

# Synthesizing Personalized Construction Safety Training Scenarios for VR Training (Supplementary Material)

Wanwan Li, Haikun Huang, Tomay Solomon, Behzad Esmaeili, and Lap-Fai Yu

George Mason University

## 1 SLIDES TRAINING

During this training session, the 15 users from the slides group were not trained from the synthesized training scenarios in the virtual scene, instead, they were taught about the construction safety fundamental knowledge through a short lecture presentation using slides. As shown in Figure 1 and Figure 2, the slides' content for lecture-based training covers the fundamental knowledge for construction safety training. Those details for the lecture include:

**Introduction.** As shown in Figure 1(a), slide 1 is a welcome slide. As shown in Figure 1(b), slide 2 covers the brief introduction of construction safety where the importance of hazard inspection is emphasized. It will be stressed on this slide that the ignorance of hazard inspection knowledge sometimes causes the death of workers and economic losses.

**Construction Signs.** As shown in Figure 1(c), slide 3 introduces the common hazardous events and the construction signs that need attention. Users are taught to be careful about the construction signs such as work ahead signs indicating that there might be hazards nearby. This will address the importance of safety inspection skills for workers who are put on construction sites to identify and avoid common types of hazards.

**Dynamic Hazards.** As shown in Figure 2(a), slide 4 introduces the dynamic hazards including struck-by hazards and any type of moving hazard that might be able to strike people. On this slide, the users are trained to understand that moving vehicles such as trucks, swinging excavators, and driving cranes are typical struck-by hazards and need critical attention when they appear nearby. Especially, it is emphasized that falling objects that might strike people are struck-by hazards instead of fall hazards.

**Fall Hazards.** As shown in Figure 2(b), slide 5 introduces the fall hazards that could result in the falling of people, causing injuries or death. It is repeatedly emphasized that falling objects do not belong to fall hazards. Instead, they belong to struck-by hazards. Fall hazards are mostly caused by missing protection or improper rail guards on high opening areas and un-tied workers stepping on the top cap of ladders.

**Caught-In Hazards.** As shown in Figure 2(c), slide 6 introduces the caught-in hazards caused by keeping materials and equipment near the edge of the cave, which might collapse the cave and bury the people inside the cave. They are also called cave-in hazards. As another example, it is emphasized that caught-in hazards happen when people are crushed from two sides and are constrained in a close space that it is difficult to escape. When considering the caught-in directions, they need to consider both left-to-right and up-to-down directions.

## Construction Safety Training Fundamentals

Presenter: XXXX



(a) Slide 1

### What is Construction Safety Inspection?

Pay attention to the hazards!  
It is important for the workers' life!



(b) Slide 2

### What should you do when you are put on a construction site?

Avoid the hazards that are moving towards you.  
Classify the hazards and point them out.



(c) Slide 3

Fig. 1: Lecture-based training slides (Part I).

**Electrical Hazards.** As shown in Figure 2(d), slide 7 introduces the electrical hazards caused by electrocution from the nearby electrical components, such as the light pole, power lines, and the lighting fixtures that are suspended by electric cords. Especially, users are taught to be careful about any objects in front of them by looking above as some of the electrical components are hanging high.

## What are the hazards?

Moving hazards!



(a) Slide 4

## What are the hazards?

Fall hazards!



(b) Slide 5

## What are the hazards?

Cave-in hazards!



(c) Slide 6

## What are the hazards?

Electrocution hazards!



(d) Slide 7

Fig. 2: Lecture-based training slides (Part II).

## 2 EVALUATION TASKS

The pre- and post-evaluation shared the same evaluation tasks synthesized on the third construction site and optimized with the parameter settings termed *All Types of Hazard* as specified in the main paper.

As shown in Figure 3, there are 12 hazard inspection tasks in total, among which five are fall hazards inspection tasks, four are electrical hazards inspection tasks, and three are caught-in hazards inspection tasks respectively. In order to avoid the influences from the dynamic hazards that can distract users' attention from inspecting nearby hazards, the dynamic hazards are disabled during the pre- and post-evaluation.

