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Immersive VR Modules for Construction Safety Education of Generation Z Students

Salman Azhar, Ph.D. and Dongnyeok Han, B.B.C.
Auburn University
Auburn, Alabama

Swarnali G. Dastider, M.Arch.
Tuskegee University
Tuskegee, Alabama

This research investigated the potential of immersive Virtual Reality (VR) technology as an assistive teaching tool for construction safety and similar courses that require hands-on training. The most significant advantage of VR technology is creating real-life experiences without exposing the students to the dangers of a jobsite. Earlier studies recognized the need to develop customized VR content for construction safety courses that incorporates specific OSHA standards; hence, this study was conducted with a focus on this objective. After in-depth discussion with two construction firms, the research team identified three most needed areas for safety training namely confined space safety, scaffolding safety, and jobsite clean-up safety. A conceptual framework for VR content design, execution, and method of delivery was designed. Then a storyboard was created for each identified area to graphically depict the concept and workflow for the VR programing. Unity® gaming engine was used as the developing platform and VR modules were created for Oculus Go® head mounted display. Each module contained demonstration of the hazards and mitigation methods based on the OSHA standards. Questionnaire survey and SWOT analysis are used as tools to collect feedback and assessment data from undergraduate and graduate students and industry experts. The survey results indicate that the VR based safety education can play a positive role in improving students' understanding, knowledge retention, and interest in the subject matter. It can help construction firms to conduct enhanced safety training without the need for physical mockups. The paper explains the strategies and lessons learned as well as provides directions for future research.

Keywords: Construction Safety, Virtual Reality, Gaming, Education, Training

Introduction

Generation Z, or Gen Z for short, is the demographic cohort succeeding the Millennials (or Gen Y). Demographers and researchers typically use the mid-to-late1990s as starting birth years (Wikipedia, 2019). Children of Gen Z have used digital technology since a young age and the use of technological gadgets is an integral part of their life. Recent research shows that today's students refuse to be passive learners - "They are not interested in simply showing up for classes, sitting through a lecture, and taking notes that they will memorize for an exam later on. Instead, they expect to be fully engaged and to be a part of the learning process themselves." (Azhar *et. al.*, 2018). In fact, Gen Z students tend to thrive when they are given the opportunity to have a fully immersive educational experience. As a digital generation, Gen Z expects digital learning tools to be deeply integrated into their education. They believe they should be able to seamlessly connect academic experiences to personal experiences through these same tools (Kozinsky, 2017). Engaging these tech-savvy students in the learning process with their preferred learning style is a challenging task. The differences in teaching and learning styles result in problems such as disengagement of students, loss of learning aptitude, and loss of knowledge retention (Azhar *et. al.*, 2018).

This paper is a continuation of an earlier research study conducted to investigate the application of Virtual Reality (VR) based games for teaching construction safety to Gen Z students (Dastider, 2019). As part of this research, the students enrolled in the Construction Safety class were first exposed to the traditional 2D teaching aids, demonstrating construction hazards, and then to few commercially available VR safety games. Their responses were recorded through written reports and oral interviews followed by a survey incorporating comparative analysis between 2D visual aids and VR technologies. The results indicated that the Gen Z students greatly welcomed VR Construction Safety exercises over the traditional 2D visual aids and were interested in exploring more. The research concluded that VR technologies have huge potential as an alternative teaching methodology for Gen Z students because they can provide the real life experience similar to jobsite visit without the potential liability that may arise on a construction site. However, the study also found that, one major challenge with implementing VR in a classroom is lack of customized construction safety related VR content (Dastider, 2019). In order to create customize VR construction safety content the team reached out to several commercial developers; however it became quickly evident that commercial developers are too expensive for pedagogical modules development. Therefore, the authors of this paper decided to join forces together to create customized construction safety VR modules, more suitable for teaching and current construction industry needs.

