Classroom Simulation for Working Safely in Storm Drain Systems

Zhen Shuai, Ohio State University

Zhen Shuai has Bachelor’s degrees in Civil Engineering and Theoretical Mathematics and Master’s degrees in Civil Engineering and Applied Statistics at Ohio State University. During her time as a Master’s student, she worked as a Graduate Teaching Assistant with the Department of Civil Engineering teaching construction safety for both undergraduates and graduates students.

Dr. Michael Parke, Ohio State University

Dr. Parke has over twenty years experience in satellite based earth science research. He has been teaching first year engineering for the past nineteen years, with emphasis on computer aided design, computer programming, and project design and documentation.

Prof. Fabian Hadipriono Tan P.E., Ohio State University

Fabian Hadipriono Tan has worked in the areas of construction of infrastructures and buildings, failure assessment of buildings and bridges, construction accident investigations, forensic engineering, ancient buildings, ancient bridges, and the ancient history of science and engineering for over 40 years. The tools he uses include fault tree analysis, fuzzy logic, artificial intelligence, and virtual reality.
Classroom Simulation for Working Safely in Storm Drain Systems

Abstract

A confined space is a space with limited entry and that is not designed for continuous occupancy. Working in confined spaces is dangerous because employers and workers do not always understand how they are in danger when they enter these spaces. Inexperienced workers have no sense of the inherent danger of entering and working in confined spaces, and experienced workers, even those with years of experience, may evaluate conditions incorrectly, which could lead to risks. Death comes silently and often without the slightest warning, so entering and exiting confined spaces is restricted due to its danger. An advanced three-dimensional (3D) visual simulation was designed to simulate real scenes of entering and working in storm drainage systems, which are considered to be confined spaces, and step-by-step instructions are provided. Unlike the traditional training related to entering confined spaces, which is paper-based training in compliance with the Occupational Safety and Health Administration’s (OSHA’s) standard 1910.146, the newly-developed, visual program allows learners to get involved safely with the actual process of entering and working in storm drainage systems through a 3D simulation model. The main purposes of the model are to educate learners by helping them (1) understand the dangers of entering and working in storm drainage systems and any associated risks, (2) evaluate hazardous conditions, and (3) make safe and accurate decisions regarding entering and working in storm drainage systems by providing the most timely and useful recommendations to workers based on the conditions they will encounter. The learners use visualized simulation to self-train in compliance with OSHA standards. Switching to the visualized simulation from the conventional method will help learners gain a better understanding of storm drainage systems and help to prevent possible adverse incidents due to the lack of knowledge of the dangers and the risks.
Introduction

It is dangerous to enter and to work in any confined space. A storm drainage system is considered a confined space due to its restricted entrances and exits. For inexperienced students, experienced workers, or anyone who wants to enter or work in a storm drainage system, one careless action can lead to risks. Exposing students or trainees to the actual scenes of entering and working in a storm drainage system via simulation models in training may help them learn step-by-step and gain a better understanding of the procedures. Therefore, the authors have developed a 3D simulation model of the process of entering and working in a storm drainage system to ensure that end users (1) understand the dangers of entering and working in storm drainage systems, (2) know how to evaluate hazard conditions, (3) make safe and accurate decisions inside the system, and (4) receive the most timely and useful recommendations or suggestions concerning their decisions. Learners will use the visualized simulation for self-training in compliance with the Occupational Safety and Health Administration’s (OSHA’s) standards. Switching from the traditional static training method to the new, dynamic, 3D simulation model will help future end users become trained and have a better understanding of storm drainage systems to prevent possible incidents due to a lack of knowledge.

