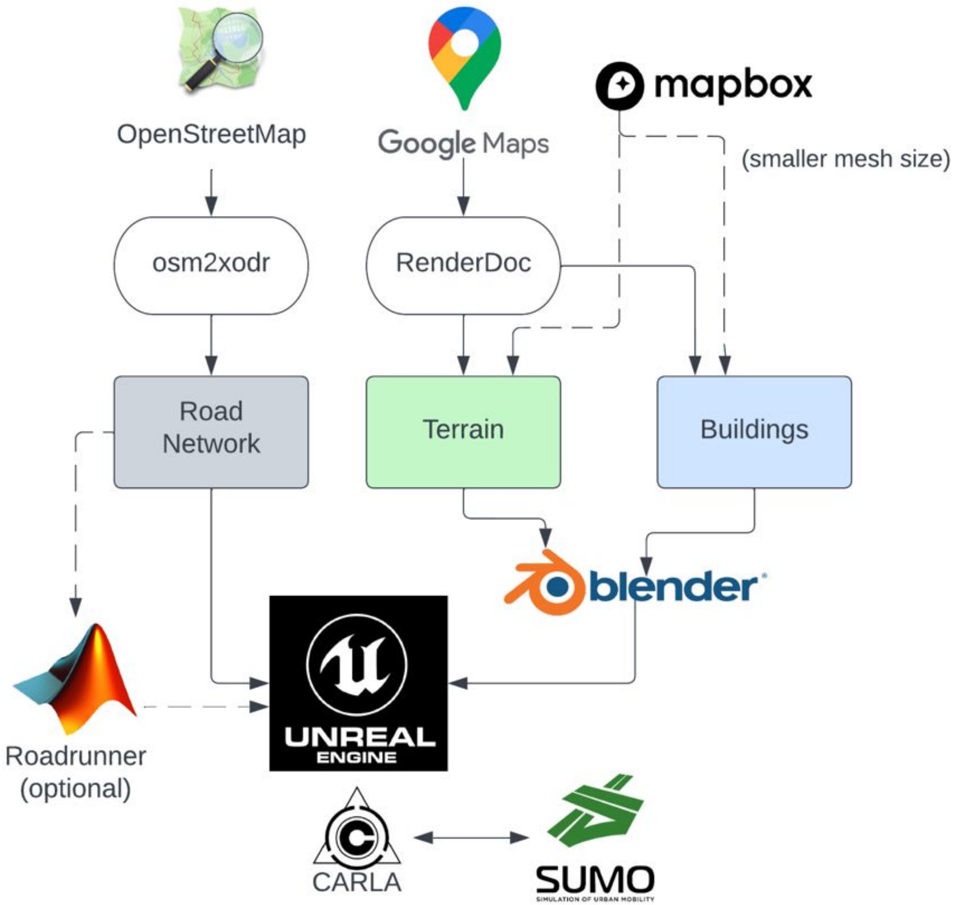
Challenges in creating Digital Models

- Road network information in OSM for university campus is incomplete or out of date
- Building information and 3D CAD models are generally not available
- No single software solution exists to create these models quickly
- Campus operation data may exist but is not available for research
- Exponential growth of digital infrastructure and sensors allow higher fidelity virtual representations but increase cost and computation requirements