It is a well-known fact that inadequate safety training in the construction industry may lead to fatalities or injuries on a jobsite. Research has shown that absence of proactive and preventive measures like workforce training, risk source identification and control, safety awareness and education have considerable influence in controlling risk and safety on site (Vitharana *et. al.*, 2015). Given all these facts, teaching construction safety remains a great challenge, both at the university and industry levels. Several research studies conducted in this regard indicate that Virtual Reality (VR) could provide an alternative with better efficacy (Azhar, 2017). VR allows spontaneous interaction to users within a virtual environment thus providing a real life experience (Fernandes *et. al.*, 2006). Education through VR also results in improved efficiency as users are learning by doing and they can develop an emotional reaction to almost real environment, which may help retain more knowledge when compared to the 2D media like textbooks and slides. Moreover, VR contents may also be more effective to foreign workers due to its emphasis on visual learning experiences. Sacks *et. al.* (2013) investigated the feasibility and effectiveness of construction workers' ability to identify and assess safety risks using VR. Sixty-six subjects were provided training in construction safety and their safety knowledge was tested prior to the training, immediately afterward, and one month later. The research subjects were divided between traditional classroom training with visual aids and 3D immersive VR power-wall. The findings indicated significant advantage when using VR training for stone cladding work and for cast-in-situ concrete work, but not for general site safety. VR training was more effective in terms of maintaining trainees' attention and concentration. Wang *et. al.* (2018) investigated the influence of engaging and immersive environments on construction engineering education and training in recent years. The researchers acknowledged the positive influence of VR technology on education and training programs to improve the participants' performance.

Research Aim, Objectives, and Scope

The aim of this research is to create interactive safety training VR modules that could enhance Occupational Safety and Health Administration (OSHA) training for construction students and workers. The research objectives include: (1) Identifying the most needed safety education topics for VR development; (2) Creation of construction safety training VR modules based on OSHA rules and regulations; and (3) Testing the VR safety modules for time management and learning effectiveness by conducting an online questionnaire survey and a SWOT analysis. The team decided to develop a minimum of three VR modules. Oculus Go® was pre-selected as the preferred head mounted display due to its lower cost and easier controls.

Research Design and Methodology

The research initiated by contacting and interviewing two regional construction companies followed by brainstorming sessions amongst the involved parties to identify the most needed areas for VR safety modules. These sessions resulted in three focus areas namely Confined Space Safety, Scaffolding and Ladder Safety, and Jobsite Clean-up Safety.

The team then formulated the scene-by-scene sequence for the three VR modules. The cross-platform gaming engine Unity® was selected for development of the VR modules. Unity® was a natural choice given that it can create three-dimensional VR environments, as well as simulations and other interactive experiences (Samuel, 2016; Dean 2018). It is also a popular choice for game developers in the Architecture, Engineering and Construction (AEC) industries. The workflow for the VR modules development is shown in Figure 1 while more details can be found in Han *et. al.* (2019).

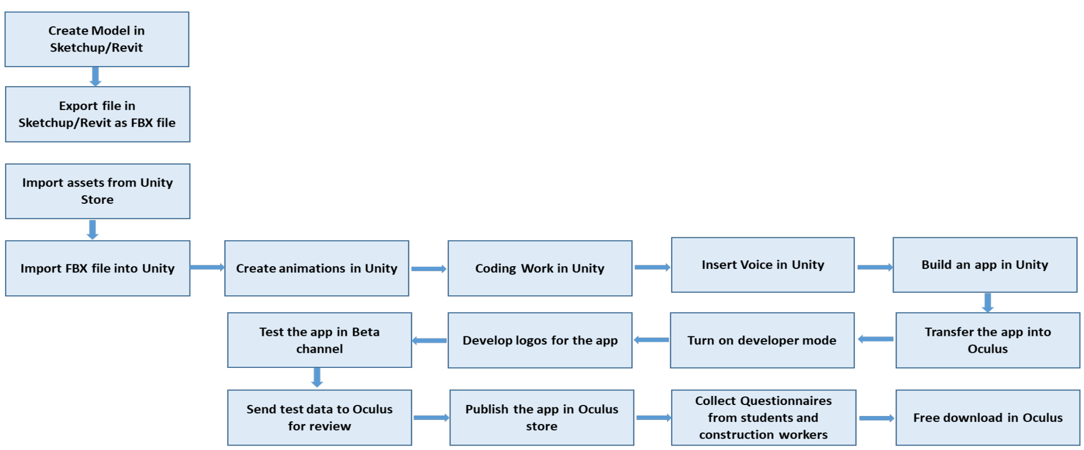

Figure 1. Workflow adopted for VR content development

After completing the three VR modules, the research team tested their effectiveness for construction safety education by engaging a group of undergraduate and graduate students, and industry experts to test them. After testing the three VR modules, each participant provided his/her feedback through an online questionnaire survey. After that, a SWOT analysis is conducted to determine the Strengths, Weaknesses, Opportunities and Threats for the use of VR technology for construction safety education and training.

