Virtual Learning for Workers in Robot Deployed Construction Sites

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Abstract

This paper provides various aspects to consider during the creation of a novel virtual learning environment (VLE) for the education of construction workers interacting with robots. First, the characteristics of existing VLEs in the construction industry, including user interface, navigation method, content, and procedure of learning were reviewed. Several drawbacks of existing environments were identified during the review. Then, the novel features of VLEs in other industries were investigated to find what can be incorporated in the VLEs for the construction industry to mitigate the drawbacks. The existing VLEs in various industries do offer novel features that can be adapted for robot-included work-site trainings and education. However, the construction industry has specific characteristics that are unique and therefore the construction industry-specific characteristics need to be considered when adapting the features of other industries' VLEs.

Keywords

Virtual learning for construction • Human-robot interaction • Construction robots

107.1 Introduction

107.1.1 Background

Existing learning opportunities in the construction industry mainly consist of lecture-based classroom learning, text-based training materials, apprenticeships, hands-on training, and on-the-job training. Despite the ongoing efforts in worker education, more than 50% of the fatalities in construction are still reported to be due to "unskilled performance," which signifies the need in placing more emphasis on frequent and skill-focused worker education [1]. Since the existing classroom training efforts are mostly lecture based, they do not provide realistic experiences, and do not allow the workers to repeatedly practice the construction skills that they have learned [2]. Furthermore, classroom-based traditional learning does not provide workers the opportunity to build work-site adaptability since these traditional methods do not fully address the unstructured nature of construction tasks, the environmental dynamicity of work sites, and various team interactions [3].

Other traditional learning methods, such as hands-on training and on-the-job training, provide the workers the opportunity to practice construction skills using real construction equipment but these trainings are often too costly to be frequently and widely adapted [4]. Virtual learning environment (VLE) has been recently emerging as an alternative method of construction

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education [5]. Following the features described by Dillenbourg et al., the definition of VLEs in this paper is determined to be an interactive social learning space that contains information in the form that varies from text-based visual animations to 3D immersive reality [6]. Unlike the existing lecture-based education efforts, the virtual learning is expected to bring increased participation and engagement of learners [6].

107.1.2 Motivation

Among various topics in construction education, we focus specifically on the education for those working in robot deployed construction sites. For clarity, in this paper, robots are defined as machines that have the potential to be programmed to do multiple tasks with increased precision or productivity rates. With this definition, a remotely controlled demolition machine is a robot as its software allows a more precise positioning of the machine arm based on the task type. In comparison, a regular excavator is not a robot as it is not programmable and therefore, does not have the potential to better its performance without having a skilled operator. The motivation behind this specific focus is that, with the introduction of robots on construction sites, a reformation is expected. According to the McKinsey Global Institute's report, the construction industry has 47% of automation potential [7]. With this expected increased level of automation, construction sites will soon be incorporated with construction robots, such as bricklaying robots and demolition robots. However, this trend does not mean that construction robots will replace construction workers. The World Economic Forum (WEF) predicts that the construction robots, slowly integrated into the construction industry, will replace certain construction tasks, but not jobs entirely [8]. In other words, construction workers will soon work side-by-side or collaboratively with construction robots and will need to learn how to interact with various robots, which will require drastically different skills, compared to the current construction workers' skills. Currently, we lack the knowledge about how the interaction between construction workers and robots will work or what kinds of dangerous situations the workers can face. Therefore, educating workers through direct hands-on trainings can put the worker at risk and can be limited in terms of covering all the possible situations the worker might face in real work sites. VLEs on the other hand, can offer hands-on trainings in virtual settings and therefore, VLEs will not put the worker at severe risk and can cover a wider range of possible situations that can happen in real work sites. Considering these characteristics of VLEs, we chose VLEs as the main education method to focus on for this review.

107.2 Objectives and Research Questions

The objectives of this paper are to review the existing literature on VLEs for workers in robot incorporated construction sites, analyze the current level of development and adaptability, and suggest ways to improve. However, our search results did not yield any paper that was directly related to VLEs for construction workers working with construction robots. To accommodate this lack of relevant publications, the objectives were slightly modified. The updated objectives of this study are first, to review the existing literature on VLEs for workers in robot deployed work sites and second, to review the current VLEs in regular construction educations. With the result of the review, we discuss what should be considered, when incorporating the features of robot-included VLEs, to the construction VLEs. Specific research questions for this study are the following:

- What are the main characteristics of the existing VLEs in the construction industry? What visualization methods and user interfaces are used for VLEs in the industry? What are the drawbacks of current VLEs used in the industry?
- What are the novel features of human-robot interaction focused VLEs used in other industries? What are the features that can be adapted or improved upon?
- What features should be included in a VLE for workers in construction robot incorporated work sites? How should the current VLEs be improved to match the needs of the construction work sites?