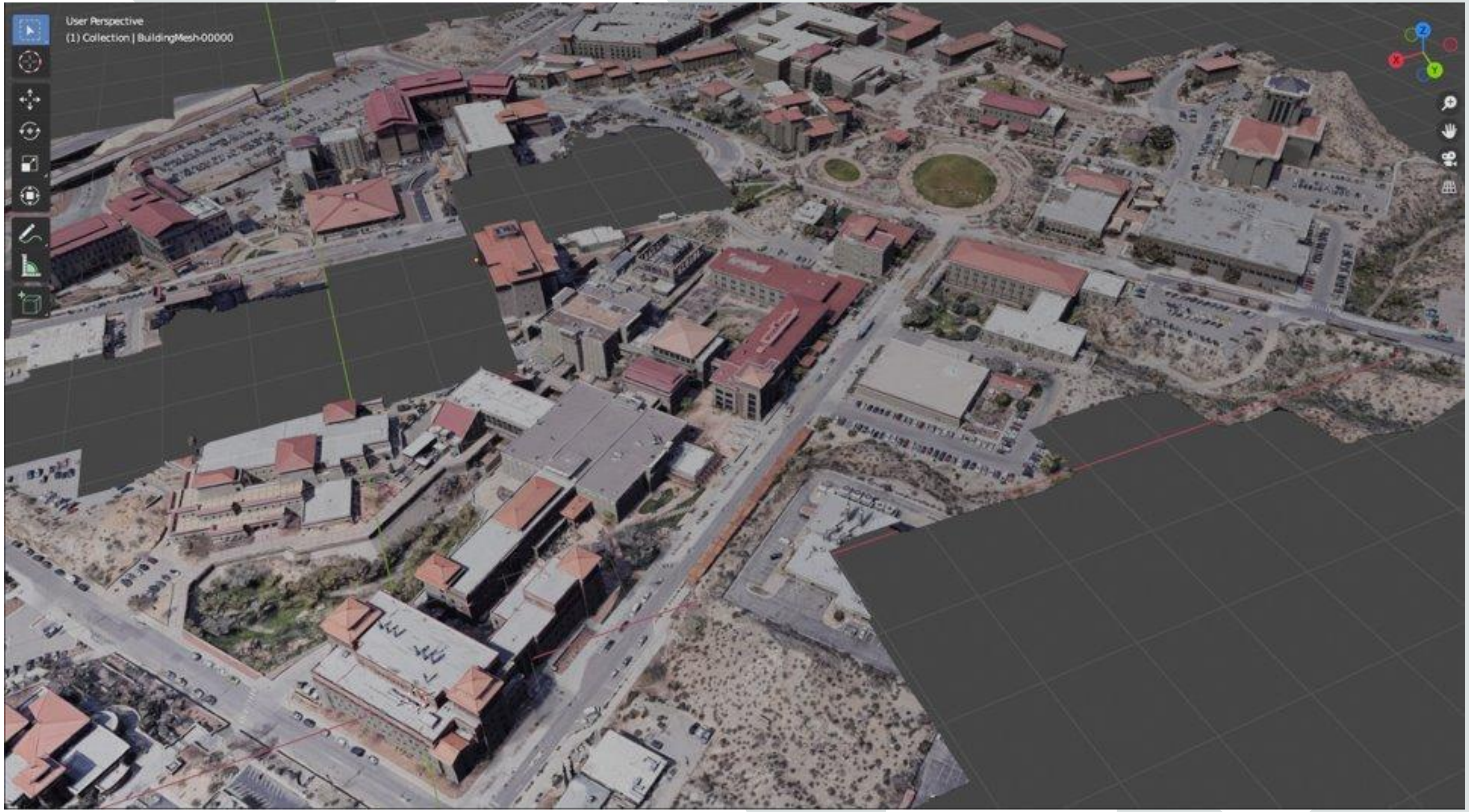
Digital Model

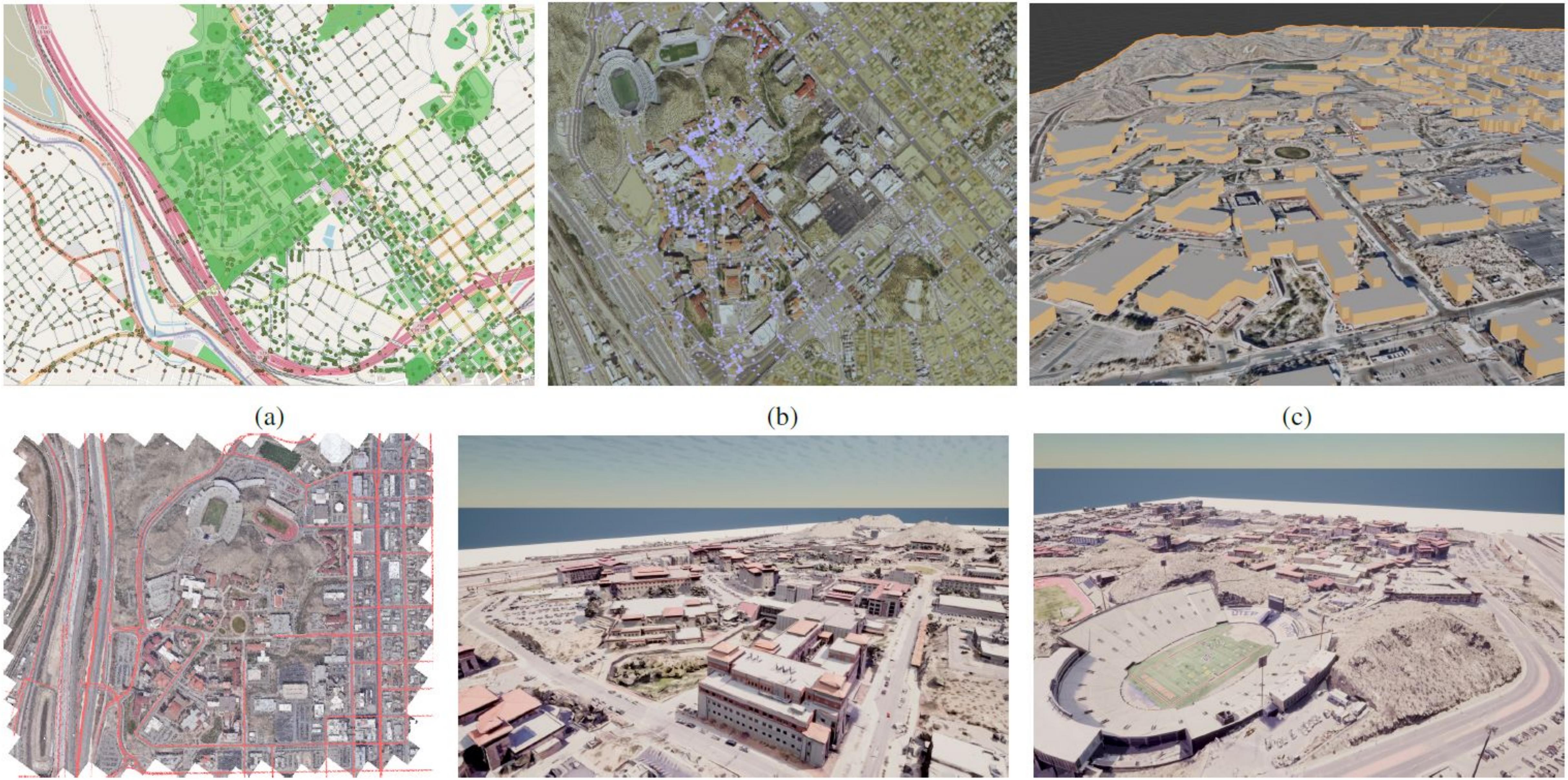
Campus Digital Model and Road Network

- 3D model of the campus that can support road network for traffic simulation
- Procedure was developed to create transportation network DT using freely available data and software
- OpenStreetMap (OSM) is used to export the map
- OSM file converted to opendrive (xodr) using python tool in CARLA
- 3D buildings and terrain can be exported from Mapbox
    - No color or texture, no objects other than buildings