Description of the VR Safety Education Modules

Module 1: Confined Space Safety Training

Confined space inspection module provides an imaginary environment such as walking inside an underground utility tunnel to inspect the damage to the electrical lines post a heavy rain. This VR module consists of two steps; first one is selection of the appropriate Personal Protective Equipment (PPEs) followed by hazards identification inside the confined space. The VR module starts with the user finding him/herself inside a locker room. The user is prompted to select the appropriate PPEs from the several given choices. The PPEs selection includes LED hardhat safety helmet, rubber insulating liner gloves, full body harness with lifeline and appropriate footwear (see Figure 2). The second phase of the module is initiated after successful selection of PPEs, which leads to the confined space work area. Inside this water-damaged tunnel, the user needs to identify six (6) carefully designed hazards that could be fatal for the oblivious worker. These six hazards are smoke hazard, chemical hazard, electrical hazard, struck by hazard, slippery fall hazard, and free fall hazard. The VR module also indicates the acceptable oxygen level by OSHA standards inside the confined space. Figure 2 shows few screenshots from the simulated confined space.

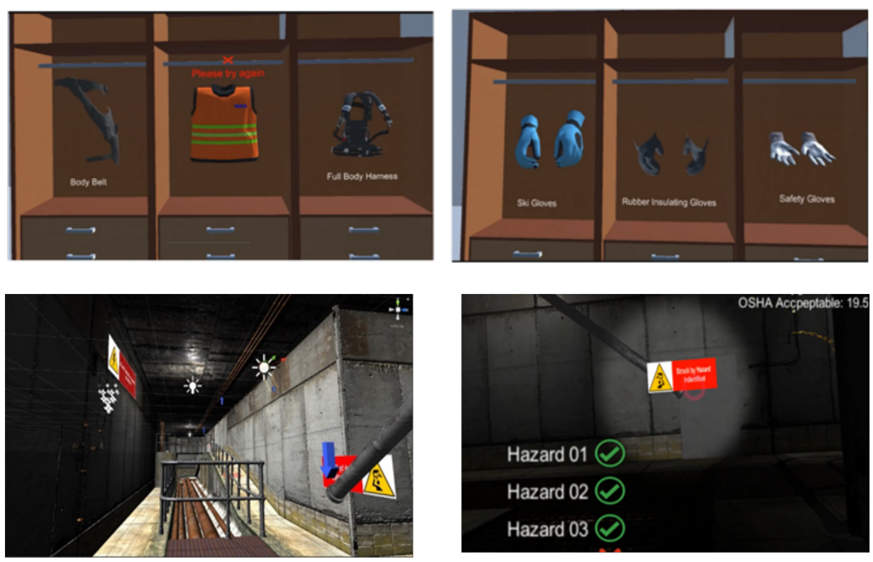

Figure 2. Confined space safety VR module: Selection of PPEs and simulated hazards in the tunnel

Module 2: Scaffolding and Ladder Safety Training

Rubio-Romero *et al.* (2013) mentioned that about 40% of serious construction jobsite injuries are caused by falls from height, and about 30% of these incidents are related to falls from temporary structures such as scaffolding used to work at heights. Thus, hazards associated with unsafe scaffolding remain as most frequently cited in the construction industry. It is a challenge to teach scaffolding safety to a little-to-no experience worker/student using mere PowerPoint slides and/or videos. The research team addressed this issue in this VR module, *the Scaffolding and Ladder Safety Training*. Similar to confined space module, this module also starts with a description of the proper

PPEs needed for installation of windows on a three-story building that requires working at a height more than 6 feet. The module continues on to identify seven (7) safety observations based on the OSHA standards. These safety observations include a detail description of how to install scaffolding, its support system, height restrictions, and guardrail and fall arrest system. The module ends with a short quiz to better reinforce the knowledge gained. Figure 3 shows some scenes from the Scaffolding and Ladder Safety training VR module.