107.3 Methodology

Based on our objectives, which are to review the existing literature on VLEs on robot incorporated work sites and to review and analyze the current VLEs used in regular construction education efforts, several keywords were selected for the literature search. The selected keywords for the review on existing VLEs on robot deployed work sites in various industries are,

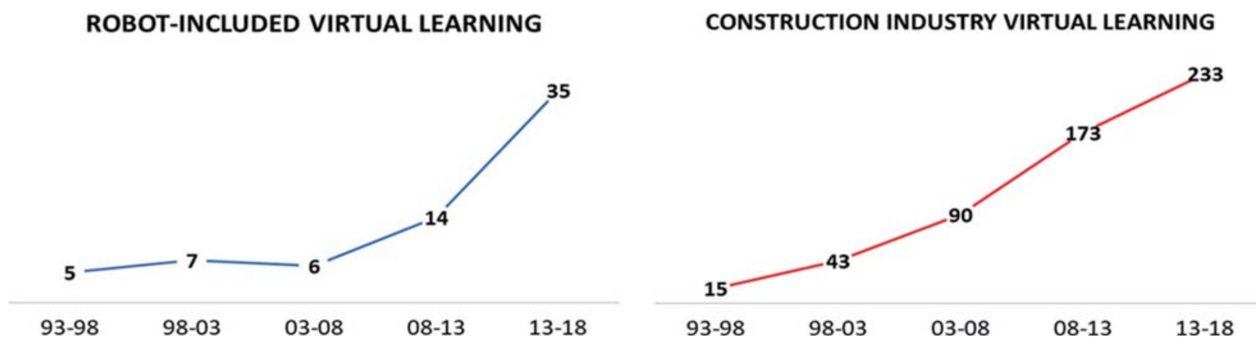

Fig. 107.1 Number of articles found in 5-year interval

"(train* OR educat* OR learn*) AND (virtual* OR virtual real*) AND (environment* OR tech* OR simulat* OR applicat*) AND (human-robot* OR human-machin* OR worker-robot* OR worker-machin* OR operator-robot* OR operator-machin*) AND (collaborat* OR interact* OR cooperat* OR team*)". The selected keywords for the review on existing VLEs in the overall construction industry are "(construct*) AND (job OR work* OR industr*) AND (train* OR educat* OR learn*) AND (virtual* OR cyber* OR virtual real*) AND (environment* OR tech* OR simulat* OR applicat*)". To focus on the most recent status of education environments, the timespan of 2008 to 2018 was used for the search. The year 2008 was chosen because for both keywords, on existing VLEs on robot deployed work sites in various industries and on existing VLEs in construction industry, the number of searched articles has significantly increased starting from 2008 (see Fig. 107.1). Using the selected keywords and timespan, a search was conducted on two main search engines: Web of Science and Google Scholar.

Web of Science was selected as one of the primary search engines for this review, considering its comprehensiveness in fields included in the library and its selectivity of the human-based publication inclusion process [9]. Comparatively, Google Scholar is a machine-automated database and is less selective than Web of Science. However, it includes the most recent conference papers. To include the VLEs that are developed most recently, Google Scholar was chosen as another main search engine.

The searched publications were then manually selected based on their titles and abstracts. The primary standards used for this selection process were, "Does the topic of this publication match the main topic of this paper: VLEs in robot incorporated industries and construction industry?" and "Can this publication be part of the answer to the research questions of this paper?"

After the above search and selection process, 37 papers [3, 4, 10–44] were included in this paper. 17 papers were about existing VLEs in construction industry and 20 papers were about robot/agent/machine-included VLEs in other industries. Overall, this review identifies what to adapt from the existing VLEs and what to further develop to match the specific needs of preparing construction workers for the future robot deployed construction sites.