- Renderdoc is a graphics debugging tool that can extract 3D data from Google maps
- 3D meshes can be imported into Blender using MapsModelsImporter plugin
- Contains terrain, buildings, trees, parking lots, and even parked cars





(a) (b) (c)

(d) (e) (f)

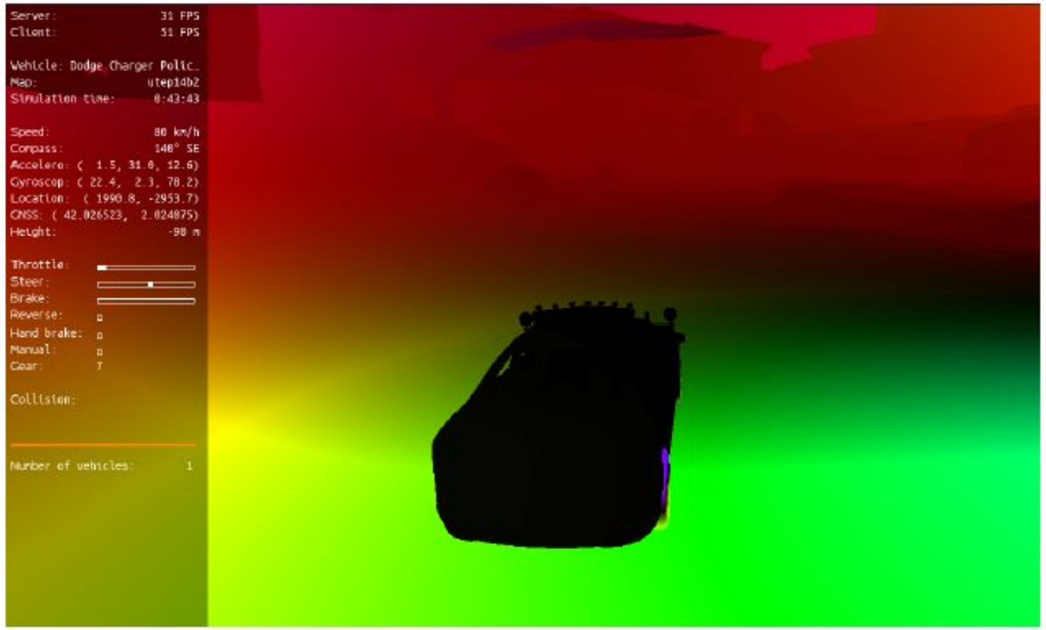
- CARLA project of Unreal Engine using 3d terrain data from Google maps using Renderdoc and Blender, and road network exported from Openstreetmap
- Composed of 1.59 million triangles on an Intel Core i9-10900X CPU, 256 GB RAM, and NVIDIA A6000 GPU