Background

1. General Information – Confined Spaces

By definition (OSHA, CFR 1926.1202) [1], a confined space is described as a space that is “large enough and so configured that an employee can bodily enter it; has limited or restricted means for entry and exit; and is not designed for continuous employee occupancy.” Generally, it is not intended for anyone to work in a confined space on a regular basis; however, confined spaces are necessary for workers to perform various tasks, such as construction, maintenance, and the repairs of tanks, vaults, storage bins, and manholes, among many others. The Occupational Safety and Health Administration (OSHA) requires a permit to enter some confined spaces, such as 1) those that have hazardous atmospheres, 2) those that have the potential to engulf, trap, or asphyxiate workers, and 3) those that contain other recognized hazards that threaten workers’ health or safety. Entering such a space can be risky for workers unless they have received adequate training. There are two major types of hazards of a confined space, i.e., a hazardous atmosphere and physical hazards.

OSHA (CFR 1926.1202) considers an atmosphere to be hazardous if it could expose workers to the risk of injury, illness, the inability to rescue themselves, or potentially cause fatalities due to any combination of (1) flammable gases, vapors, or mists that exceed 10% of its lower flammable limit (LFL); (2) concentrations of airborne combustible dust that reach or exceed the LFL, or, alternatively, concentrations of combustible dust that reduce visibility to 5 feet or less; (3) an atmospheric oxygen concentration below 19.5% or above 23.5%; (4) an atmospheric concentration of any substance exceeding certain permissible exposure limits; and (5) any other atmospheric conditions that may cause immediate danger to workers.
Lack of oxygen is a major cause of death among people who work in confined spaces. Since there is no distinctive smell or color indicating an abnormal concentration of oxygen, an air monitor must be used to determine the oxygen concentration before anyone enters the space. An oxygen-enriched confined space is also dangerous because the enrichment increases the risk of material burning or an explosion inside the space. Substances will become immediately dangerous to life and health (IDLH) when their concentrations reach certain limits. If substances reach their permissible exposure limit concentrations, workers may become unconscious, and their lack of consciousness obviously will impair their escape from the confined space.

Confined spaces also can cause physical damage, which, in turn, may lead to serious illnesses, loss of the functioning of a body part, or reductions in the efficiency of the body. Such confined spaces should be inspected by competent individuals because physical hazards may occur as any combination of (1) the flow of loose materials that could trap, bury, or crush workers; (2) a fall from a height, so workers should use guardrails or harnesses and lanyards; (3) the improper use of equipment or machinery, e.g., workers should always shut the power off and lock and secure any equipment if it is not in use to prevent parts of equipment falling and electrical shocks; (4) toxic substances and combustion products, which can enter through pipes and threaten the safety of workers; and (5) any other unmentioned physical conditions that make it unsafe for workers to enter and perform assigned tasks in a confined space.

2. General Information – Storm Drains

A storm drainage or storm sewer is considered to be a confined space based on the information in previous section. Storm drainage systems, which are located along curbs and driveways, are designed to help solve flooding problems by using pipes or open ditches to carry excess rain runoff and groundwater to nearby streams, rivers, lakes, or other natural bodies of water without any treatment. Thus, any chemicals or hazardous wastes that enter the storm drainage system will damage a body of water and the environment. Obviously, storm drains serve a different purpose from sewer systems, which convey wastewater to wastewater treatment plants.

A storm drainage system consists of three parts, i.e., the inlet, piping, and the outlet. There are two main types of inlets, i.e., side inlets, which are the most common and are next to the curb, and grated inlets, which are located on the surface of the road with gratings to prevent people or any objects from falling into the inlets. Both types of inlets capture flow, and, although they can block leaves, sediment, and other materials that may clog the system, they cannot stop small objects from falling into the inlets. Piping provides a transformative function in that it carries storm water from groups of inlets on the surface to outlets that are located near a natural body of water. Due to different design limits, pipes are available in various cross-sectional shapes and sizes. Pipes can be made from many different materials, such as concrete, bricks, steel, and fiber-reinforced plastic, with the latter being the most common type of drainage pipe. Most of the time, outlets are large exits that discharge storm water into a stream, river, lake, sea, or other body of water.
Since storm drainage systems transfer surface groundwater to a nearby body of water without any treatment, anything that passes through the storm drainage system will go directly into the natural body of water. During heavy rains or stormy seasons, water and debris from storm drains often run down the road and carry trash and hazardous materials to the storm drainage system. Also, the storm drainage system can easily become clogged if there are large amounts of trash and leaves falling into the system. Trash and leaves can block storm drains and contribute to urban flooding, which causes sewer backups and affects residential properties. Also, the storm water may become contaminated when it runs through a polluted area and carry hazardous chemicals to the body of water. Untreated polluted stormwater poses significant threats to the body of water, the environment, and public health. However, the case of contaminated runoff is not considered in this paper.

