INCREASING CONSTRUCTION SAFETY THROUGH VIRTUAL REALITY

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Abstract

The construction industry generates jobs for large numbers of people and makes up about 12 percent of the global gross domestic product (GDP). Even though labour conditions vary widely throughout the world, construction represents one of the most dangerous industries. Construction safety intends to prevent people from dying or becoming injured. International Labour Organization estimates that losses of GDP due to this type of accidents represent about 4% of GPD. On the other hand, every construction site is different, unique. It is influenced by many internal and external factors that affect the execution of construction works. The proper training and teaching process can lead to the reduction of occupational accidents and hazards. The education system is increasingly part of the digital transformation of society, which can take advantage of its benefits and opportunities. We are witnessing society's demand for online education and increasing people's digital skills in the field of health and safety in construction.

The aim of the paper is to present an interactive educational tool for the design of a safe construction site using a universally interoperable virtual environment which was developed as part of an educational project supported by the Erasmus+ program. Training tool allows to identify the safety risks during the implementation of construction works and propose measures for their elimination in virtual reality. The emergence of possible safety risks is identified in six groups of scenarios (e.g. fall hazard, tripping hazard) describing 18 dangerous situations on the construction site. A significant benefit of the developed tool is its dynamic dimension, which allows each user (instructor, teacher) to create their own hazard scenarios and their own construction site environments by building information model. The developed educational tool can be used without installing additional software, only with the support of an internet browser on any device (smart phone, PC, tablet).

Keywords: Construction, safety, education, virtual reality, digitization

1. INTRODUCTION

Architecture engineering and construction (AEC) belongs to an important part of the European Union (EU) economy. AEC activities contribute to about 10% of GDP in the European Union and create 20 million jobs [1]. On the other hand, AEC presents represents a dangerous working environment for all stakeholders. In addition, it is characterized by the following features:

- each building and each construction site are unique,
- more contractors are interested in construction project implementation,
- more contractors and subcontractors participate in construction process,
- construction process requires its own production place (construction site),
- construction process has stationary character – people, machines, products „follow“ the construction,
- construction process requires many workers – in terms of number of workers, as well as professions,
- main construction works (earthworks, foundations, framework) are influenced by weather conditions,
- relatively long duration of construction – project implementation.

These aspects confirm the fact that AEC represents one of the most dangerous industries from the point of view of occupational health and safety. The construction site is a dynamic and complex environment, which makes it difficult to manage and monitor. Ensuring a safe working environment, i.e. the construction site and the construction process, prevents working accidents and even deaths. It is a socially actual issue. According to the Occupational Safety and Health Administration (EU-OSHA) in 2020, more than a fifth of all fatal accidents at work in the EU took place within the construction sector [2]. It also represents an economic problem, costing about 4% of world GDP [2]. In the XXI. century, it is unacceptable for a worker to be fatally injured during the implementation of his work. Safety challenges are particularly significant for new and often low-skilled workers due to a lack of training. Injuries and accidents occur because workers are not properly trained in occupational safety [3, 4]. Every construction site is different, so it is necessary to train technicians, workers and engineers on the potential risks that can arise from each new environment [5, 6]. In order to prevent the emergence of safety risks on construction sites, it is not possible to rely only on traditional, current measures for their prevention [7].

There is a solution. The construction industry complies with the concept of Industry 4.0 and provides significant space for the application of the latest trends, knowledge and technologies in the field of Smart&Safe solutions. One of the possible ways of applying this idea is the field of digitization and automation of construction related to the design of an intelligent construction site and the monitoring, identification and elimination of safety risks. It is necessary to solve it already in the educational process by using current innovative elements and approaches. Educational project “Construction Safety with Education and Training using Immersive Reality” (CSETIR) dealt with the development of interactive educational tool for the design of a safe construction site using a universally interoperable virtual environment.

2. CONSTRUCTION SAFETY WITH EDUCATION AND TRAINING USING IMMERSIVE REALITY (CSETIR)

The education project CSETIR was developed as part of an educational project supported by the Erasmus+ program. The civil engineering faculties of universities from Slovakia, Croatia, Portugal and Greece was involved as project partners. The opinions and experience of construction practice were implemented in the project through the representative of a construction company from Croatia. The following chapter provides information about the given project, its goals and outputs.