Server: 38 FPS
Client: 57 FPS
Vehicle: Nissan Patrol 2021
Map: utep14b2
Simulation time: 0:10:17
Speed: 0 km/h
Compass: 74° NE
Accelero: (-0.4, 0.2, 9.8)
Gyroscop: (-0.0, 0.0, 0.0)
Location: (1920.1, -2136.9)
GNSS: (42.019106, 2.023222)
Height: -72 m
Throttle:
Steer:
Brake:
Reverse:
Hand brake:
Manual:
Gear: 1
Collision:
Number of vehicles: 1

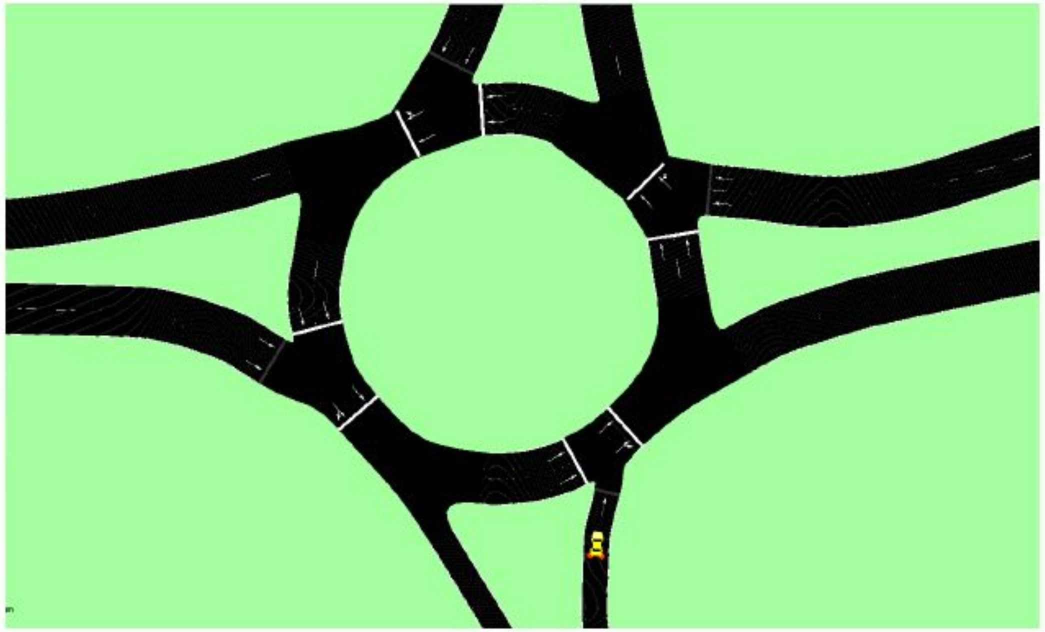
(a)


Server: 47 FPS
Client: 62 FPS
Vehicle: Mercedes Sprinter
Map: utep14b2
Simulation time: 0:11:51
Speed: 0 km/h
Compass: 152° NW
Accelero: (0.1, -0.6, 9.8)
Gyroscop: (0.0, 0.0, 0.0)
Location: (2506.8, -2175.2)
GNSS: (42.019546, 2.030300)
Height: -64 m
Throttle:
Steer:
Brake:
Reverse:
Hand brake:
Manual:
Gear: 1
Collision:
Number of vehicles: 1

(b)


Server: 31 FPS
Client: 51 FPS
Vehicle: Dodge Charger Polic…
Map: utep14b2
Simulation time: 0:43:43
Speed: 80 km/h
Compass: 140° SE
Accelero: (1.5, 31.0, 12.6)
Gyroscop: (22.4, 2.3, 78.2)
Location: (1990.8, -2953.7)
GNSS: (42.026523, 2.024875)
Height: -98 m
Throttle:
Steer:
Brake:
Reverse:
Hand brake:
Manual:
Gear: 7
Collision:
Number of vehicles: 1

(c)