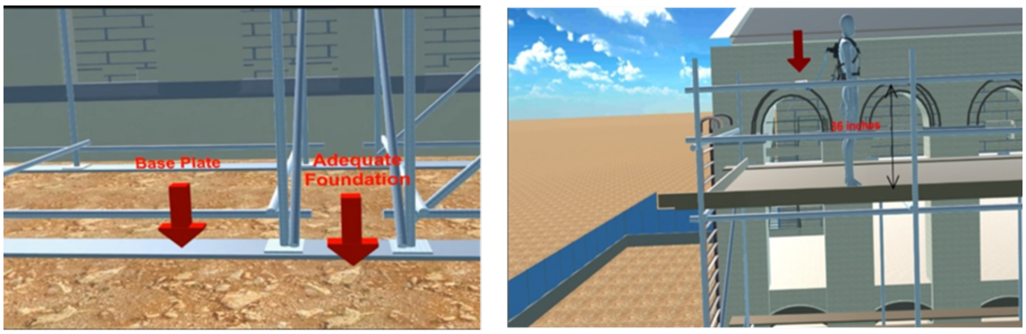

Figure 3. Scaffolding and ladder safety VR module: Selected screenshots depicting hazards/standards

Module 3: Jobsite Cleanup Safety Training

Construction jobsite cleanup is a very important task that is often overlooked. This deficiency prompted the research team to create a VR module to bring focus to this area by demonstrating proper handling and disposal of construction debris. The module begins on a jobsite cluttered with scrap plastic/metal pieces, paints, and other hazardous substances that could lead to tripping, fall, or other hazards. The goal of this module is to train a worker/student on how to dispose or recycle the construction waste using appropriate disposal methods. In the VR module, users must pick up all unused material such as light bulbs, paint, scrape metal and lumber, and dispose them into the right recycling bin provided adjacent to the site. This module further reinforces the experience of the user using a short quiz. Figure 4 shows some scenes from the Jobsite Cleanup VR module.

Figure 4. Jobsite cleanup safety VR module: Selected screenshots depicting various hazards

Challenges Encountered

During the VR modules development process, the research team encountered several challenges that indeed helped to shape up this research. Some important lessons learned are as follows:

1. Length of a module is very important to keep the user engaged and alert. We created the first module using three different durations of approximately 5, 10 and 15 minutes using 4-10 different types of hazards. Through pilot testing, we found a 5-7 minutes duration with 4-6 hazards to be most appropriate. Anything above 10 minutes resulted in user disengagement.
2. Motion sickness is a big concern in the VR modules. The research team paid special attention to the speed and change of environment to make it easier on the users.
3. The VR modules were enhanced with both audio and visual aids to create a realistic experience.
4. The research team also learned about the quality control challenge during transfer of the Unity® based VR modules from a tethering Head mounted device (such as Oculus® Rift) to a standalone head mounted device (Oculus® Go). Although there was no loss of computation power, a moderate visual/screen resolution quality loss was noted.

Results and Discussion

Questionnaire Survey

After completing the three VR modules, the research team tested their effectiveness for construction safety education. Seventeen (17) undergraduate and 8 graduate students enrolled in the Building Science program at Auburn University and 5 VDC experts from a regional construction company participated in the testing. All participants have completed the OSHA 30-hours construction safety training prior to testing. Most of them received their safety training via videos and PowerPoints. Only 4 participants had an exposure to VR environment before testing these modules. The whole testing was completed in five sessions with 4-8 participants per session. All participants completed the three modules back-to-back. After completing the testing, each participant was asked to complete an online questionnaire survey categorized into 6 sections as follows: (1) Background information of the participant; (2) Overall effectiveness of VR based safety training system; (3) User feedback about confined space module; (4) User feedback about scaffolding module; (5) User feedback about jobsite clean-up safety module; and (6) User feedback about the VR headset. Table 1 summarizes the results about the overall effectiveness of a VR based safety training system.

Table 1

Survey results to measure the overall effectiveness of a VR based safety training system

No.	Question/Statement (1: Worst score; 3: Neutral; 5: Best score)	Mean	St. Dev.
1	Ease of use (Did you feel comfortable interacting with the VR system?)	4.48	0.48
2	How real is the virtual environment in the VR modules?	4.12	0.76
3	Do you believe the VR system could improve the hazard recognition process for a real construction site?	4.32	0.52
4	Do you think the VR system enhanced your safety knowledge or understanding?	4.64	0.56
5	Does VR system improve your long-term memory about hazards recognition?	4.09	0.68
6	Does the information provide in the VR safety training system more understandable than a traditional safety training?	4.36	0.58