To prevent the issues associated with flooding, it is recommended that regular checks and clean-ups of the system be conducted. By removing trash and leaves from storm drains, the storm drainage system provides a smooth path for the runoff to follow from the surface of the ground to the nearby body of water. However, an important point to emphasize is that entering a storm drainage system can be dangerous, even for workers who are permitted to check, clean, and otherwise maintain these systems.

Since storm drainage systems are mostly people-related infrastructures, they are one of the most recognizable public facilities around the communities where people live, and they often are targeted as urban exploration destinations. Urban exploration, known as “urbex,” is an activity that involves exploring man-made infrastructures, and the exploration of storm drains is one of the most common forms of urban exploration. However, storm drainage systems are considered to be confined spaces, and there are risks associated with entering these systems. The serious outcomes that could occur in these confined spaces include physical harm, serious illness, loss of function of a body part, reduction in the efficiency of the body, and death. It is dangerous to enter storm drainage systems without permission and proper preparation, and specific training and permission are required to enter a storm drainage system. Also, entering a storm drainage system without a permit is prohibited by law. Even so, urban explorers treat storm drainage systems as one of their most common targets.

The authors of this paper believe that safety education about working in confined spaces, especially in storm drains, should begin in the classroom. It generally is expected that students will be adequately prepared when they begin to work in industry. For this reason, we have developed and introduced a three-dimensional (3D) virtual training program to simulate working safely in storm drains.

3. Use of simulations and games in construction

The use of simulation in 3D models lets users become highly engaged with the process of training, which helps them develop their cognitive skills. Castronovo et al. [2] developed game simulations to help end-users engage their cognition with assigned tasks that involved game mechanics. By using simulation in construction training or other areas, timely and informative
practice can be enhanced and perhaps guaranteed. With enforced practice, it is believed that simulations could possibly reduce the probability of accidents due to human error, such as underestimating the dangers associated with work sites, lack of awareness of hazardous conditions [3], and the lack of proper safety training [4]. Such practice also could enhance learning experiences [5], thereby allowing the delivery of comprehensive information through interactive teaching methods [6].

Simulations have been used extensively in the construction industry relative to the safe operation of equipment [7], and they have included safety training [8] and civil engineering education [9]. A large variety of simulation methods have been used, and examples, such as construction safety games, can be found in Lin et al. [10]. However, no simulations were identified that addressed the issues of construction workers entering storm drainage systems and performing work inside these systems.

**Simulation**

The 3D visual training program simulates real scenes of entering and working in a storm drainage system. Real scenarios with suggested working processes are simulated through the program. A software package entitled “Unity 3D” uses a storytelling approach to simulate the entire process of entering and performing activities in a storm drain. Companies, employers, employees, and researchers can use the 3D simulation model as a tool for training people who perform such work. This 3D animation can lead end users, such as workers, employees, and trainers, through the process of entering and working in a storm drainage system without facing any risk of danger. With step-by-step guidance in the simulation, end users can “enter” the storm drains and “complete” their work safely.

The simulations have two major parts. The first part focuses on entering a storm drainage system, and the second part focuses on inspecting the storm drainage system. In the 3D visualized simulation model, users make the choices that they think are correct. Based on the users’ decisions, distinct interfaces are shown on the screen, and end users perform their work in the simulation. The 3D models also provide a safety check for the users.