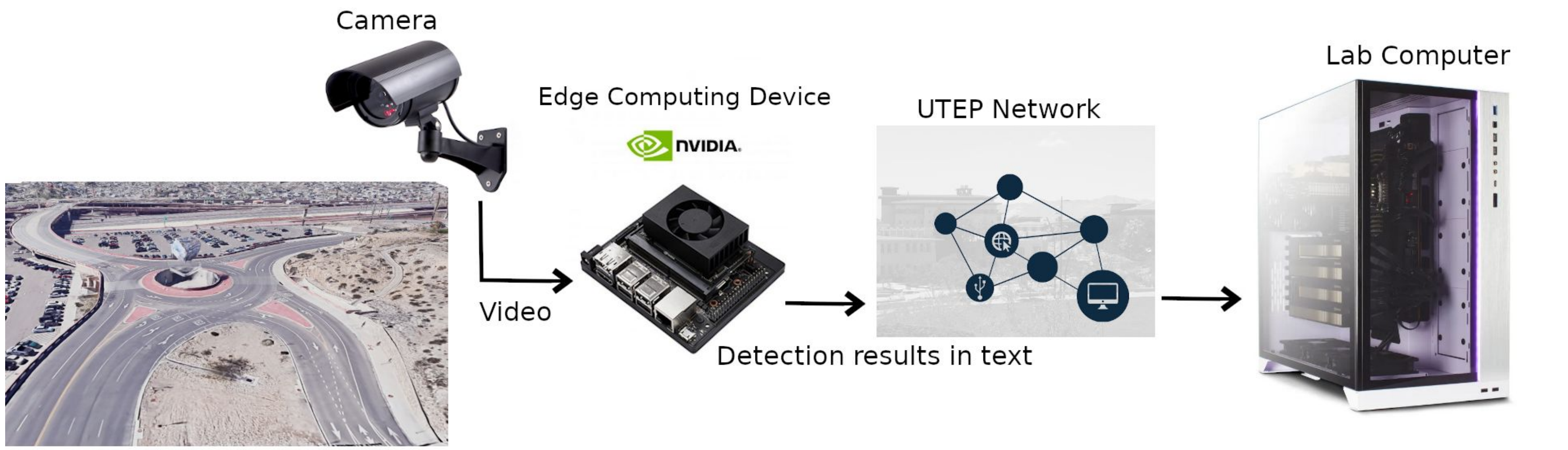


(d)

Implement the Prototype Digital Twin

Vehicle Detection and Tracking on Edge Device

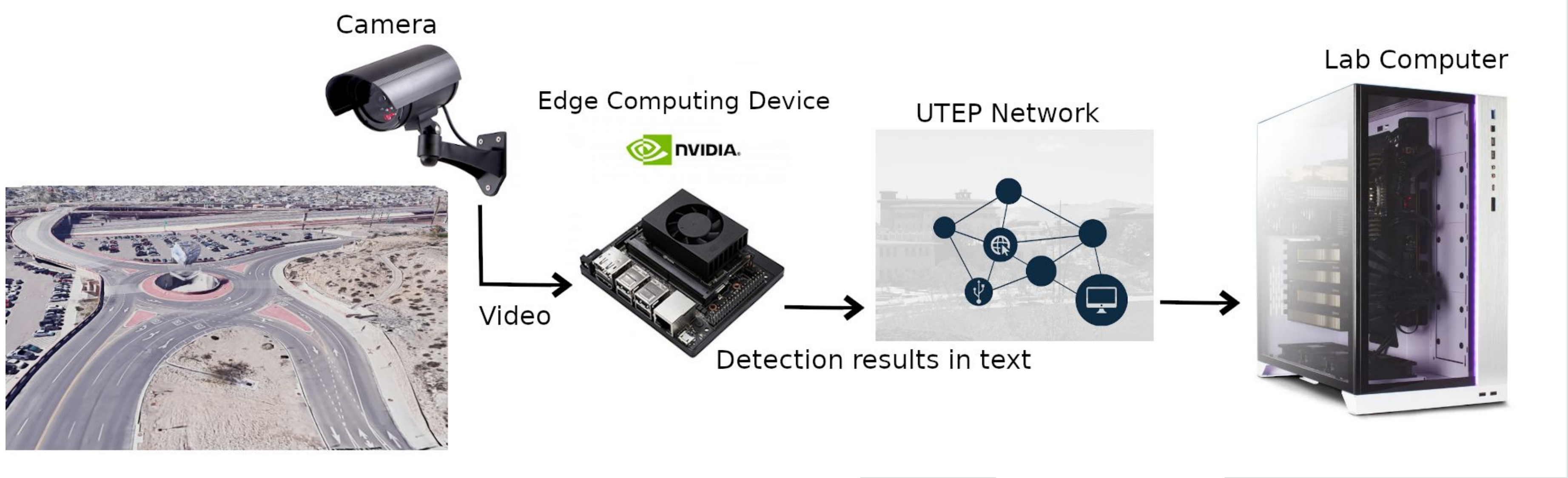
- Based on the Nvidia DeepStream SDK which provides a complete pipeline for training computer vision algorithms and deploying them
- Jetson Xavier NX edge device and cameras on the fourth floor of the Schuster Garage
- Yolov5 and DeepSORT for vehicle detection and tracking to get real-time traffic flow information in all directions including the trajectory of each vehicle