## 3 NUMBER OF MISTAKES

Figure 4 plots the number of mistakes users made on each type of hazard during the pre- and post-evaluation. Darker colors represent the number of mistakes made in the pre-evaluation, while the lighter colors

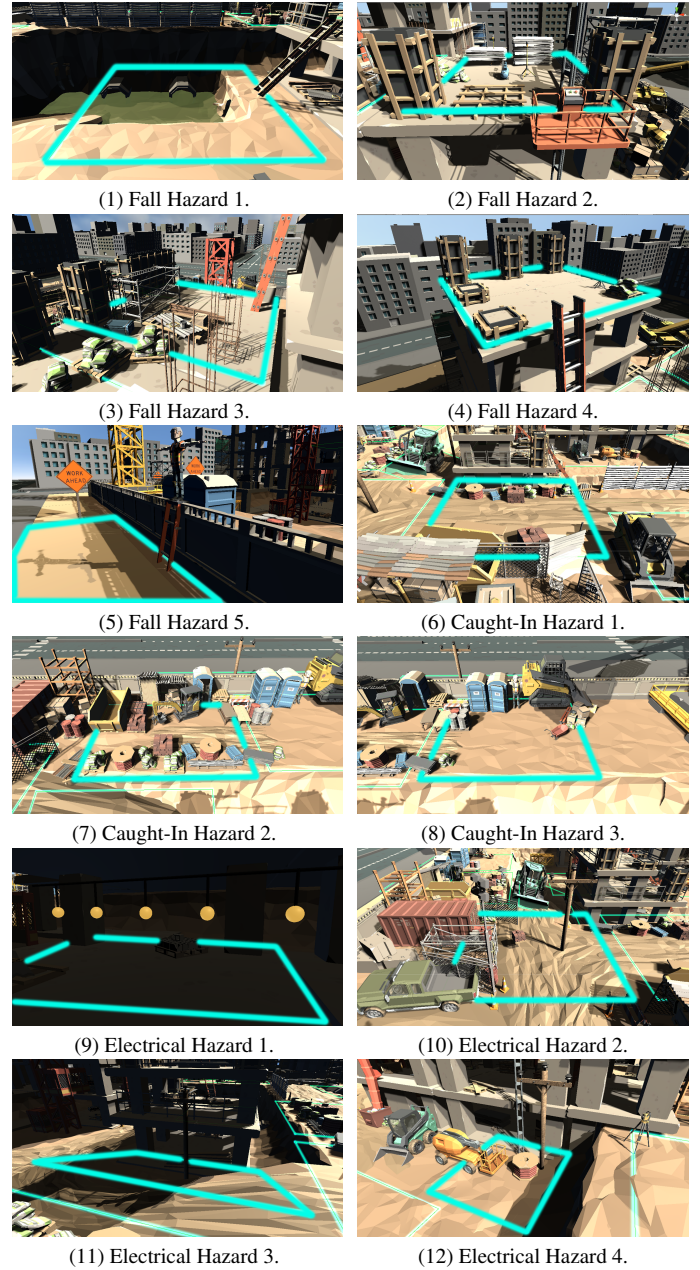


Fig. 3: The 12 evaluation tasks, including 5 fall hazards, 3 caught-in hazards, and 4 electrical hazards. Blue boundaries highlight the hazardous object in that region. During the pre- and post-evaluations, users from both three groups are suggested to pay attention to the potential hazards in their proximity (indicated by a blue boundary).

represent those in the post-evaluation. Different types of hazards are represented with different colors: blue denotes the fall hazards, orange denotes the caught-in/between hazards, and green denotes the electrical hazards. For each type of hazard, we measure the improvement of users' performance after training by subtracting the number of mistakes made in post-evaluation from the number of mistakes made in pre-evaluation.

