A Novel and Immersive Virtual Reality Platform for Health & Safety Training of Construction Workers
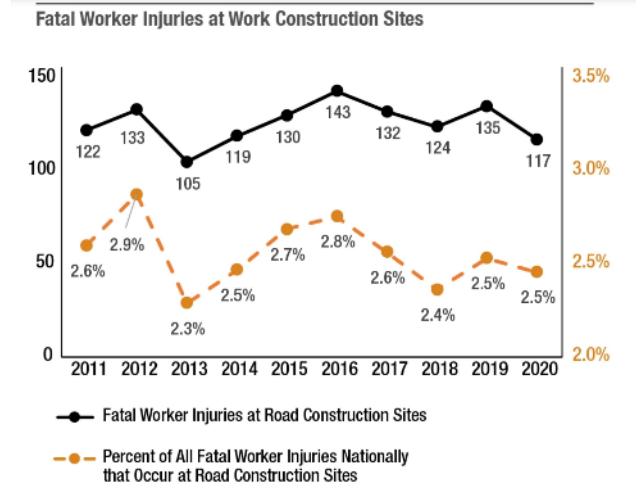
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Motivation

- Highway construction workers are often inexperienced, with 43% having a tenure of less than 1 year (BLS, 2021).

- The estimated cost of a fatality for a company is $1.42M (National Safety Council).

- Safety knowledge is a strong indicator of safety performance (Sawatcha et al., 1999).

- Ineffective delivery of training leads to negative attitudes on safety (Haslam et al., 2005).

- Despite recent advancements in technology, construction fatalities remains relatively stagnant (BLS, 2020).

Number of Years	Percentages
Less than 1 year	43%
1-2 years	27%
3-4 years	13%
5-7 years	9%
8-10 years	2%
11+ years	6%

Table 1: Tenure of Road Construction Workers in 2021

Fatal Worker Injuries at Work Construction Sites

Fatal Worker Injuries at Road Construction Sites:
2011: 122, 2012: 133, 2013: 105, 2014: 119, 2015: 130, 2016: 143, 2017: 132, 2018: 124, 2019: 135, 2020: 117

Percent of All Fatal Worker Injuries Nationally that Occur at Road Construction Sites:
2011: 2.6%, 2012: 2.9%, 2013: 2.3%, 2014: 2.5%, 2015: 2.7%, 2016: 2.8%, 2017: 2.6%, 2018: 2.4%, 2019: 2.5%, 2020: 2.5%

From Workzonesafety.org

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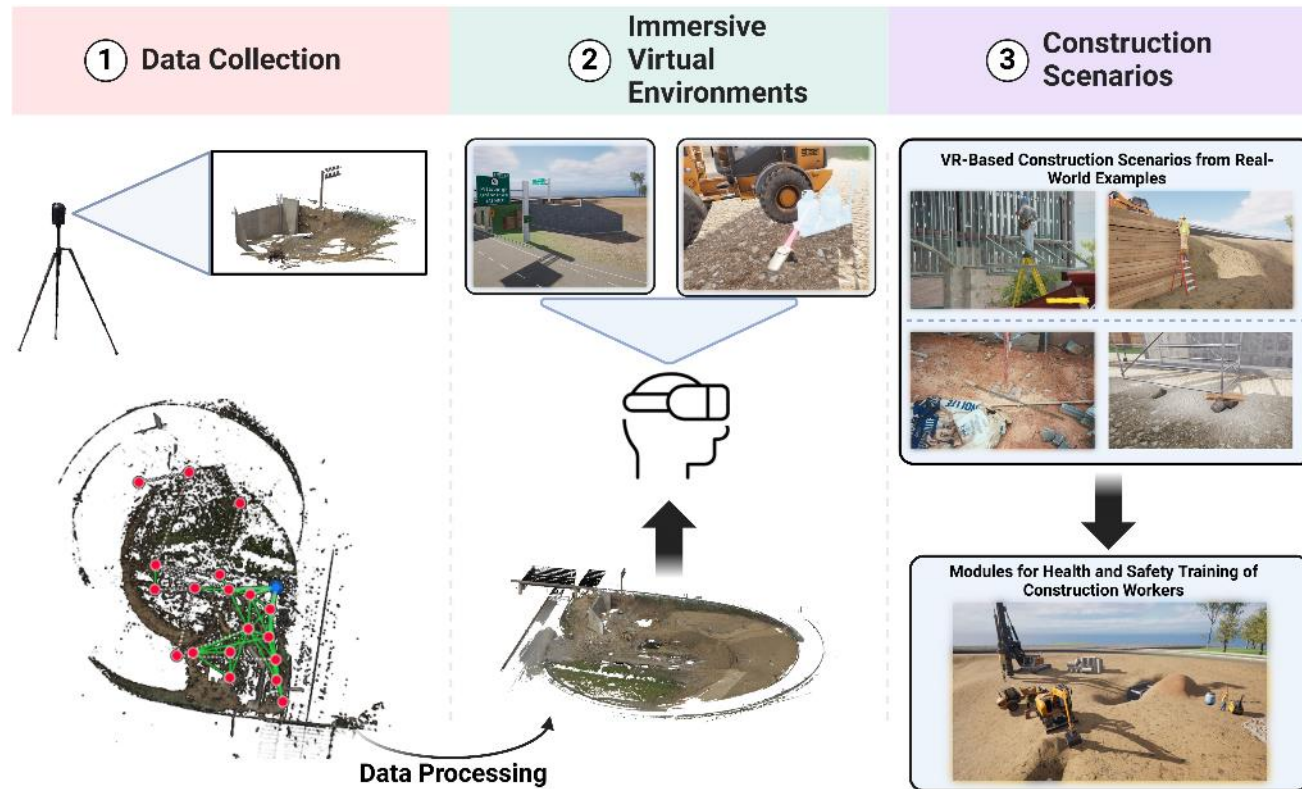
Motivation