2.1. Project CSETIR – project goals

The CSETIR project was based on the synergy between higher education institutions and representatives of construction practice. The goal was to introduce the use of intelligent technologies in the proper training process for the elimination of safety risks in the construction industry. The effort is the implementation of digital tools that enable the creation of a virtual environment that simulates construction scenarios and enables teachers, instructors, technicians and engineers to identify and prevent safety risks.

The aim of the project was also to improve the exchange of knowledge between representatives of the three sectors with the aim of innovating approaches to accident prevention through effective cooperation between researchers in the field of virtual reality and construction companies. The CSETIR partnership has developed innovative and interactive VR/AR (virtual and augmented reality) solutions for the prevention of construction site accidents. CSETIR has created a useful tool for teachers, technicians and engineers that can be used in any construction project. The created digital tool with study materials is accessible online on the web site. The project solution supports the horizontal priorities of the Erasmus+ program: (i) supporting individuals in acquiring and developing basic skills and key competences, (ii) tackling skills gaps and mismatches; (iii) promoting and rewarding excellence in teaching and skills development. Project is aimed on three topics: ICT - new technologies - digital competences; new innovative curricula/educational methods/development of training courses; health and wellbeing.

2.2. Project CSETIR – project outputs

The CSETIR project was focused on the creation of a digital education tool for the elimination of safety risks on the construction site. To create the tool, it was necessary to process the following partial outputs:

- needs analysis,
- safety risks scenarios,
- development of interactive educational tool,

- training manuals.

2.2.1. *Needs analysis*

An analytical part provided input information for the solution of the project. It was focused on choosing a suitable VR/AR environment and finding training methods at all levels of qualifications.
Based on systematic and literature reviews done by project participants, on involvement in several international meetings and conferences focused on H&S, in construction sector contributions, several conclusions and guidelines became clear. The research analyzes were mainly focused on tools of BIM-based augmented reality/virtual reality (AR/VR) which can be used as a working environment for development of the interactive educational tool. The selection criteria were set as:

- is the tool available for use,
- is the tool proprietary or freely available, and if proprietary is it affordable,
- what are the hardware requirements (for computing power),
- is any additional special hardware needed (i.e. special hardware elements, not including Head Mounted Displays (HMD)),
- does the tool have a desktop version in addition to a full virtual environment,
- does the tool have a smartphone version (i.e. for Samsung Gear) in addition to a full virtual environment,
- does the tool support multiple platforms (supports more HMD's such as HTC Vive, Oculus Rift, etc.),
- does the tool require additional supporting software, and if yes, is it available to use,
- how detailed and realistic can the virtual environment be,
- how simple is the tool to install and to use,
- does the tool support multiple users in VR at the same time,
- how simple would it be to replicate the research results outside the project partners' institutions,
- is the tool appropriate to teach Health and Safety related topics,
- what hazards/scenarios are available in the tool,
- does the tool support the import of user generated BIM models,
- does the tool support creating additional scenarios,
- does the tool have open source, enabling modifications to suit the user's needs.

Tab. 1: Summary analyzed tools of BIM-based augmented reality/virtual reality [8-17]

TOOL	CRITERIA							
	A	B	C	D	E	F	G	H
1. 3M	YES	YES	NO	NO[1]	NO	YES	NO	YES[2]
2. CAT	YES	YES	NO	NO[1]	NO	NO	NO	YES[2]
3. SRI	YES	NO	NO	NO[1]	NO	NO	NO	YES[2]
4. SAFETY COMPASS	YES	NO	NO	YES	NO	NO	YES	YES[2]
5. LANDMARK VR	YES	YES	NO	YES	NO	YES	NO	YES[2]
6. FULMAX CUBE	YES	YES	YES	YES	NO	N/A	NO	YES[2]
7. VISUALIZATION TECHNOLOGIES IN SAFETY PLANNING AND MANAGEMENT	YES	YES	YES	NO[1]	NO	YES	NO	YES[2]
8. SMVS	YES	YES	YES	NO[1]	NO	YES	NO	YES[2]
9. OSHA PIXO	YES	YES	NO	NO[1]	NO	YES	NO	YES[2]
10. LIRKIS G-CVE	YES	YES	YES	YES	YES	YES	YES	YES