## 4 EVALUATION RESPONSES

Here we demonstrate the users' answers collected from the evaluations in the tables. The column names refer to the correct answers for the hazard inspection tasks. The rows show the answers from each user. Table 1 lists the answers for pre-evaluation collected from the users in the slides group. Table 2 lists the answers for pre-evaluation collected from the users in the FE-VR group. Table 3 lists the answers for pre-

User ID	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
1	None	Fall	Fall	Fall	None	None	Fall	NoAnswer	CaughtIn	None	Electrical	NoAnswer
2	CaughtIn	CaughtIn	Fall	CaughtIn	Fall	CaughtIn	CaughtIn	Fall	Electrical	CaughtIn	Electrical	Electrical
3	NoAnswer	Fall	Fall	Fall	Fall	CaughtIn	Fall	None	Fall	Fall	Fall	Electrical
4	CaughtIn	NoAnswer	Fall	Fall	None	Fall	Fall	CaughtIn	CaughtIn	Fall	Fall	Electrical
5	Fall	Fall	Fall	Fall	None	None	None	None	None	Fall	Fall	Electrical
6	Fall	Electrical	NoAnswer	Fall	Fall	Electrical	Fall	Electrical	Fall	CaughtIn	CaughtIn	Electrical
7	CaughtIn	None	None	None	Fall	CaughtIn	CaughtIn	Fall	CaughtIn	CaughtIn	Electrical	Electrical
8	Fall	CaughtIn	CaughtIn	Fall	None	Fall	Fall	Fall	Fall	Fall	CaughtIn	Electrical
9	None	Fall	Fall	Fall	Fall	None	None	CaughtIn	Fall	Fall	Fall	None
10	Fall	Fall	CaughtIn	Fall	Fall	NoAnswer	Electrical	CaughtIn	CaughtIn	Fall	NoAnswer	Electrical
11	CaughtIn	Fall	Fall	Fall	CaughtIn	None	Fall	None	CaughtIn	NoAnswer	Fall	None
12	None	Fall	Fall	Fall	Fall	Fall	Fall	Fall	Electrical	Electrical	None	None
13	Fall	CaughtIn	Fall	Fall	CaughtIn	Fall	Fall	NoAnswer	CaughtIn	Fall	CaughtIn	Electrical
14	NoAnswer	Fall	Fall	Electrical	None	Fall	CaughtIn	NoAnswer	NoAnswer	Fall	NoAnswer	NoAnswer
15	NoAnswer	None	Fall	Fall	None	CaughtIn	None	NoAnswer	CaughtIn	None	CaughtIn	Electrical

Table 1: Answers for pre-evaluation (Slides Group).

User ID	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
1	CaughtIn	Electrical	Fall	None	Electrical	Fall	Fall	Fall	CaughtIn	Electrical	CaughtIn	Electrical
2	CaughtIn	Fall	Fall	Fall	CaughtIn	Fall	Fall	CaughtIn	CaughtIn	Electrical	CaughtIn	Electrical
3	None	Fall	Fall	Fall	NoAnswer	CaughtIn	Fall	NoAnswer	CaughtIn	Fall	CaughtIn	CaughtIn
4	None	Fall	Fall	Fall	CaughtIn	None	Fall	CaughtIn	NoAnswer	Electrical	CaughtIn	Electrical
5	Fall	Fall	CaughtIn	Fall	CaughtIn	CaughtIn	Fall	NoAnswer	CaughtIn	None	CaughtIn	Electrical
6	Fall	Fall	Fall	Fall	Fall	CaughtIn	Fall	Fall	CaughtIn	Electrical	CaughtIn	Electrical
7	CaughtIn	Fall	CaughtIn	Fall	Fall	CaughtIn	None	NoAnswer	CaughtIn	Electrical	Fall	Electrical
8	Fall	Fall	CaughtIn	None	None	Fall	CaughtIn	CaughtIn	Electrical	CaughtIn	CaughtIn	Electrical
9	None	Fall	Fall	Fall	Fall	CaughtIn	Fall	Electrical	CaughtIn	None	CaughtIn	Electrical
10	None	Electrical	Electrical	None	None	CaughtIn	Fall	None	None	Fall	None	Electrical
11	NoAnswer	CaughtIn	Electrical	CaughtIn	CaughtIn	CaughtIn	Fall	NoAnswer	NoAnswer	Fall	Electrical	None
12	NoAnswer	Fall	Electrical	Fall	CaughtIn	Electrical	Fall	NoAnswer	CaughtIn	Electrical	CaughtIn	NoAnswer
13	Fall	Fall	Fall	Fall	None	Fall	Fall	None	CaughtIn	Fall	CaughtIn	Electrical
14	None	Fall	None	Fall	NoAnswer	CaughtIn	Fall	NoAnswer	CaughtIn	Electrical	Fall	CaughtIn
15	None	NoAnswer	Electrical	CaughtIn	NoAnswer	CaughtIn	CaughtIn	NoAnswer	NoAnswer	Electrical	NoAnswer	Fall