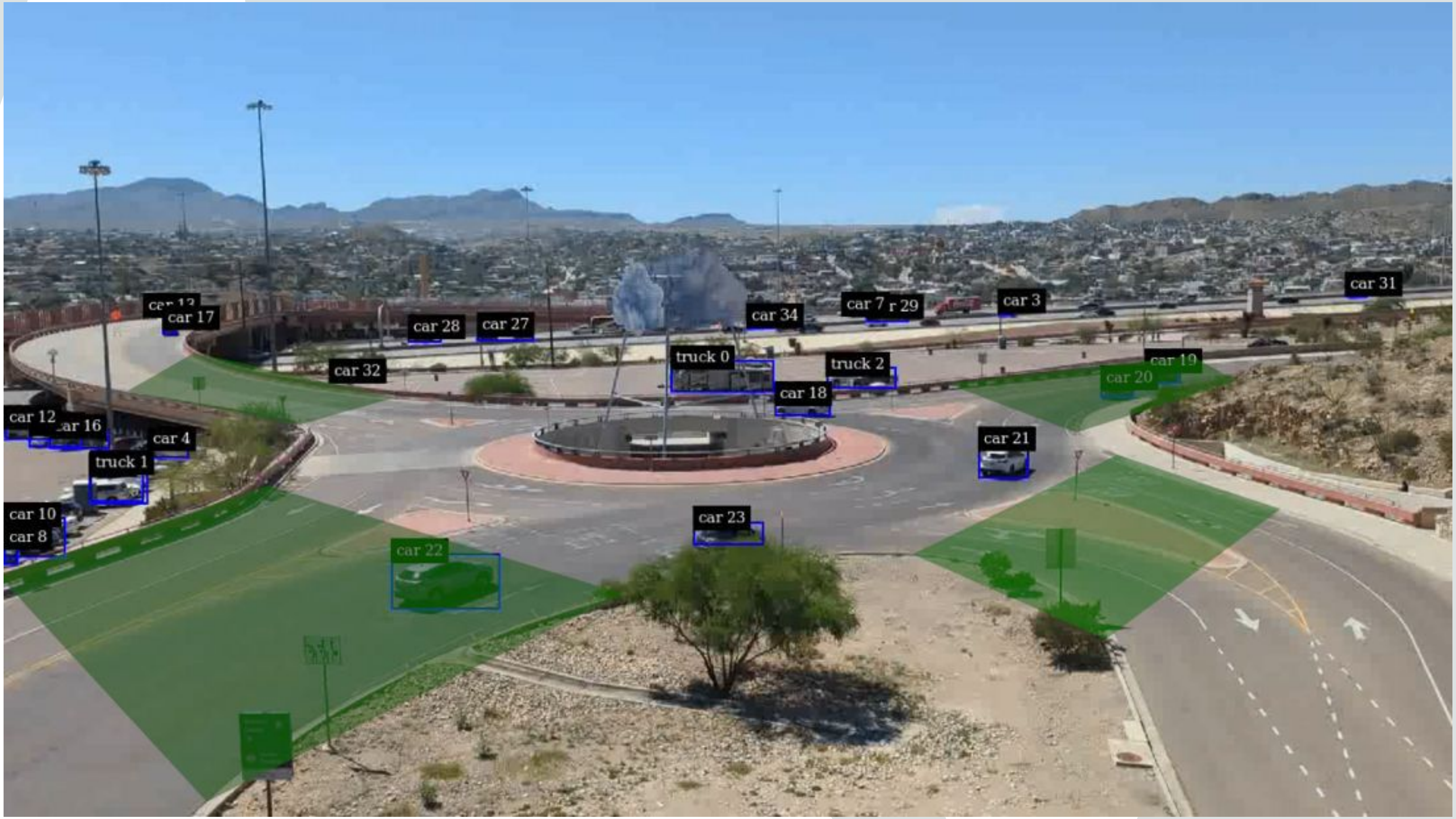
Implement the Prototype Digital Twin

Vehicle Detection and Tracking on Edge Device

- Mounted in a NEMA rated box on top of the Schuster garage
- Target detection and tracking algorithms count the number of vehicles for every type within the roundabout region
- Main errors stem from occlusion with other vehicles and the roundabout center structure
- Required approvals from the Police department, Planning and Construction, Facilities, Legal Affairs, the Vice President of Business Affairs, and Information Technology



Implement the Prototype Digital Twin



Implement the Prototype Digital Twin

Mapping and Calibration

- M2D coordinates of bounding box centers converted to 2D coordinates in the digital model with a constant Z (height) component