Criteria: A - The tool is available; B - The tool is suitable to teach health & safety (H&S) topics; C - Ability to create and customize scenarios; D - Possibility to have multiple users in VR, E - Has open source; F - Supports various HMD's; G - Has mobile and desktop versions; H - Possible to use and to replicate in outside the project partners' institutions
Notes: 1 Only one user in VR, however others can watch on a separate screen; 2 Possible, but the intended user needs to buy the software and/or special hardware

Ten tools of BIM-based AR/VR were analyzed considering the selected evaluation criteria (Tab. 1). The result of the evaluation analysis was the selection of a suitable tool for solving the project. The development of interactive educational tool for the design of a safe construction site using a universally interoperable virtual environment was implemented in LIRKIS G-CVE environment which present web-based collaborative virtual environments. This VR collaborative virtual environment allows interaction in virtual space among more participants that may be spread over large distances. Globally, multi-user groups can participate together in one completely immersive virtual environment to achieve goals. Distributed virtual environments can be purposely used as training tools for real-time 3D simulations or scenarios. The main benefits of G-CVE tool are: (i) multi user, (ii) no expensive SW/HW needed, (iii) web based (only web browser needed), without installation of any software, (iv) work on any operation system and any device (also with Oculus, HTC, MS Hololens products), (v) switch to VR mode (with VR headset), (vi) open source. VR environment LIRKIS G-CVE was developed by researcher at Faculty of Electrical Engineering and Informatics, Technical university of Košice. LIRKIS G-CVE tool can combine the requirements of the construction site layout and construction smart management with the VR collaborative environment. This compatible virtual environment based on web-based VR technology for the design, monitoring, updating and change of construction conditions will not require the installation of any software. It will work on any of the currently available hardware solutions for working with VR. An indisputable benefit of the proposed application (VR based on web based VR technology) is the possibility of its use in the design of Smart&Safe construction site already in the project construction phase (as part of the site organization project processing) and also in the construction phase (as part of the site equipment project) with respect for all necessary aspects of the construction design, in term of the investor, designer or contractor.

Training was provided for levels 1 to 7 of the European Qualification Framework (EQF) [18]. In terms of training methodologies the partnership is mostly composed by higher education institutions that are experienced in training levels 5 to 7. Concerning levels 1 to 4, generally designated as Vocational Education and Training (VET) the partnership was employ the approaches suggested by European Centre for the Development of Vocational Training (CEDEFOP) and used by VET providers like European Association of Institutes for Vocational Training (EVBB) or European Vocational Training Association (EVTA). The training was based on the outcome based method proposed by Tuning Academy. All modules and training activities was designed and prepared taking into account the knowledge, skills and attitudes required. The competences required was defined to face the several risks and preventive measures adequate for the respective level of qualifications. This outcome based training will allow to prepare everyone from basic level (1) to master level (7), as follow:

- Level 1 – basic general knowledge,
- Level 2 – basic factual knowledge of a field of work or study
- Level 3 – knowledge of facts, principles, processes and general concepts, in a field of work or study
- Level 4 – factual and theoretical knowledge in broad contexts within a field of work or study
- Level 5 – comprehensive, specialised, factual and theoretical knowledge within a field of work or study and an awareness of the boundaries of that knowledge
- Level 6 – advanced knowledge of a field of work or study, involving a critical understanding of theories and principles
- Level 1 – highly specialised knowledge, some of which is at the forefront of knowledge in a field of work or study, as the basis for original thinking and/or research [18].

2.2.2. Safety risk scenarios

Construction workers face numerous hazards every day, but some are however more frequent and have more serious consequences. Due to the limitations of the final training module, not all hazard scenarios designed to teach safe work practices can be presented to the users in a reasonable amount of time. Therefore, a prioritizing of hazards was needed as an initial step in the BIM model creation and construction hazard scenario building process.

Construction injury statistics are often unreliable due to injury underreporting. Most injuries which do not require immediate assistance of a medical professional and more than a few lost work days are seldom reported. This is due to contractor's cost with regards to government penalties, health & safety (H&S) injury rating, worker compensations, higher insurance premiums and others. Injuries that are always reported are those with serious consequences, which might skew the total injury type statistics. For example, all falls from height are reported, while some less severe accidents which happen quite often, are most likely underreported. Both types of hazards are significant in their own way and both should be included in safety training tools.