Table 2: Answers for pre-evaluation (FE-VR Group).

User ID	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
1	CaughtIn	Fall	Fall	Fall	Fall	Fall	Fall	NoAnswer	CaughtIn	Electrical	CaughtIn	None
2	NoAnswer	Fall	Fall	Fall	None	NoAnswer	Fall	None	Electrical	CaughtIn	CaughtIn	None
3	None	CaughtIn	Fall	CaughtIn	Fall	CaughtIn	CaughtIn	Fall	CaughtIn	Fall	Fall	Electrical
4	None	None	Fall	Fall	Fall	Fall	Fall	None	None	NoAnswer	Fall	NoAnswer
5	Fall	Fall	Fall	Fall	None	None	Fall	Fall	Electrical	Fall	Electrical	Electrical
6	Fall	Fall	Fall	Fall	Fall	None	CaughtIn	Fall	CaughtIn	Fall	Fall	None
7	CaughtIn	Fall	CaughtIn	None	Fall	NoAnswer	CaughtIn	Electrical	None	CaughtIn	CaughtIn	Electrical
8	None	Fall	CaughtIn	Fall	Fall	Electrical	CaughtIn	CaughtIn	Electrical	CaughtIn	CaughtIn	CaughtIn
9	None	Fall	Fall	Fall	Fall	CaughtIn	None	None	Electrical	Fall	Fall	None
10	CaughtIn	CaughtIn	CaughtIn	CaughtIn	Electrical	CaughtIn	CaughtIn	Fall	Electrical	Fall	None	Electrical
11	CaughtIn	Fall	Fall	Fall	Fall	CaughtIn	Fall	Fall	Electrical	Fall	CaughtIn	Electrical
12	Fall	Fall	Fall	Fall	Fall	Electrical	CaughtIn	None	CaughtIn	None	Fall	CaughtIn
13	None	Fall	Fall	Fall	NoAnswer	CaughtIn	Fall	NoAnswer	CaughtIn	None	None	Electrical
14	NoAnswer	Fall	Fall	Fall	Fall	CaughtIn	Fall	NoAnswer	Fall	Electrical	CaughtIn	Electrical
15	Fall	Fall	CaughtIn	Fall	NoAnswer	CaughtIn	Fall	NoAnswer	NoAnswer	Fall	Fall	NoAnswer

Table 3: Answers for pre-evaluation (PG-VR Group).

evaluation collected from the users in the PG-VR group. Table 4 lists the answers for post-evaluation collected from the users in the slides group. Table 5 lists the answers for post-evaluation collected from the users in the FE-VR group. Table 6 lists the answers for post-evaluation collected from the users in the PG-VR group. The mistakes are counted

as the number of mismatches between the users' answers listed in the rows and the correct answers listed in the columns. As we can see from Table 6, users from the PG-VR group have the highest number of correct answers in the post-evaluation.