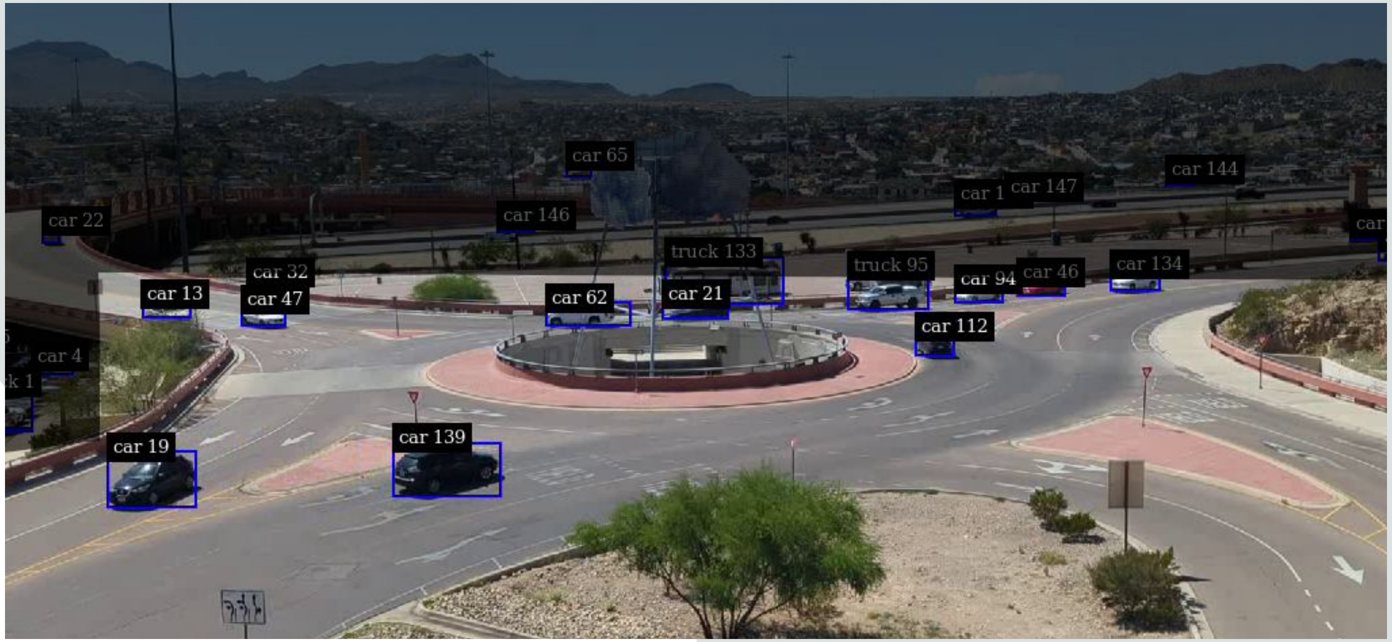
- Linear transformation between the two coordinate systems:

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

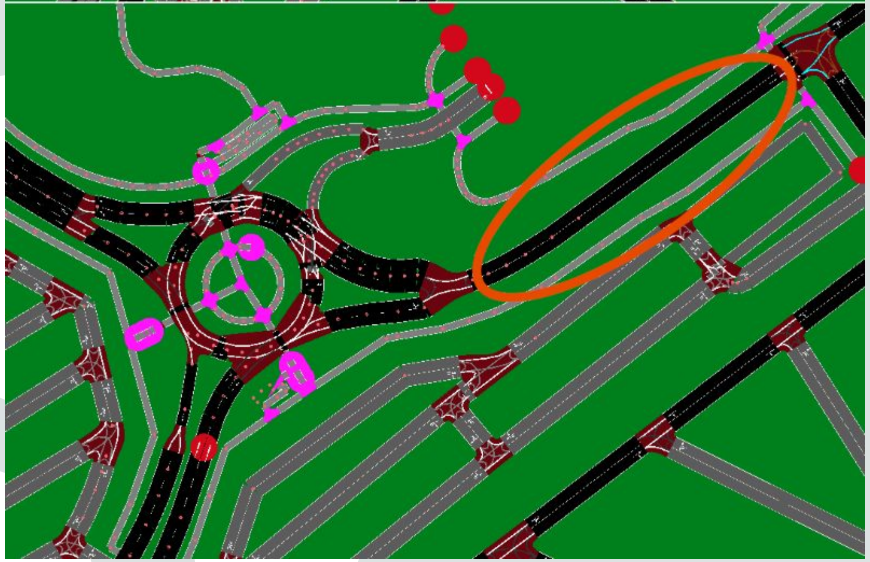
$$y_{model} = a_2 x_{image} + b_2 y_{image} + c_2$$