Injury statistics for severe injuries are reliable as they are reported to the authorities. Most frequent severe injuries are from falls, struck-by accidents, electrocutions and caught in-between accidents, also called fatal four by the US Occupational Safety and Health Administration. Lower severity injuries are not often reported to the authorities, but there is however a way to quantify and rank them using tacit knowledge contained in either H&S experts' personal experience or in the contractor's private databases.

To structure the presentation of those more significant hazards, it was necessary to group them by type of construction workers who were exposed to the hazards, while the hazards to which all workers can be exposed to were grouped by injury type and severity rate (Tab. 2).

Tab. 2: List of safety risks scenarios

HAZARD TYPE	SCENARIO	SEVERITY RATE
1.FALL HAZARD	fall from height when working on roof structures	high
	falling from a mobile scaffold	medium to high
	fall from ladders	low to medium
	fall from an unprotected edge	medium to high
2.TRIPPING HAZARD	tripping on slab rebar	low to medium
	tripping when walking through the construction site	low
3.STRUCK BY	angle grinder accidents	high
	hazards when concreting with a pump	medium to high
	objects flying in the worker's eyes	low to medium
	fall of objects from height	high
	fall of object from a crane	high
	worker struck by construction machinery	medium to high
	collision with a vehicle	medium to high
	trench cave in	medium to high
4.CUTS AND AMPUTATIONS	table saw accidents	medium
5.OBJECT FALLING ON A WORKER	formwork collapsing on a worker	medium
	wall and column formwork overturning and falling on a worker	medium
6.ELECTROCUTION	electrocution due to faulty wires or tools	medium

2.2.3. *Interactive educational tool and training manuals*

The proposed digital tool for the elimination of safety risks at the construction site in a collaborative virtual environment enabling interaction in the virtual space between multiple participants; and a description of the visualization of security risk scenarios. The tool enables a training process for students (not only) in the field of occupational safety and health on the construction site. Developed tool consists of 3 inputs (BIM model and construction site, hazard scenario and safety requirements and measures) embedded and cooperating in a virtual environment LIRKIS G-CVE (Fig. 1).

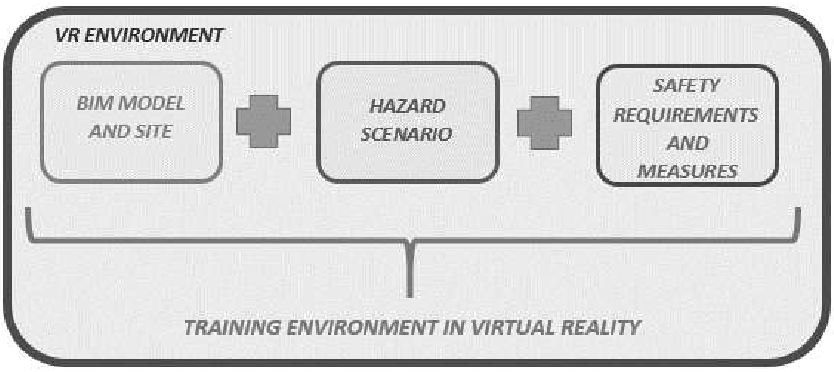

Fig. 1: Elements of the training environment in VR

Training tool allows to identify the safety risks during the implementation of construction works and propose measures for their elimination in virtual reality. The training strategy is based on visual display of the safety hazard situations, of preventive measures and simulation of the consequences of adopting the preventive measure. The particular scenario with safety hazard uses a BIM model in web-based collaborative virtual environments and preventive measures adequate for each risk using BIM. The trainee´s avatar, who has completed interactive training, stands on the construction site. VR environment enables the selection of suitable solutions for a specific safety hazard situation (Fig. 2) [19].