User ID	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
1	Fall	Fall	Fall	Fall	NoAnswer	None	Fall	NoAnswer	None	Electrical	NoAnswer	CaughtIn
2	CaughtIn	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	None	Electrical	Fall	Electrical	Electrical
3	CaughtIn	NoAnswer	Fall	Fall	Fall	CaughtIn	CaughtIn	Fall	Fall	Fall	Fall	NoAnswer
4	None	Fall	Fall	Fall	None	None	None	None	None	Electrical	Electrical	Electrical
5	CaughtIn	None	Fall	Fall	None	None	None	None	Electrical	Electrical	Electrical	None
6	CaughtIn	Fall	Fall	Fall	None	None	None	CaughtIn	Electrical	Electrical	Electrical	None
7	None	Fall	Fall	None	None	Electrical	CaughtIn	None	Electrical	CaughtIn	CaughtIn	CaughtIn
8	None	Fall	Fall	Fall	None	Fall	Fall	Fall	Electrical	CaughtIn	None	Electrical
9	Fall	Fall	Fall	Fall	Fall	None	Fall	CaughtIn	Electrical	None	Electrical	Electrical
10	Fall	Fall	None	CaughtIn	None	Electrical	None	Electrical	None	Fall	Electrical	Electrical
11	None	Fall	Fall	Fall	None	None	None	None	CaughtIn	Fall	None	None
12	CaughtIn	Fall	Fall	Fall	None	None	None	None	Electrical	Electrical	None	CaughtIn
13	CaughtIn	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	NoAnswer	CaughtIn	None	CaughtIn	Electrical
14	None	Fall	Fall	Fall	NoAnswer	CaughtIn	CaughtIn	NoAnswer	CaughtIn	None	CaughtIn	Electrical
15	CaughtIn	Fall	Fall	Fall	Fall	Fall	CaughtIn	NoAnswer	CaughtIn	Electrical	Electrical	Electrical

Table 4: Answers for post-evaluation (Slides Group).

User ID	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
1	Fall	Fall	Fall	Fall	None	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
2	None	Fall	Fall	Fall	CaughtIn	CaughtIn	Fall	Fall	CaughtIn	Electrical	Electrical	Electrical
3	Fall	Fall	Fall	Fall	Electrical	Fall	CaughtIn	CaughtIn	NoAnswer	Electrical	CaughtIn	CaughtIn
4	None	Fall	Fall	Fall	Electrical	CaughtIn	Fall	CaughtIn	NoAnswer	Electrical	Electrical	Electrical
5	None	Fall	CaughtIn	Fall	CaughtIn	CaughtIn	CaughtIn	NoAnswer	NoAnswer	Electrical	None	Electrical
6	None	Fall	Fall	Fall	None	CaughtIn	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical
7	NoAnswer	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	NoAnswer	CaughtIn	Electrical	Electrical	CaughtIn
8	Electrical	Fall	Fall	Fall	None	Fall	Fall	CaughtIn	CaughtIn	Electrical	None	Electrical
9	None	Fall	Fall	Fall	Fall	Fall	None	CaughtIn	CaughtIn	None	None	Electrical
10	CaughtIn	Electrical	Electrical	None	None	Fall	CaughtIn	Fall	None	Fall	Electrical	Electrical
11	CaughtIn	Fall	None	Fall	None	None	CaughtIn	NoAnswer	Electrical	Electrical	Electrical	CaughtIn
12	Electrical	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	NoAnswer	CaughtIn	Electrical	Electrical	Electrical
13	Electrical	Fall	Fall	Fall	CaughtIn	CaughtIn	Fall	None	CaughtIn	None	CaughtIn	Electrical
14	None	Fall	Fall	Fall	None	None	CaughtIn	NoAnswer	CaughtIn	Electrical	Electrical	CaughtIn
15	Fall	Fall	Fall	Fall	Fall	Electrical	Fall	NoAnswer	CaughtIn	CaughtIn	CaughtIn	Electrical

Table 5: Answers for post-evaluation (FE-VR Group).