Two primary issues concerning current health and safety training practices:

1. Overreliance of low-engagement methods of instruction.
2. Need for additional high quality educational material of dangerous activities on highway construction sites.

1. Data Collection

- A high-fidelity point cloud of an active highway construction site was built from 20 individual scans.
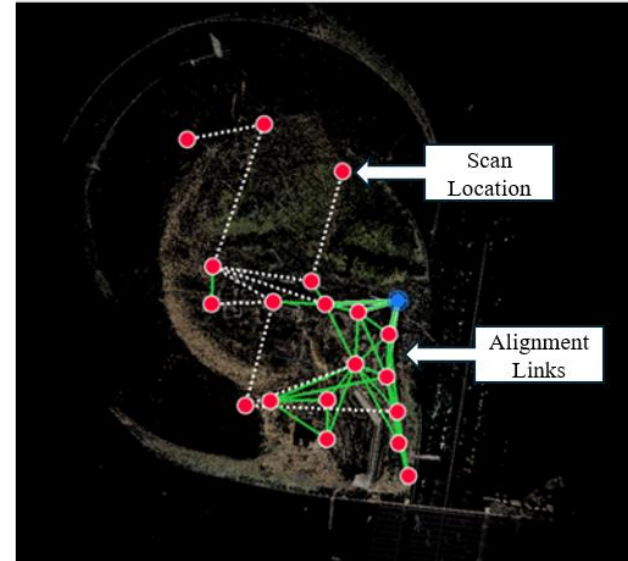

Laser Scanner

Leica BLK360 Terrestrial LiDAR Scanner

(A)

Site Map & Scan Locations

Scan Location

Alignment Links

(B)

Scan Previews
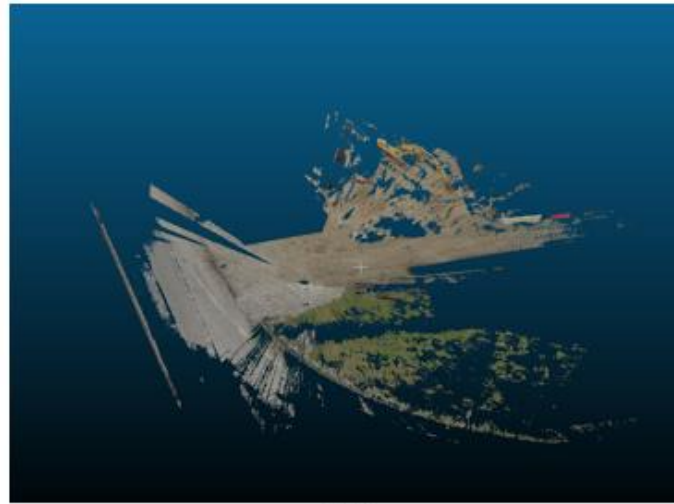
(C)