A significant benefit of developed tool is the processing of the dynamic environment which enables the creation of specific construction sites by instructors/teachers who do not have to use a static environment of BIM models of construction and its sites. The design, validation, feedback and subsequent improvement of the tool environment, identification of critical safety construction processes and the design of preventive measures were carried out within the framework of meetings of the international working group, which was made up of experts from the academic environment and construction practice. Scientific methods, analysis and synthesis of knowledge focused on the VR/AR environment, construction safety risks and education were used. Validation of the designed educational tool was carried out through meetings of experts, structured interviews and questionnaire surveys. Questionnaire surveys were aimed at verifying the choice of safety risks scenario, interactive environment and ways of evaluating the training process. The initial survey was attended by 46 respondents from universities and construction practice (OHS coordinators, site managers, construction workers, etc.). The representatives of the International Safety and Health Construction Coordinators Organization (ISHCCO) and International Association of Civil Engineering Faculties (IACEF) were involved to the validation process.

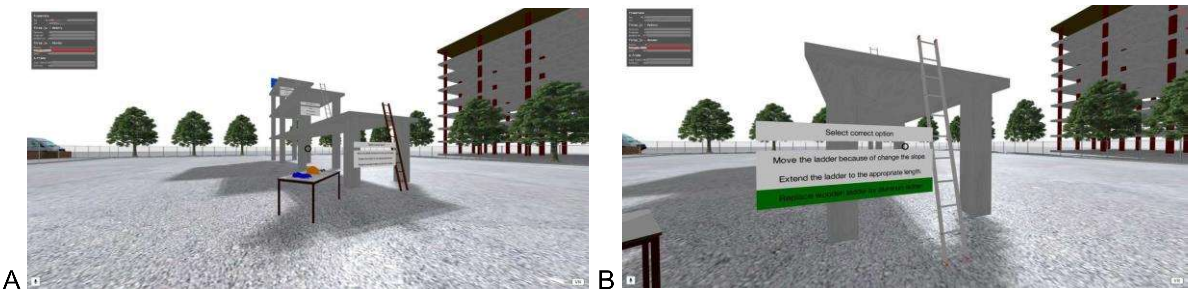

Fig. 2: A: Safety features of construction site equipment (ladder); B: Selection of preventive measure

The processing of training manuals was also an integral part of the developed tool. It presents instructions (manuals) for the use of a web-based interoperable virtual environment, where it is possible to create construction sites or upload modeled construction sites with safety hazards. Two types of training manuals were created - for instructors (teachers) and students (workers, learners), supplemented with links to video manuals. Manuals were created for both groups, which provide information about the software and hardware environment of the developed VR tool, the text and figure guide. The content, scope, arrangement of the training manuals was designed based on cooperation (meetings) with representatives of academic institutions and construction practice in Croatia, Slovakia, Portugal and Greece. Their functionality was subsequently verified by employees of selected construction companies (OHS coordinators, site managers, etc.) and construction workers. Their comments were incorporated into the final design of the training manuals. Verification was carried out through structured interviews.

3. CONCLUSIONS

Virtual simulation techniques are not often used in the construction industry for risk analysis and subsequently in the educational process of students, workers, engineers or technicians. Based on the discussions and research from the table, it became clear that the implementation of VR/AR tools for the elimination of safety risks on construction sites can also benefit construction practice. In fact, digital education and training technologies can be used in the field of health and safety. However, a condition is the close cooperation of the academic community and construction companies. These facts were an indication of the involvement of new technologies in the daily operation of the industry with regard to construction safety. VR/AR have shown potential in the field of research and have subsequently been implemented as promising tools for education and training.

The solution of the CSETIR project and its results are proof of this. This project offered innovative and different education and training techniques. VR/AR, BIM and other digital tools have been on the market for some time and can be used as part of a construction safety solution. The synergy of using practical experiences and digital platforms based on BIM and VR/AR simulations represents an innovative way of transferring competence enhancement in the field of health and safety in the construction industry to various target groups, which makes it possible to prevent risks and support the identification of dangerous situations.

CSETIR aims to implement a methodology for collaboration and practice, integrating a broad vision of the project, where all disciplines create a very close and interconnected communication. The developed tool supports improved communication, experiential training, a more practical and innovative approach to learning in an environment that reproduces the future practical challenges and situations. The transnational character of the project affected the reality of the labor market more globally, different cultures enabling the universality of results and outputs. In addition, the use of e-learning tools and digital platforms enabled the development of autonomous learning and training and the exchange of solutions and case studies between participants.

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