User ID	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
1	Fall	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical
2	Fall	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
3	Fall	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
4	Fall	CaughtIn	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
5	None	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical
6	Fall	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
7	CaughtIn	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	Electrical	CaughtIn	Electrical	Electrical
8	Fall	Fall	CaughtIn	CaughtIn	Fall	CaughtIn	CaughtIn	CaughtIn	CaughtIn	None	CaughtIn	Electrical
9	Fall	Fall	Fall	Fall	None	Fall	Fall	CaughtIn	None	Fall	Fall	Electrical
10	Fall	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
11	None	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical	Electrical
12	None	Fall	Fall	Fall	Fall	None	CaughtIn	CaughtIn	Fall	Fall	Electrical	Electrical
13	None	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	CaughtIn	CaughtIn	Electrical	Electrical	Electrical
14	CaughtIn	Fall	Fall	Fall	NoAnswer	CaughtIn	CaughtIn	NoAnswer	CaughtIn	Electrical	Electrical	Electrical
15	Fall	Fall	Fall	Fall	CaughtIn	CaughtIn	CaughtIn	NoAnswer	CaughtIn	Electrical	Electrical	Electrical

Table 6: Answers for post-evaluation (PG-VR Group).

	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
Avg Time(sec)	22.2	27.8	22.7	26.4	33.9	43.4	32.4	39.2	35.4	32.6	29.3	37.5

Table 7: Estimated average time for pilot users' finish the 12 evaluations tasks.

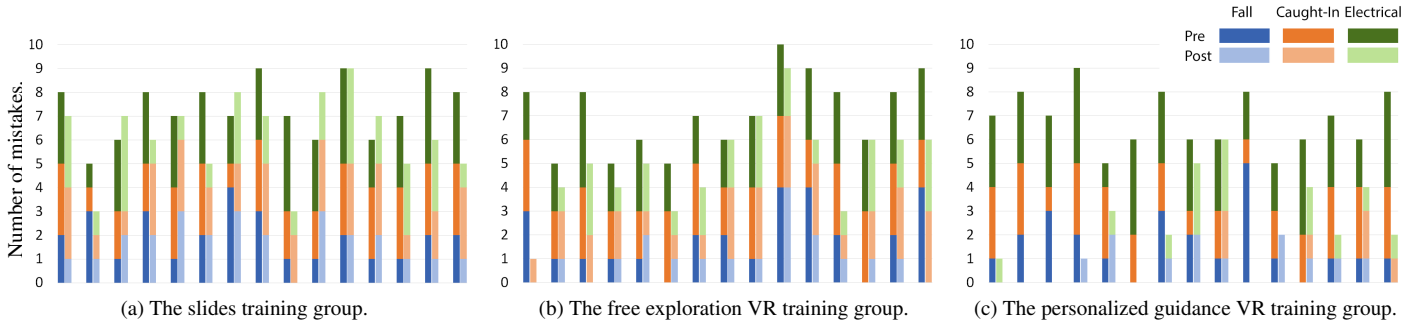


Fig. 4: The number of mistakes users made on each type of hazard during the pre- and post-evaluation are plotted. Each pair of columns refer to a user's results. Darker colors represent the number of mistakes made in pre-evaluation while lighter colors represent those in post-evaluation. Blue, orange, and green colors denote the errors made on inspecting fall, caught-in/between, and electrical hazards, respectively.