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1. Data Collection

- The scans went through a data cleaning process to remove instances of noise from moving vehicles, workers, reflections, etc.
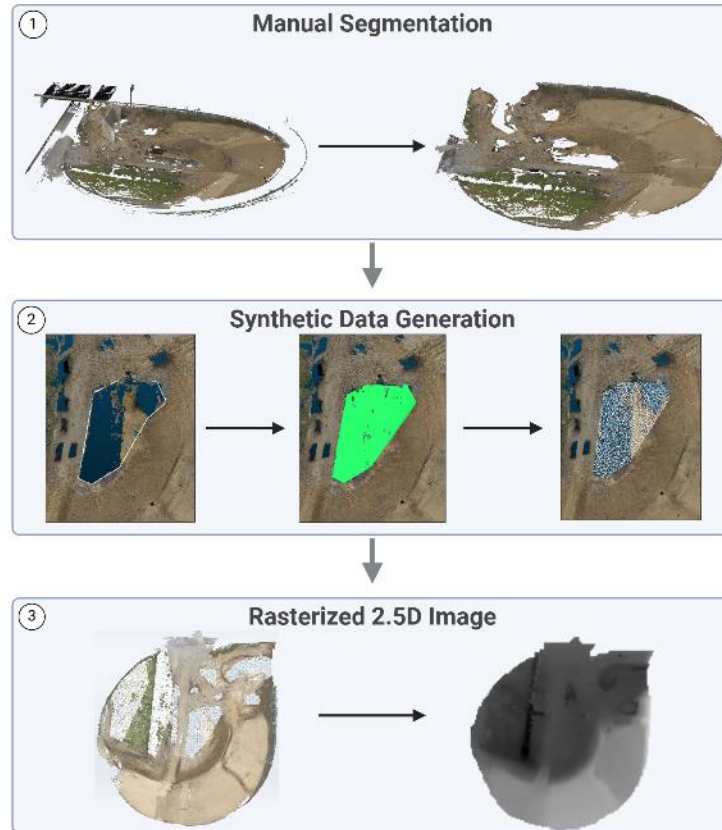

(A)

(B)

2. Immersive Virtual Environments

- The point cloud was segmented into a landscape such that the geometries could be reconstructed in Virtual Reality.

2. Immersive Virtual Environments

- Virtual assets for construction tools, materials, vehicles, and workers were collected from a variety of open-source repositories to build modules for health and safety training.
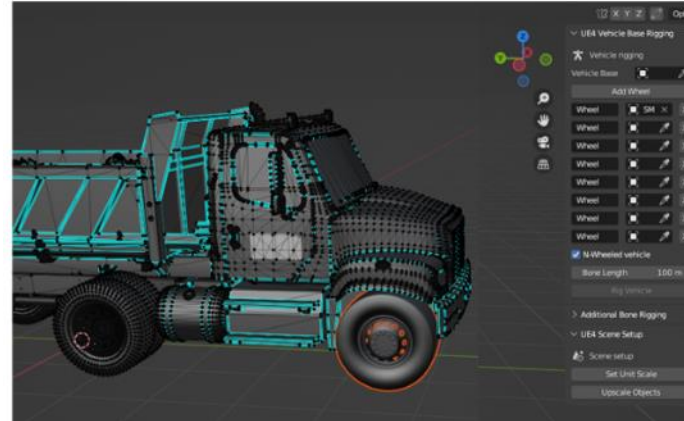
3. Construction Scenarios

- Construction scenarios refer to virtual reproduction of real health and safety training content and were developed from annotated examples from OSHA's construction image database.

| Category	Count
Falls	100
Machine Guarding	79
Electrical	40
Chemical Hazards	33
Excavations	31
Scaffolds	27
PPE	26
Construction	25
General Industry	20
Cranes Lifting Devices	19
Clip Art	17
Silica	16
Maritime	14
Housekeeping	14
Fire	10
Powerlines	10
Forklifts	8
Ergonomic	6
Compressed Air	5
Lockout	3
Bloodborne Pathogens	2
Asbestos	2
Radiation	1