The algorithms of the 3D simulation process of entering and working in a storm drainage system are depicted in a logic flowchart in Figures 1 and 11. There are three main types of symbols in the flowchart. A diamond-shape symbol denotes a decision-making process; users must make a choice to process to the next step. The decision-making process is either a “yes” or a “no” question, and the scenario that follows is based on user’s previous selection. A parallelogram indicates a process that requires input from the user. A rectangle represents processing steps or activities that users must complete to continue. The line with an arrow indicates the direction of the path.
1. Entering a Storm Drain

![Flowchart of Atmospheric Checks]

**Figure 1: Flowchart of Atmospheric Checks**

To prepare for entry, it is required that the person evaluate the storm drainage system for both atmospheric and physical hazards. The program assessment of working conditions in the storm drain is based on the correctness of three checkpoints, i.e., 1) the status of the weather, 2) the surroundings at the point of entry, and 3) the results of atmospheric tests.

Figure 1 shows that the first decision users are required to make before entering the storm drainage system is whether or not it is a rainy day. No rain is the foremost condition that protects users from danger since the water level inside the pipes can increase dramatically, even when there is a minor drizzle. Therefore, checking the weather conditions is vitally important.

After checking the weather conditions, users are asked to complete a list of general information, which includes the date and the names of the inspector, the attendants, and the supervisor. The workers who are going into the storm drainage system are responsible for 1) knowing and understanding the hazards of the storm drainage system, 2) knowing how to use the equipment to ensure that they can enter safely, 3) communicating with attendants about the ongoing situation.
inside the system, and 4) alerting the attendants, who are the workers stationed outside the entrance, if there are any suspicious conditions. The attendants are responsible for understanding the hazards, communicating with the workers who are entering the system, monitoring the tasks outside the space, and summoning emergency services, if necessary. The attendants are not allowed to enter the system. They work outside to protect the entering workers inside the system. The supervisors are responsible for supervising every aspect of the task and verifying the rescue services. The step that requires the names of all people involved and their roles details the duties of the workers at entry points to ensure that all workers understand their own assigned roles. Then, users are asked to fill in information about the purpose and how long they will be inside the drainage system. This step ensures that the workers fully understand their assigned tasks and how long it should take to perform those tasks. Both input requirements ensure the completeness of the work and rescue procedures and ensure the safety of the workers who are going to be working inside the storm drainage system.

Like entering other confined spaces, workers who are entering the storm drainage system should follow basic procedures concerning entering a confined space. For this reason, two major hazards should be considered in the simulation before entering the confined space, i.e., atmospheric hazards and physical hazards.

All workers assigned to enter storm drainage systems are provided with an approved calibrated gas detector and fresh air ventilation to check and ensure the safe atmospheric working conditions. Before entering the storm drainage system, an oxygen detector is used to measure the oxygen levels at the bottom, middle, and top of the system. Safe oxygen concentrations are between 19.5% and 23.5%. If the oxygen concentration is below 19.5% or above 23.5%, users are not allowed to enter the storm drainage system. Next, similar to how users use an oxygen detector to measure the oxygen concentration, users use a detector to measure flammability at all levels. The acceptable concentration of flammable gases, vapors, or mists is less than 10% of their LFLs. If the concentration exceeds 10% of the LFL, users are not allowed to enter. Last, users use a detector to measure toxicity in terms of the threshold limit value (TLV) at all levels. Users are not allowed to enter if the TLV reaches the level that threatens the safety of the workers when they enter. To test the oxygen concentration, LFL, and TLV, a 60-second test measurement should be conducted at all levels in an area of the storm drainage system. Since the result of reading numbers on a detector is either a pass or non-pass option, there are no uncertainties involved. For each passed result, the users move forward and continue to the next steps. For a non-pass result, the users take the appropriate actions to continue. We created a simple simulation model to visualize the condition of each step for entering.