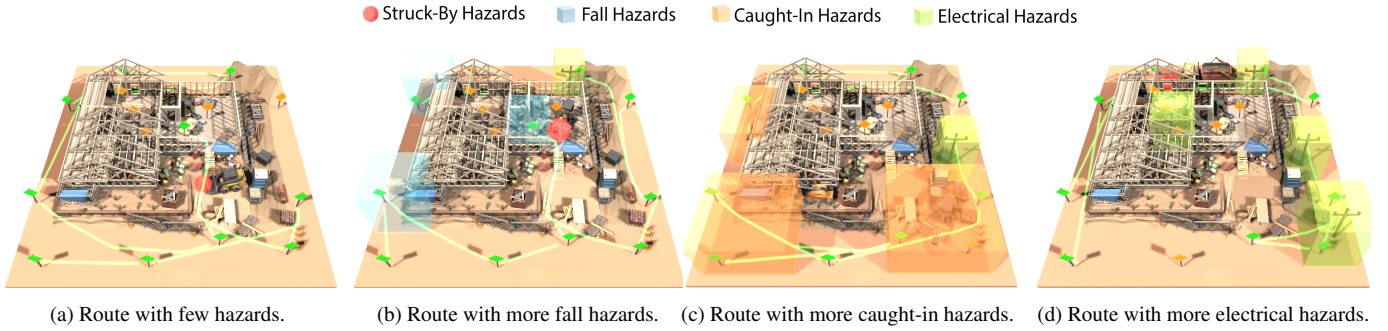


Fig. 5: Personalized training scenarios synthesized on construction site 1. Yellow curves are the navigation routes. The regions with fall hazards are highlighted in blue, caught-in hazards are in yellow, electrical hazards are in green, and the struck-by hazards are in red. Four different training scenarios are shown. (a) A route passing through few hazardous regions; this scenario is easy for the beginners to start with and is used for the pre-training. (b) A route passing through more regions with fall hazards. (c) A route passing through more regions with caught-in hazards. (d) A route passing through more regions with electrical hazards.

## 5 ESTIMATED TRAINING TIME

In order to estimate the training time to finish inspecting each type of hazard  $H_i$ , we set up a small-scale preliminary pilot study including 10 users. Noted that these 10 pilot users are not included in the large-scale user study experiments described in the main paper. During the pilot study, we set up a timer in the evaluation program and count the average time taken by the users for identifying each hazard that appears in the scene. As shown in Table 7, the average time for pilot users to finish those 12 evaluation tasks is listed. According to this result, we have the average estimated time for inspecting fall, caught-in/between, and electrical hazards are 26.6, 38.3, and 33.7 seconds respectively. Therefore,  $t(H_i)$  returns 26.6, 38.3, or 33.7 according to which type of hazard  $H_i$  belongs to.

## 6 USERS' FEEDBACK DETAILS

After having the users completed the post-evaluation tasks, we collected the users' feedback through a questionnaire that offered different questions to evaluate our training programs. Here are some selected answers from the users with respect to the positive and negative feedback towards our training and evaluation programs.

**Positive Feedback.** Examples of positive feedback: (1) The graphics were very realistic and engaging. After the training, it was easier to complete the post-evaluation. (2) I really liked the training, it's fun and interesting. (3) The simulation is very good and helpful. (4) One feature I liked in the training program was the setting and the way the objects were placed because it resembles an actual construction site which is very realistic. (5) As a first-time VR user, this training was very realistic and entertaining for me. Not the ones (games) where people might sleep out of boredom. (6) The movement (navigation) of the player as well as the animations of the trucks is realistic. (7)

The caught-in hazards look brilliant. (8) The selection of a hazard with a pointer (lightsaber) is innovative. (9) I like the interactions through controllers, which are engaging. (10) I like the placement of hazards, especially, there are some hazards coming from above. (11) The fall hazard was informative. (12) Multiple-choice questions are the parts I like. (13) I like the navigation and control. (14) I love the path planning in VR, which mimics reality.

**Negative Feedback.** Examples of negative feedback: (1) I think some cases consist of more than one hazard. So sometimes I feel a little confused. (2) More scenarios would be great especially if there were more populations in the site. If there were more workers, there could have been more hazardous situations similar to the real world ones. (3) I didn't like the unclear pathways. Sometimes, obstructions were breaking my concentration. (4) Questions need to match the zones precisely. Sometimes I was unsure about which problem is corresponding to which zones. (5) It may not be comfortable for some older people to play this 3D game. (6) The graphics are good but they can be even more realistic. (7) When I speed up, I feel dizzy. (8) I feel a little dizzy when I go upstairs in the program. (9) I feel terrible when I run into VR objects, especially when I am struck by moving hazards.

## 7 SYNTHESIZED RESULTS (CONSTRUCTION SITE 1)

As shown in Section 4.2 of the main paper, different parameters are applied for generating different training scenarios on construction site 2. Similarly, on construction site 1, we synthesize personalized training scenarios that emphasize users' skills for inspecting each type of hazard through the parameter settings such as *A Few Hazards*, *More Fall Hazards*, *More Caught-in/between Hazards*, and *More Electrical Hazards*, respectively. These settings are same as those defined in the main paper. The synthesized training scenarios are shown in Figure 5.