Developing and Evaluating a Virtual Training Process for Energy Audit Education

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Abstract

This paper is a work-in-progress (WIP) and an evidence-based practice paper. As efforts to decarbonize buildings increase, energy workforce development efforts are greatly needed to train the next generation of professionals. One such program that is training this new energy workforce is the Department of Energy's Industrial Assessment Center (IAC) program which aims to increase the efficiency and productivity of small and medium sized industrial facilities and commercial buildings through conducting energy audits. Student training is an integral part of this program, where students participate in all aspects of these audits. However, training participants to be prepared for field work can be challenging without ready access to a manufacturing or commercial space. As immersive technologies have increased in availability, such technologies have the potential to be used to help support training. However, the methods of use and effectiveness of immersive technology for student learning have yet to be evaluated. Virtual Reality (VR) is among the most preferred methods across these immersive technologies. While there are many studies using VR technology, there are no known studies specifically focused on its use for commercial and industrial energy audit training. This WIP paper discusses an overview of the project and proposed methods that use virtual models to train students in energy audit processes and evaluate their effectiveness in comparison to traditional methods of teaching. In this project, first, virtual models as training environments are created by scanning real-world environments and used to train students via computers and VR headsets connected to these created virtual models. As a follow-on evaluation, students' performance is then assessed during a real-world, in-person energy audit to understand the effectiveness of the various modes of training. Their effectiveness on student learning is then evaluated by conducting surveys and comparing performance metrics. The results can be used by organizations and programs to improve the training of the energy workforce.

Introduction

As the United States moves towards decarbonizing its infrastructure systems and efforts to decarbonize buildings increase to meet climate change goals, educational programs to support such energy workforce development efforts are becoming more prominent at many levels, including in the K-12 school systems, and in higher education. A recent report [1] funded by the U.S. Department of Energy (DOE) provides state-level workforce projections for the energy efficiency sector for 2025 and 2030. Within higher education, one long standing program that has focused on this since the 1970s is the Industrial Assessment Center (IAC) program including 37 university-based IACs operating across the U.S., typically with 10-30 active students per center at any given time [2]. The IACs have two main goals. First is conducting building energy audits of small and medium-sized industrial facilities and commercial buildings. The second main goal is to provide college students with education and hands-on training in energy and manufacturing through participation in all aspects of the energy audit processes. This includes participating in and leading energy audits, as well as writing energy, cost, and emissions savings recommendations. The IAC goals are similar to that of many other energy workforce development efforts in the energy space, thus the applications of training-related developments extend beyond the IAC program boundaries.

One challenge in the training of students for careers in energy and manufacturing is the relative lack of relevant spaces that can be used for students to understand what equipment and manufacturing processes look like, and how to identify potential opportunities for energy, cost, or emissions improvements. This is a key skill needed for energy auditors [3] in commercial and industrial buildings. Research on the engineering students has suggested they were more strongly active, sensing, visual, and sequential learners [4-6], indicating that opportunities to support teaching that aligns with students' learning styles are likely to lead to improved outcomes [7]. Immersive technologies such as Virtual Reality (VR) have the potential to support this requirement as their availability and complexity of features have increased and their costs have decreased [8]. However, the methods of use and effectiveness of immersive technology for student learning in energy engineering education have yet to be evaluated. This WIP paper aims to identify methods of use of virtual models to teach students energy audit processes and evaluate their effectiveness. Specifically, the research question considered is: Is the implementation of VR technology in energy audit training more effective and efficient than traditional lecture-style training methods? To achieve this goal, virtual training environments are created by scanning real-world environments with an infrared scanning device. VR environments are then used for the training of students via VR headsets and computers, and finally, the impact on student learning will be evaluated by comparing students' perceptions of effectiveness of training methods. Evaluation of the methods (i.e., VR training with headsets, computer-based VR training, and traditional training) is based on pre- and post-training surveys, and students' performance metrics from their participation in the VR and real-world assessment.

Background

Immersive technologies such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) have become more popular and widely used in research studies related to construction and buildings [9]. VR allows users to immerse themselves in a digital environment that is completely detached from the real world [10], and it is one of the most preferred immersive technologies for these studies [11]. While there are many studies using VR technology, there are no known studies specifically related to its use for energy assessments and/or building inspection. For example, Du et al. [12] used a VR environment for more efficient design decisions. For example, Niu et al. [13] used this technology to determine the best location for lighting switches by comparing users' behavior in a VR environment. Some of the studies found VR technology to be an effective tool to train workers for different health and safety scenarios such as working at height [14-16]. Other studies have used VR environments for construction safety and constructability discussions [17-19]. Goh et al. [20] simulated crane usage in a dangerous area to train the operator before using it in a similar real-world environment. Lastly, there is a study focused on the training of workers for scaffolding installation [21]. However, none of these recent studies have applied the use of VR for energy audit training.