Figures 2 through 10 show screenshots of the process of entering a storm drainage system. First, users are asked about whether it is rainy (Figure 2). The condition of the weather is vitally important for workers to perform their work inside the storm drainage system. Different responses will show up based on users’ choices. Second, users are asked to enter information as shown in Figures 5 and 6 to ensure that they know and understand their assigned work. Then, users are asked to check if the atmospheric working condition is inside the safe range by looking.
at the numbers on the monitors and by selecting answers for the questions (Figures 7 through 10).

Figure 2: Screenshot of the process of entering the storm drain in a rainy day.

Figure 3: Screenshot of the response if the user incorrectly selects “Yes” to the question in Figure 2.
Figure 4: Screenshot of the response if the user correctly selects “No” to the question in Figure 2.

Figure 5: Screenshot of a field log for a specific entry.
Figure 6: Screenshot showing an example of a completed field log.

Figure 7: Screenshot introducing atmospheric checking.
Figure 8: Screenshot asking the user if the value on the shown oxygen meter is acceptable.

Figure 9: Screenshot of the response if the user correctly states the value is acceptable.
Figure 10: Screenshot asking the user if the value on the shown Lower Flammable Limit (LFL) detector is acceptable.
After the check of the atmospheric conditions, the next step of the simulation is to check the physical working conditions, but a check of the surroundings should be done first, and the users are asked to do a surroundings’ check before entering. If there is someone near the entrance, the users must tell her or him to leave to go to the next step in the simulation. A checklist of safety equipment is provided to the users, and this list includes a safety helmet, a safety harness, a lifeline, and high visibility safety apparel (HVSA). The users must check all of the safety equipment to continue. Then, the users are requested to check whether they have properly equipped their safety helmets and whether the safety harness is connected to the tripod safety system by the lifeline. Next, the users are asked if there are any engulfing materials at the entrance. If there are engulfing materials at the entrance, the users will not be allowed to enter the storm drainage system. The users will take the permanent ladder to go into the storm drainage system. However, if there is no permanent ladder, the users will use a well-conditioned aluminum ladder to enter the system. Figure 11 shows the logic flow.

A fresh air ventilation system also must be set up and operating before and during the entire period of entering and working. In addition, there are two types of ventilation, i.e., supply ventilation and exhaust ventilation. Table 1 lists the comparison of the advantages and
Advantages of these two types of ventilation. Based on the information in Table 1, supply ventilation should be applied in the storm drainage system because the presence of fresh air in the breathing zone is the most critical for the workers who are entering and working in the system. Ventilation helps the workers maintain safe atmospheric conditions inside the storm drainage system. For the use of supply ventilation, users should set up the intake of the ventilation 10 inches above the ground since the concentration of carbon monoxide could be too high if the ventilation is placed next to a roadway. Carbon monoxide is slightly less dense than air, and it is harmful to workers when its concentration reaches 35 parts per million or more. The end of the ventilation system should be located near the bottom of the storm drainage system.

Table 1: Advantages and Disadvantages of Supply Ventilation vs. Exhaust Ventilation

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Supply ventilation | • Rapid and local dilution directly to workers’ breathing zone  
|                  | • Better control over air movement                  | • Contaminated discharge at the access point  
|                  | • Effective air mixing                              | • Dust spreading                                       |
| Exhaust ventilation | • Concentrates contaminants                          | • Ineffective air mixing and dilution                  |
|                  | • Discharge of contaminants away from access         | • Bring contaminants into workers’ breathing zone      |
|                  | • Localized contaminants                             | • Highly localized contaminant concentration           |

Figures 12 through 15 show the process of physical surrounding checks. This process leads users to ensure there is no unauthorized person around the work site. Figure 16 shows that users are asked to check whether they are properly equipped and are ready to go into storm drainage system. After all of the safety requirements have been checked for both the atmospheric and physical conditions, the workers are allowed to enter the storm drainage system.
Figure 12: Screenshot asking the user if there is any unauthorized person around.