107.4 Main Findings

107.4.1 Status of Virtual Learning Environments in Construction Industry

Several VLEs for the construction industry were reviewed [3, 4, 10–24]. Since the main purpose of reviewing existing VLEs in the construction industry is to find the main characteristics and the level of development of current VLEs, the user interface and visualization method for each environment were identified as the main features to focus on in terms of technological aspects of virtual learning. It was found that 52.9% of the VLEs in the construction industry included in this paper use static PC monitor as the visualization method along with mouse and keyboard as the user interface. PC monitor with mouse and keyboard however, does not provide the user the feeling of being immersed in the VLE, which can make learning less engaging and thus, having PC monitor as visualization method does not offer a learning experience that matches the level of real-life hands-on trainings [45]. Another type of VLE used in the construction industry is a "power wall". 17.6% of papers on VLEs in the construction industry included in this paper use power walls and similar physical platforms [3, 14, 15]. A power wall is a wide, large-sized virtual environment screen that surrounds the environment of the users, who are wearing active see-through glasses. With the increased immersiveness, power walls make learning more realistic [25] and worker-friendly [37]. It was also found that increased immersion has positive effects on increasing learner's motivations and helping learners remember the material better in the long term [46]. Although the power wall environments provide enhanced immersive experiences, one drawback of the current learning programs is that they only allow third-person views. A third-person view in VLEs allow the users to see not just parts of their bodies but also their full-body as avatars. In third-person views, since the users can see the motions of their whole bodies, they can be more aware of their postures, gestures, and proximity to other workers and machines [47]. Although having this view is important in robot-included VLEs for the users' enhanced understanding of the consequences of interactions with virtual robots, in third-person views, the users consider themselves to be apart from the avatar and therefore, the users will not feel like they are present in realistic training simulations [27, 28].

Another 17.6% of VLEs in the construction industry, included in this paper, use Head Mounted Displays (HMDs) as the platform for learning environment [21–23]. Unlike the power wall, the currently developed construction education environments with HMDs mostly support only first-person views. First-person views in VLEs display only the parts of the users' bodies, similar to what the users would see in real life. In other words, the users will not see their entire bodies or what is happening behind them unless they turn around. First-person views increase immersiveness but do not provide the users the sense on how the users are interacting with other workers [21, 22]. In terms of user interface, the existing HMD-based environments mostly use handheld controllers or keyboards as their navigation and user-interaction tools. Not having a freedom to navigate and interact with the environment without the controller means that the users will have to focus on the environment itself while learning, which can scatter their attention, make the learning environment less immersive and less natural [48].

In terms of content of virtual learning, 88.2% of construction industry VLEs, included in this paper, are in the format of tutorial-like games [3, 4, 12–24]. Although the games provide different levels of difficulties and example scenarios, these VLEs are only focused on the acquisition of a specific skill or on safety training in pre-determined conditions [13, 14, 19, 20]. Therefore, these environments do not provide any interactive scenarios where the learner collaborates with other workers. If these environments were to be used for robot-included virtual learning, the lack of interactive scenarios would be a drawback because learning how to work with or sharing the same space with robots requires interaction between the user and the virtual robots and virtual avatars. One environment included in this review provides interaction with virtual machines but does not offer collaborative interaction between the user and other workers represented as virtual avatars [18].

In terms of learning procedures, although VLEs can offer activity-based learning, only 11.8% of environments included in this review [19, 20] utilize learning while doing activities. The majority of environments still follow the traditional sequence of learning the material and skill sets based on virtually-provided lectures or texts and then applying the already learned material to examples that are not as complex as on-site situations [10]. Considering that construction workers are adult learners who are experienced and self-directed, one of the drawbacks of the current VLEs in construction industry is that it is hard to correlate the immediate relevance between what the workers learned and what the workers will need on-site [49].

In terms of focus of the existing VLEs in construction industry, 76.5% of papers included in this review have environments that focus exclusively on safety [3, 4, 10, 12–17, 20, 22–24]. Some specific topics are safety inspection and hazard identification. For robot-included VLEs in construction, interactive skill learning as well as safety will be necessary topics to cover [50].

107.4.2 Advancements of Virtual Learning Environments on Robot Incorporated Work Sites

Several robot-included VLEs in other industries including the manufacturing and mining were also reviewed [25–44]. To answer one of the main research questions, the novel features of human-robot interaction-focused VLEs were identified. One characteristic unique to the robot-included VLEs, was that 35% of these environments were interactive scenario-based [27, 28, 33, 37, 39, 42, 43] and therefore, promote "learning while doing." For example, "beware of the Robot" is a heterogeneous VLE in the manufacturing industry that lets the user complete a tape-laying task in collaboration with an industrial robot. This environment goes further than simply showing the user how to interact with robots and puts the user in different scenarios, helping the worker build the necessary safety-related situational awareness near robots. In addition, 55% of the robot-incorporated environments included in this review offer interaction between the robot and the user as the main content [25–27, 30–35, 42, 43].