Developing the virtual training for energy audit

Selecting the Virtual Reality Technology: To use VR technology, first a virtual environment must be created. If this virtual environment is a model of a real building or space, first this building or space must be scanned. Next, collected scan data is processed to create the virtual model. There are different methods for scanning such as infrared scanning, and laser scanning [22-23]. Among the studies reviewed [23-29], many use infrared scanning devices since they generally have high accuracy and are less expensive than laser scanners. As an example of such a device, the Matterport Pro2 [30] combines three structured-light sensors at different pitches to capture 18 RGB and depth images during a 360° rotation at each scan location. After the scanning, collected data including point clouds, texture meshes, and photos are processed using software packages based on data type. Some of these software packages include Matterport Cloud Service, Autodesk Recap, and Pix4D [22]. These allow the viewing and use of the collected data in a virtual environment. For this study, the Matterport Pro2 device is selected to scan the areas and Matterport Cloud Service is selected to process the scanning data and visualization.

Developing the Virtual Energy Audit Environment: After determining the scanning method, device, and processing software package, a location for conducting the training is selected so it can be scanned, and processed and a virtual model can be created. As an example, a classroom building is shown in Figure 1. This figure includes a demonstration of the scanning process and the resulting developed virtual model. The most important criterion for choosing a good training space is whether it contains examples to point to for each topic to be taught to students. In addition, the size of the space and the density of furniture and/or equipment can also be considered for selection, as larger and denser spaces require more time for scanning and processing the scanned data. Also, for inexperienced students, these more complex models may be difficult to navigate.

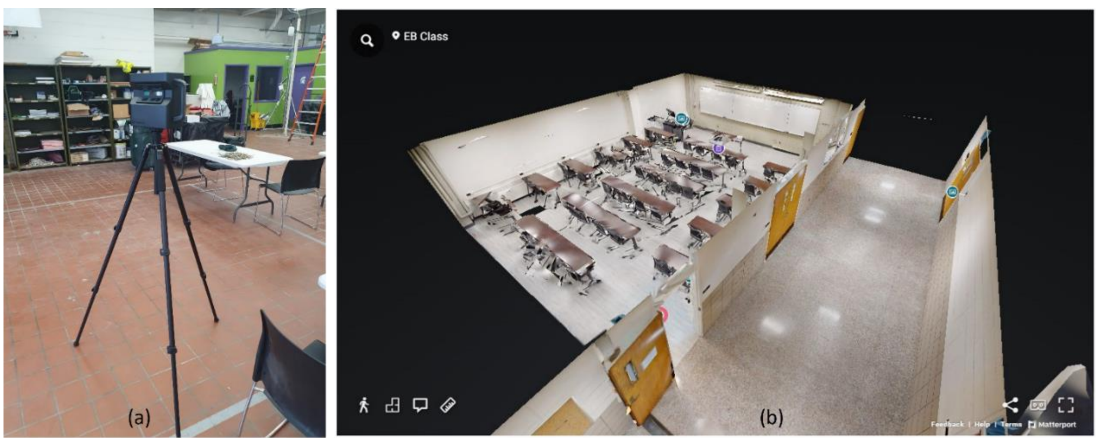

Figure 1: (a) Scanning the area and (b) an example of a processed virtual model.

Selecting Energy Audit Measures to Evaluate: To conduct energy audits of buildings, there are many energy-consuming systems that energy auditors need to be aware of, understand how they operate, and be able to identify energy, cost, or emissions savings for. For this research, three main energy-consuming systems are selected. These include lightning, plug loads (small appliances plugged into wall outlets), and heating, ventilation, and air conditioning (HVAC). These topics were chosen because these are three of the energy-consuming systems for which energy recommendations are most frequently recommended throughout the history of energy audits within the IAC program [31]. The specific recommendations of focus are also the most appropriate ones for the selected area being used for teaching (i.e., the classroom space). It is aimed to select at least three recommendations for each topic to increase diversity. First, from the IAC database, the most recommended recommendations on these topics were filtered and those that were appropriate for the selected classroom were selected. Secondly, those with substantial experience in conducting energy audits within the research team identified specific recommendations for this space on these topics. For example, the selected lighting related recommendations targeted in this study includes replacing lighting with LED, installing occupancy sensors, and zoning the room for lighting.