3. Construction Scenarios

- A module contains a collection of construction scenarios, such that a user can navigate the environment and explore each one.
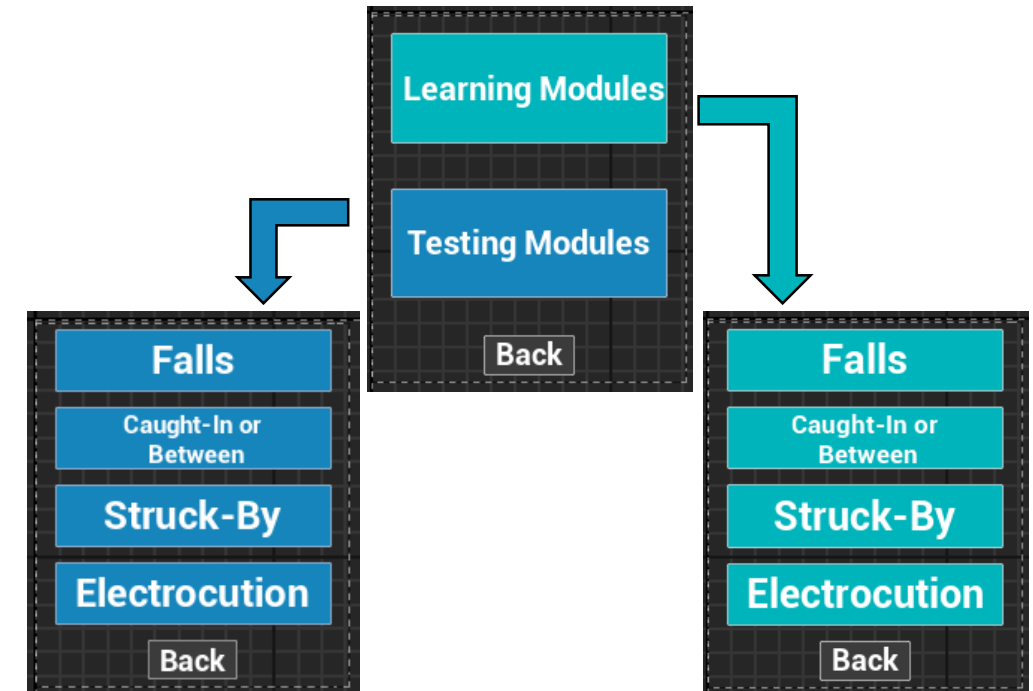
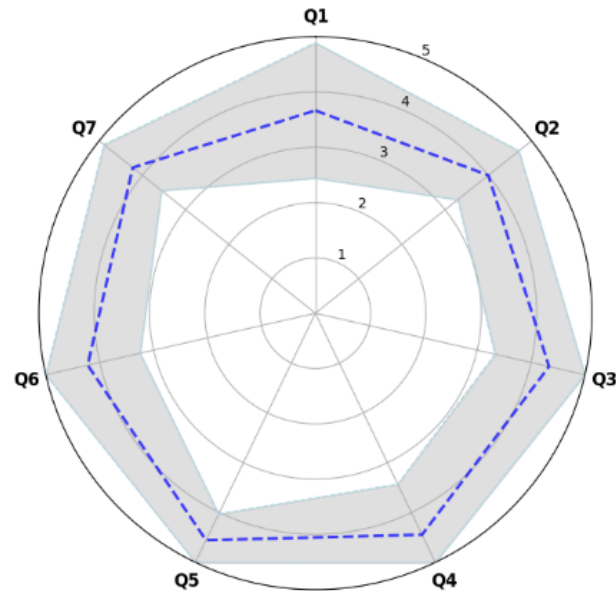**Preview – Learning Module**

Preview – Testing Module

Evaluation

- The methodology was an of expert- based evaluation. Firstly, the evaluators completed the tutorial to learn how the platform works. Secondly, they completed one module to evaluate the technical details.
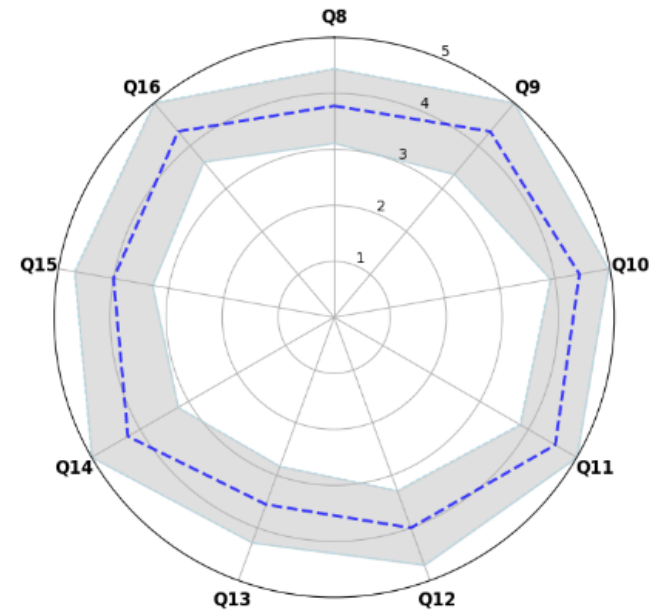