Figure 13: Screenshot of the response if the user correctly selects that there is an unauthorized person around.
Figure 14: Screenshot of the command that allows users to ask the unauthorized person to leave.

Figure 15: Screenshot of the instruction to the unauthorized person.
2. Working in a Storm Drain

The main work we assigned to end users in the 3D simulation was to inspect the inside of the storm drainage system. While the user “walks” through the storm drain in the simulation, the atmospheric detector appears continuously at the top right corner of the screen. The users must pay attention to the number displayed on the detector since the number changes with time. If the number exceeds the safety range, the users “lose” their lives in the simulation, and messages notify the users. The users must decide whether they want to return to the surface based on their working process and atmospheric conditions. If they feel they are in danger, they can return to the surface by clicking a “return” button in the simulation to avoid losing their lives.

According to the storm drain inspection form [11], users are asked to inspect the conditions of the storm drains. There are four major elements that the users are looking for during the inspection process, i.e., debris/pollution, odor, water clarity, and failure of structural integrity such as cracks.

During the inspection, the users are provided with a checklist and are asked to check all the applicable conditions. In the example of debris or pollution, the users must check if there is any pollution, such as white foam, brownish foam, dead animals, trash, or debris. When they walk through the simulation, random pollution appears on the pipe, and the users mark their checklists when they notice any corresponding pollution. For odor, the users are asked if there is a musty

Figure 166: Screenshot of a safety checklist before entering the storm drain.
smell, the smell of sewage, or the smell of anything strange. They enter and describe the smells on the sheet. However, since the smells cannot be visualized and performed by the simulation, the odor depends only on the users’ descriptions based on their experience. The users also are prompted to describe the transparency of the water. The users must state if the water is clear, cloudy, or opaque. Moreover, the users are asked to inspect drainage structures for cracks or leaks. Cracks and leaks can allow for accumulation of soil at the bottom of the drain and result in the blockage of flow.

In addition to the major inspection items, the users also are asked for some additional information based on the conditions in the storm drains, such as the location of sediment and the condition of the structure. The users must inspect the sediment location and state its proportion within the structure. For example, if the sediment occupies 25% of the channel, the users must mark the circumstances and record the location of the sediment. Users also are required to inspect the condition of the structure and the conditions of the structure/channel side, and they must record these conditions based on their experience.

Figures 17 and 18 show different situations that users may experience during an inspection inside a storm drainage system. Users must pay attention to the number that shows on the top right corner of the monitor. If the atmospheric condition goes too low or too high, users should return to the surface by clicking the “return” button on the bottom right corner. By failing to return to surface in time, users will “lose” their lives. A message box, as shown in Figure 19, will be shown to the users. The message will warn users that, even though they can play as many times as they wish in the simulation, they only have one life to lose. They should be careful when they enter and work in the storm drainage system. A more detailed 3D simulation could be built for further study if there is sufficient interest.
Figure 17: Screenshot of an example of white foam.

Figure 18: Screenshot of an example of trash.
Potential Benefits of the Simulation Model

By using this 3D simulation model, the authors expect that the users can understand and learn the danger of entering and working in a storm drainage system without facing any risks. In the simulation, users can “lose” their lives if they make the wrong decisions. However, in real life, there is no restart button. It is safe for users to use the simulation as practice and to become trained. The users can practice evaluating the atmospheric and physical hazard conditions in the simulation models without being physically present. The safety of the trainees, as users, has been ensured, and the trainees are not exposed to any danger. The users must follow certain steps to pass the simulation. Every step in the simulation demonstrates to users the appropriate process that they must follow in real-life scenarios. In addition, the simulation provides users with information about the regulations for entering and working in a storm drainage system.