Evaluation of effectiveness of energy audit training methods

The effectiveness of three different methods of training participants to conduct energy audits will be evaluated. These methods include "traditional" training in a classroom lecture-style environment (Group 1), computer-based training that uses a computer to view a 3D model (Group 2), and VR-based training using a VR headset (Group 3), each to teach the three groups the same content but using three different methods. A diagram outlining the proposed methodology and steps is provided in Figure 2. These steps are consistent with the literature in this area. Most studies begin with a questionnaire to determine the background and experience of the participants and to collect demographic information [32-36]. A general approach to determine the effectiveness of VR-based training is to compare it with traditional methods [34-35], [38-41]. In addition, some studies have compared it with computer-based training methods that also use VR environments [32], [42-43]. The methodology we propose involves comparing VR-based training with both traditional and computer-based training methods. Finally, a common method to evaluate the effectiveness of the proposed VR-based methods is by conducting post-surveys [34], [38-40], [42], post-training VR tasks [32], [41], [43-44], and real-world tasks [33-35]. Our proposed methodology includes all of these. This also helps to compare how virtual energy audits represent real-world energy audits.

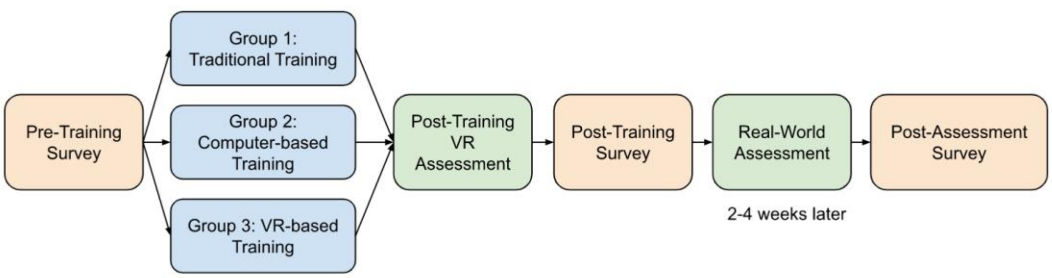

Figure 2: Evaluation methodology

First, a pre-training survey will be completed by participants. This survey includes questions related to the participant's experience and background in conducting energy audits of buildings, which is similar to other studies [33-39]. It also includes questions regarding the participant's level of experience in identifying energy-saving opportunities in the training topics (lighting, plug-load, and HVAC). This question will be used to establish a baseline of their pre-training knowledge, to see how much the training improved their knowledge of these topics. This follows the methods of similar studies [34], [38-39].

Next, participants will be randomly assigned to one of the three training groups (traditional, computer-based, and VR-based). "Traditional" training methods will use PowerPoint presentation slides to present training topics. Computer-based training will use the same virtual model that will be used for VR-based training, but it will be presented to participants on a computer. The participant will control the computer and walk around the model while the instructor provides information about energy-saving recommendations and points out the relevant locations in the model. This computer-based training method can also be called nonimmersive training [32], [42-43]. VR-based training will use the virtual model that the participants will be in and can move around the model via VR headsets. The instructor will guide the participants through the model giving instructions and information about the training topics. All training groups will follow a similar script of topics covered. The main difference will be the mechanism used for participants to visualize what is being taught. This is consistent with other VR-based studies [32-43]. Following the training using one of the three methods, all participants will complete an energy audit of a room using a VR headset. During this energy audit, participants will be prompted to look around the space and to identify, through speaking out loud, what lighting, HVAC, and plug load recommendations they see. The number and list of recommendations identified (correctly or incorrectly) will be recorded and be used to compare the relative performance of participant groups. Right after the virtual audit, participants will complete a post-training survey. This survey will ask participants to evaluate their confidence in being able to conduct an energy audit, and their opinion on the effectiveness of the training. It also includes the same question asked in the pre-training survey about their level of experience in terms of identifying energy-saving opportunities in the training topics. The recorded metrics in virtual assessments (completion time, correctly and incorrectly identified recommendation numbers) and results of the post-training surveys (as compared to the pre-training survey) will be used to measure the effectiveness of the virtual training methods. Similar metrics (i.e., time, correct answers, wrong answers) were recorded in other studies when participants were asked to complete given tasks [32-34], [41], [44-45].

Lastly, approximately 4 weeks later, participants will complete an in-person energy audit. The four-week period was chosen because similar studies waited the same time to measure the retention of learned information [38-39]. The results of the in-person audit will be used to determine the retention of the learned information as compared to the practice audit that occurred directly after the training. The number and list of recommendations identified (correctly or incorrectly) will be recorded. For this real-world energy audit, a similar space and the same metrics as the virtual energy audit will be used. Finally, a post-assessment survey will be conducted. The result of real-world assessments and post-assessment surveys will be used to measure the effectiveness of the virtual training methods. This is similar to other studies using VR [34].

Preliminary results and next steps

This WIP paper aimed to discuss efforts to develop and evaluate a virtual training process for energy audits. A methodology for the evaluation of this training process is proposed and is being piloted to iteratively improve methods prior to the final study. Preliminary results suggest that participants trained using VR-based training methods remember more recommendations compared to the other groups. Next steps include finalizing the survey questions and training materials according to the collected feedback.

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