Average Response with Standard Deviation: UI/UX

Q1: Teleportation Satisfaction
Q2: Controller Ease of Use
Q3: 3D menus Ease of Use
Q4: Headset Comfort
Q5: Ease of Balancing
Q6: Feelings of Nausea
Q7: Fear of Heights

Average Response with Standard Deviation: Educational Content

Q8: Environment Realism
Q9: Vehicle-View Usefulness
Q10: Aerial-View Usefulness
Q11: Audio Voiceover Quality
Q12: Tutorial Effectiveness
Q13: Effectively Mirror Real-Life
Q14: Clarity of Educational Content
Q15: Environment Immersion
Q16: Platform Engagement

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User Manual

- The final report contains a user manual, which instructs users on how to set up the training space, connect headset and controllers, start and use the simulation.

Figure 48: Example of base stations anchoring the corners of the play area. Image from HTC Vive support page [21].
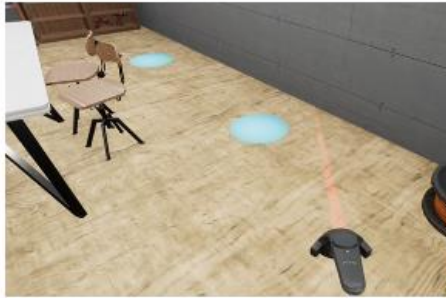

Figure 60: Teleportation hotspots from the view of the VR player.

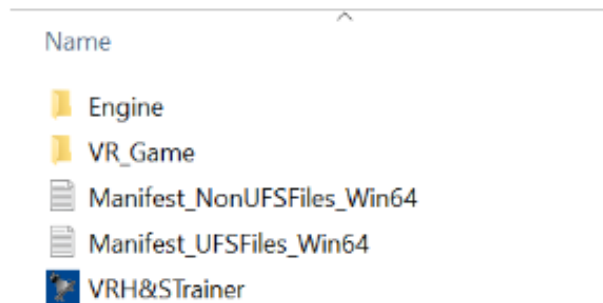Figure 61: Teleportation hotspot from the view of the VR player hovering with the VR controller.

Figure 52: Virtual reality platform launcher & engine files.

Figure 49: Base station setup for the DISCOVER lab at the University of Pittsburgh.

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Implementation Use Cases

- Virtual reality teaching tool for users to experience construction sites in first-person.
- Virtual reality testing tool for analysis of safety understanding in a complex context.
- Desktop based teaching/testing tool for group settings or those who cannot use VR.
- Tool for custom image generation of health and safety topics.
- Specialized training (vehicle maintenance, emergency response, etc.).
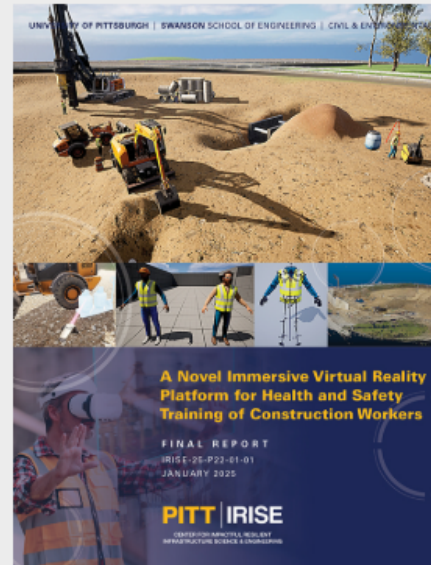- Active highway work zone training for inspectors.

Final Report

- Published Q1 2025

Abstract: Health and safety (H&S) training in the construction industry is paramount, given the sector's high injury and fatality rates. Traditional training tends to exhibit over-reliance on passive methods of instruction, bringing challenges associated with knowledge retention and engagement. This study leverages virtual reality (VR) to enhance H&S training through immersive virtual environments (IVE)s and serious gaming. Laser scanning data captured from an active highway construction site created a highly realistic IVE. This environment was then leveraged to build a virtual reality platform containing modules for construction safety training using Unreal Engine 5 (UE5). Users navigate these modules, interacting with objects to identify hazards and learn about safety guidelines. All platform construction scenarios are parametric, so context-specific training can be implemented. Evaluation of the module's realism, usability, and potential for enhancing traditional training programs was performed through beta testing on a user group composed of experts in both construction safety and computer science. The results of this research demonstrate the potential of VR in creating immersive and engaging training experiences, which could lead to improved safety performance outcomes in highway construction operations.

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FINAL REPORT

Thank you

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