7	Was the safety content of the VR safety training system helpful in safety cognition?	4.68	0.38
8	Do you think the VR safety training system can enhance construction safety education effectively?	4.76	0.29
9	Do you think the VR safety training system is more beneficial than the class-based educator's lectures?	4.36	0.66

The results indicate that most users have a favorable opinion towards the VR based safety training system. The highest mean score is 4.76 whereas the lowest is 4.09. Almost all respondents mentioned that a VR safety training system could effectively improve the construction safety education. Almost all indicated that the three modules were helpful in safety cognition. Most students pointed out that a VR safety training system is more beneficial than class-based lectures. Due to quality of the VR device, some respondents described that the VR environment was not as real as they expected. The Oculus Go headset has a resolution of 2560x1440 with a refresh rate of 60-72 Hz. Due to medium resolution, sometimes the digital environment looks grainy especially when a user moves close to an object. This limitation is addressed in the new model called Oculus Quest® which has a combined resolution of 3200x2880 with a 72 Hz refresh rate. Due to the change in resolution and other technical specifications, the VR modules developed for Oculus Go® do not directly work in Oculus Quest® and a transformation is needed. We are currently working to reconfigure our VR modules for Oculus Quest® headsets. Participants' feedback about the effectiveness of the three VR safety modules is summarized in Table 2.

Table 2

Survey results to measure the effectiveness of the three VR safety modules

No.	Question/Statement (1: Worst score; 3: Neutral; 5: Best score)	Mean	St. Dev.
Effectiveness of confined space safety VR module			
1	Was it easy to identify hazards in the confined space?	4.60	0.34
2	Was it more understandable than a traditional safety training?	3.90	1.20
3	Was it realistic?	4.60	0.34
4	Did it better prepare you to understand a confined space?	4.32	0.62
Effectiveness of scaffolding safety VR module			
5	Was it easy to understand scaffolding requirements in the VR system?	4.40	0.42
6	Was it more effective than the traditional safety training on scaffolding?	4.32	0.46
Effectiveness of jobsite clean-up safety VR module			
7	Was it easy to understand the overall cleanup module?	4.76	0.29
8	Was it easy to pick up materials in the VR cleanup module?	4.48	0.38
9	Was it more effective than the traditional safety training on jobsite cleanup?	4.60	0.42

The results indicate that the majority of the participants found the VR safety training to be very effective as compared to the traditional safety training systems. Results of the participants' feedback about the VR headset experience are shown in Figure 5. As shown, some testers did not find the Oculus Controller very intuitive. They felt that the gaming controllers (such as Xbox or Nintendo) are better than the Oculus®. The controller is vastly improved in Oculus Quest® and we hope that the users will have a better experience.

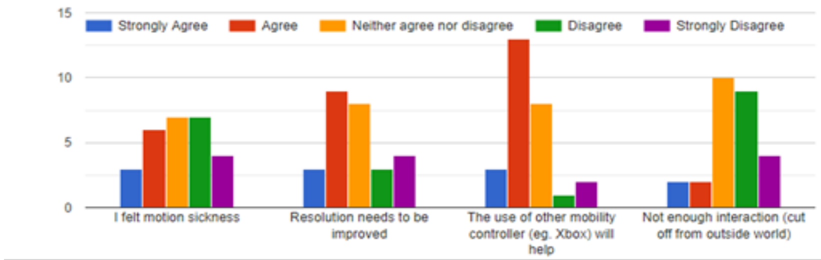

Figure 5. Issues associated with a VR headset

SWOT Analysis

Selected participants provided additional feedback by participating in a SWOT analysis exercise. The results of the SWOT analysis are summarized in Table 3.

Table 3

SWOT analysis of VR applications in construction safety education/training

Strengths	Weaknesses	Opportunities	Threats
• Interactive • Accurate depiction • Improve knowledge retention • Improve interest in the subject matter • Reduce dependence on field visits	• Substantial time commitment in the development phase • Motion sickness • High cost • Not suitable for all instructors/trainees • Immature technology	• Highly effective for 21st century education • Technology is becoming cheaper and affordable • Encourage Active Learning	• Less sustainable • Not suitable in a traditional classroom • Multiple support platforms "confuses" users