In terms of technological features, only three of the environments included, in this paper, offer both first-person and third-person views to the workers and give the users the freedom to choose the view that fits the purpose of learning [11, 13, 27]. Although not commonly adapted yet, these three environments can serve as good references when creating a VLE that provides both views to the users. Moreover, 25% of existing robot-included VLEs are controller-free and let the users navigate freely, using a motion-sensing device. If adopted, the mentioned features have the potential to solve the identified drawbacks of current VLEs in the construction industry. However, these features should not be simply re-used. Instead, they should be carefully adapted, considering the specific conditions of the construction industry.

In terms of other characteristics of existing VLEs, 80% of the robot-included VLEs in this review, require the user to be stationary, either sitting down or standing up, wearing an HMD [25–36, 41–44]. Some environments allow walking, but only a few steps [37–40]. In addition, 90% of robot-included VLEs in other industries have only one or no virtual avatar present in the environment [25–36, 39–44]. In terms of displayed environment, 80% of robot-included VLEs in other industries are based on indoor environments [25–27, 29, 31, 32, 34–40, 42–44].

107.5 Discussion

Adapting the useful features of the most recent technologies used in VLEs in other industries can be the first step in advancing VLEs in the robot deployed construction industry. However, when adapting such features, unique characteristics derived from worker-robot interaction need to be considered.

First, utilizing both first and third-person views and providing the learners the freedom to choose the view that suits the purpose of learning are recommended. First-person views are useful for learning equipment controls but do not provide the learners, a sense on their interaction behaviors. Third-person views, on the other hand, are less immersive but provide full body views for the learners and are useful for learning dynamic interaction behaviors.

Second, implementation of controller-free navigation system is recommended for increased diversity of interactions. When workers control or assist robots, the workers oftentimes walk around the robots to see the robots' movements. Considering that the learners will be equipped with robot controllers, having another controller for navigation can inhibit natural interactions between the robot and the learner.

In addition, unique characteristics of the tasks and sites in the construction industry need to be considered. Even the environments with above features have a drawback that the virtual objects in the environments do not have physical mass and therefore, the users cannot get any force feedback during operation. This will not accurately represent construction tasks with heavy and bulky materials.

Additionally, as shown in the findings, the majority of VLEs require the users to be stationary. User being stationary is not a major issue in other industries like manufacturing because manufacturing cells are not as spacious as construction sites. However, the construction work processes would require workers to walk around the site and interact with other workers and robots without the limitation of area size [50].

Furthermore, in most of the current VLEs, only up to one avatar is present, which does not fit the dynamic nature of construction tasks. The existing construction robots require collaboration of multiple workers. For example, for bricklaying robot SAM, a human worker needs to feed brick piles to the robot while another worker checks the quality of the wall joints [51]. Therefore, it is recommended for future VLEs to have a multi-avatar platform where virtual workers interact with human workers and robots.

Lastly, existing robot-included VLEs in other industries mostly show indoor environments and therefore do not provide displays of uneven surfaces and dust or weather conditions like glare, wind and rain. Since construction sites are usually outdoors and since even small effects, such as shadows can affect the realistic response of the user [41], the display conditions need to be enhanced.

107.6 Conclusion

In this paper, the existing VLEs in the construction industry, as well as robot-included VLEs in various other industries were reviewed. To summarize, the main technological drawbacks of the current VLEs are: (1) The current VLEs support either first-person or third-person view, but not both and do not provide the user the opportunity to choose the view that suits the specific learning purposes; (2) Even the most recently developed HMD-based environments require handheld controllers and lack free navigation, which reduces user's immersion to the environment. The main learning content-related drawbacks are: (1) The current VLEs are in the form of tutorial-like games and do not provide interactive scenarios; (2) Majority of VLEs follow traditional sequence of "learning before practicing" but for construction workers, "learning by doing" needs to be utilized; (3) The focus of the majority of existing VLEs is exclusively on safety but for robot deployed VLEs, interactive skill learning will also be an important topic to focus on. The identified drawbacks can be solved by adapting the novel features of robot-included VLEs in other industries. However, before the adaption of novel features, the dynamic and complex conditions of construction sites need to be considered.

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