The 3D simulation model allows trainees to visualize the actual scenes. Without physically entering work sites, such as the storm drainage system in this paper, now trainees can be trained by using the simulation model. Compared to the traditional training method, which begins with meetings about theoretical trainings followed by practical trainings, the simulation models can be applied as visual training programs and test models before actual practical trainings. Users can apply the knowledge they have acquired from the theoretical trainings to the simulation model. Everything according to the regulations is visualized for the purpose of training the users. By
visualizing the actual steps that must be followed in the simulation, the simulation models give users examples of what the work will be like in real-life situations.

A third expected benefit of using the simulation model is saving money. By using the simulation model, the overall cost of the training process is reduced. Instead of requiring both trainers and trainees to attend meetings in person and for trainees to be trained through the traditional training method, the simulation model allow the trainees to train themselves without being taught by trainers in person. With the simulation models, there are fewer restrictions on training locations and schedules for both trainees and trainers. Trainees can decide when and where they want to complete the training based on their availability. Although building a simulation model might be costly, considering the training costs in the long run, a simulation model will save money.

The models also will provide practical feedback [12] to users when they go through the simulation models. Instant feedback will be provided to users without the users facing any risks. Based on the feedback that is provided, the users will know and understand where and how they have made wrong choices and the corresponding correct answers. Hand-eye coordination will be practiced by the interactive simulation [13]. Since the feedback is provided immediately, the entire period of the learning process is shortened, time is saved, and the efficiency of the training is increased.

Educational Application

The 3D simulation models can be used in the classroom to demonstrate the processes of actual work in storm drainage systems or any other construction areas. The 3D simulation model can be an effective method for teaching because it shifts the traditional static training method to dynamic learning processes. By presenting the simulation models in the classroom, trainers can give clearer explanations about the actual working processes with visualized 3D simulations as a means of aiding understanding, and trainees can see what is going on through step-by-step guidance. The simulation models can help trainees gain a better understanding of how work is done in real construction areas.

The users can decide their own learning pace in the simulation training. The simulation allows the users to change their learning paces according to their level of understanding of the project/work goal. Users also can replay the simulation as many times as needed. In addition, the simulations can be used as test programs to check how well trainees have prepared for the actual work in the workplace.

Future researchers can build similar simulations to visualize the process of any working sites, and this method of building 3D simulation models can be applied to all construction areas. Interested researchers can go through the Institutional Review Board (IRB) and create surveys to receive feedback from users on the simulation and then improve their simulation models for better use.
Summary and Conclusion

The 3D visualized simulation could be helpful to students. The use of the 3D simulation model as a training and learning tool will provide several benefits for users, e.g., (1) learners can go “inside” the drain tunnel without subjecting themselves to the danger of confined spaces, hence, this tool is expected to increase safety during training; (2) trainees can visualize and “walk through” the scenes faster and investigate all drainage components from various perspectives with few or no obstacles; (3) trainees can practice these activities in groups and at their own time and pace, thus allowing a cost-saving training program; and (4) since both the trainer and the trainees can “enter” the drain tunnel multiple times and en masse, trainees will be provided with feedback almost immediately, and training efficiency and effectiveness are expected to be enhanced considerably.

The 3D simulation models demonstrate the step-by-step instructions of entering and working in storm drainage systems, and they shift the traditional static training method to dynamic learning processes. This newly-developed, visual-oriented program will allow learners to get involved with the actual process of work through a 3D simulation without being in danger. Users will have a better understanding of storm drainage systems, which will help to prevent possible incidents due to the lack of knowledge. The next stage of research will involve a survey to obtain users’ feedback concerning the utility of this tool by the users (trainees) and the migration of these 3D models into augmented reality and virtual reality environments. As the related research progresses, additional information and guidance will be presented in the future.

Acknowledgments

The authors wish to acknowledge the reviewers for their comments that have greatly enhanced this paper. Thanks also go to members of the Construction Laboratory for Automation and System Simulation (CLASS) for their suggestions concerning this paper. The first author wishes to thank her husband, Linyang Sun, for his help and dedication without which this paper, as part of her thesis, would not have been materialized.
References