The SWOT analysis results indicated that the VR technology is very effective in creating real-life scenarios thereby educating students about jobsite safety planning and other risks without the need to take them out on a real jobsite. It immensely helps and improve student's understanding of the subject matter, knowledge gained, and retained. However, the VR technology has several shortcomings which must be considered before its implementation. First of all, the VR technology itself is still in the development stage and not perfect. Substantial time is required in learning related hardware/software and creating exercises. Many instructors may find this process too much time consuming and lacking added value. In addition, it may not be attractive to instructors that are not well versed with the technology. Other issues include motion sicknesses and/or related medical side effects as well as high cost. There are numerous opportunities for blending VR technology into today's and future classrooms which closely match the life and education styles of Gen Z students. As the cost of technology is becoming cheaper day by day, it can be envisaged that the academic institutes may find it easier to procure and implement in classes. It has equal applicability in traditional as well as continuing education and workers' training. Last but not least, the VR technology supports the active learning style which is becoming popular among the current academics in most disciplines. Several threats were also pointed out in the discussion. First of all, there are number of start-up tech companies that are developing VR technologies and many of them may not be successful in the long run. Hence it is difficult to rely on a single technology platform because it may not be available in the future. It is very important for the users to invest in those technologies/platforms which seem sustainable and will be available in the long run.

Concluding Remarks

This research is in progress and the project team is collecting feedback data from additional participants. So far, the participants have indicated positive learning experiences. They found the VR based learning for construction hazards as being more realistic and effective than the traditional methods. This is a good indicator of improved pedagogical approach to teach construction safety in an innovative way. However, the team does recognize that a more in-depth investigation is needed to push adoption of these modules in the academic curricula as well as OSHA safety training courses. Two strategies are recommended to enhance the use of VR technology for education and training: (1) Instructors/trainers form small teams to jointly develop open-access VR material; (2) Academic publishers should come forward and develop supplemental educational material based on the VR and related technologies and provide it free of cost to instructors.

References

1. Azhar, A. (2017). Role of visualization technologies in safety planning and management at construction jobsites, *Procedia Engineering*, Vol. 171, 215-226.
2. Azhar, S.; Kim, J.; and Salman, A. (2018). "Implementing Virtual Reality and Mixed Reality Technologies in Construction Education: Students' Perceptions and Lessons Learned." *Proceedings of the 11th ICERI Conference*, Seville, Spain, November 12-14, 2018.
3. Dastider, S.G. (2019). Effectiveness of virtual reality technology to teach Gen Z students about construction safety: A pilot study, *International Journal of Scientific Research*, DOI: https://doi.org/10.18535/ijsrm/v7i2.cs01
4. Dean, T. (2018). John Riccitiello Q&A: How Unity CEO views epic's fortnite success. *VentureBeat*. Retrieved October 17, 2018. https://venturebeat.com/2018/09/15/john-riccitiello-interview-how-unity-ceo-views-epics-fortnite-success/
5. Fernandes, K., Raja, V., White, A., Tsinopoulos, C. (2006). Adoption of virtual reality within construction processes: A factor analysis approach, *Technovation* 26(1):111-120.
6. Han, D., Dastider, S.G., Azhar, S., & Salman., A. (2019). "Strategies and Lessons Learned to Create Virtual Reality Immersive Games for Construction Safety Training." *Proceedings of the 19th International Conference on Construction Applications of Virtual Reality,* Bangkok, Thailand, November 13-15. 2019.
7. Kozinsky, S. (2017). "How Generation Z is Shaping the Change in Education," Forbes, Retrieved November 11, 2018 https://www.forbes.com/sites/sievakozinsky/2017/07/24/how-generation-z-is-shaping-the-change-in-education/#7d0f97336520.
8. Samuel, A. (2016). Unity at 10: For better or worse - game development has never been easier. *Ars Technica,* Retrieved October 17, 2018 https://arstechnica.com/gaming/2016/09/unity-at-10-for-better-or-worse-game-development-has-never-been-easier/
9. Vitharana, V. H. P., De Silva, G. H. M. J., & De Silva, S. (2015). Health hazards, risk and safety practices in construction sites. *Engineer: Journal of the Institution of Engineers*, Sri Lanka, 48(3).
10. Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International Journal of Environmental Research and Public Health*, 15(6), 1204.
11. Wikipedia (2019). Generation Z. Retrieved November 16, 2019, https://en.wikipedia.org/wiki/Generation_Z