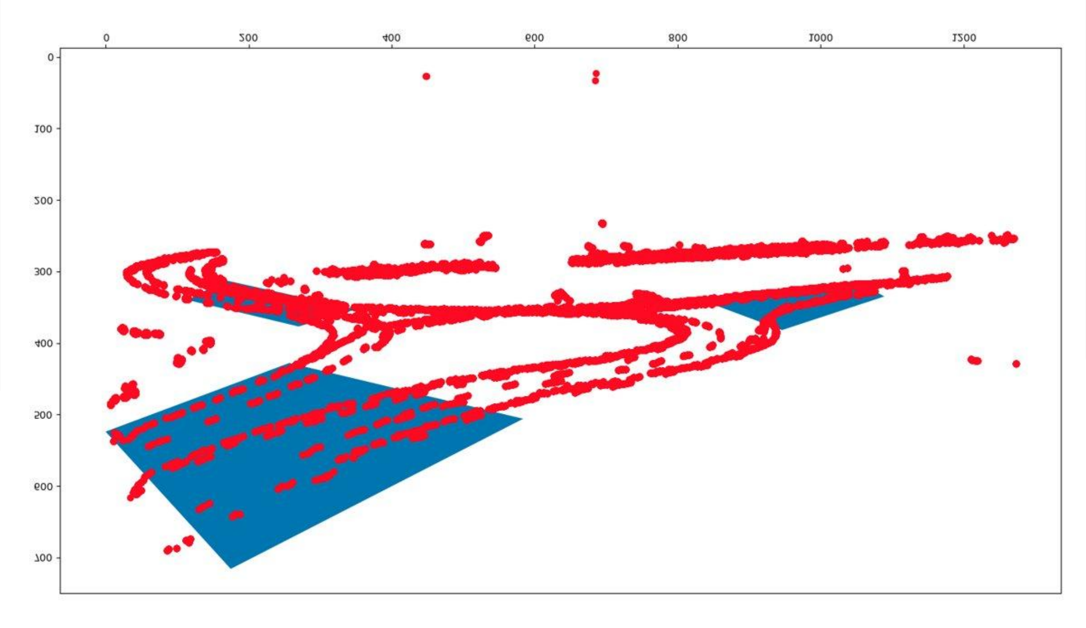
- Detections from the video do not smoothly transition from one frame to the next, so running average was used

- List of vehicles refreshed after every 30 seconds for only the latest detections


car 65
car 22
car 146
car 1
car 147
car 144
truck 133
car 32
car 13
car 47
car 62
car 21
truck 95
car 94
car 46
car 134
car 112
car 4
car 19
car 139

- Without construction average time loss per vehicle was 31.13 seconds, with construction loss was 34.54 seconds, meaning additional average delay of 3.41 seconds
- At higher demands, the 4-lane scenario gives 32.89 seconds loss while the 2-lane scenario gives 49.84 seconds, increasing additional delay to 16.95 seconds
- Queue buildup only observed in the two-lane scenario




0
200
400
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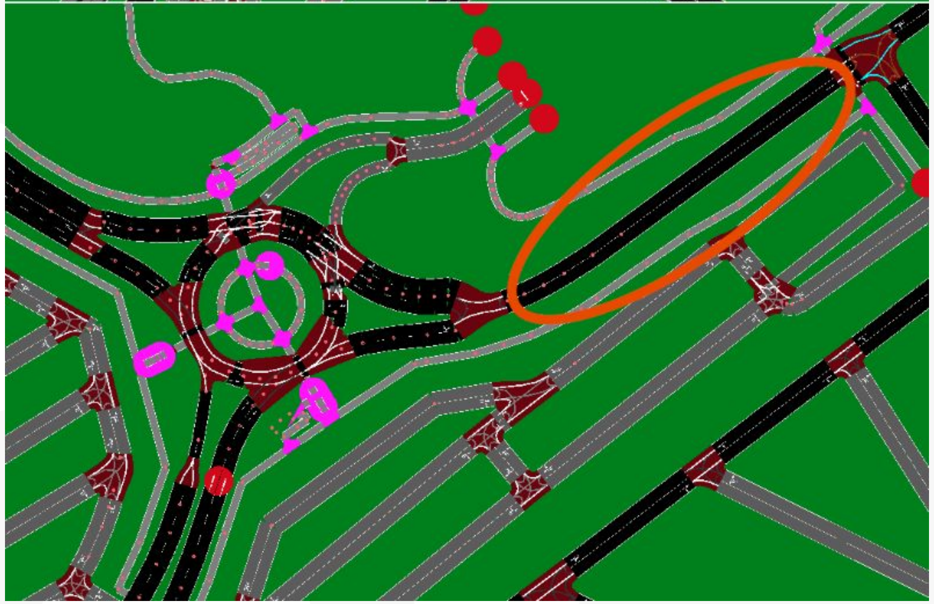

Selected Project Outcomes

- Azfar, T., Weidner, J., Raheem, A., Ke, R., & Cheu, R. L. (2022). Efficient procedure of building university campus models for digital twin simulation. *IEEE Journal of Radio Frequency Identification*, *6*, 769-773.
- Azfar, T., Wang, C., Ke, R., Raheem, A., Weidner, J., & Cheu, R. L. (2023). Incorporating Vehicle Detection Algorithms via Edge Computing on a Campus Digital Twin Model. In *International Conference on Transportation and Development 2023* (pp. 400-409).
- Tutorial on building the campus digital twin model at C2SMARTER learning hub: https://c2smarter.engineering.nyu.edu/c2smart-students-learning-hub/
- Project webinar: https://www.youtube.com/watch?v=tYYnSCZ3UEE
- Poster presentations at TRB 2023 and ICTD 2023

Thank you for your attention!

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