Possibility analysis of danger factors visualization in the construction environment based on Virtual Reality Model

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***Abstract*—The construction industry is one of the most accident-prone sectors of the branch of industry. It is caused to construction site workers by numbers of danger factors which affect humans health and life. These danger factors may cause negative physical and mental effects by instant or long-term actions. Together with development and evolution of 3D technology in design, construction and use of buildings, new possibilities arise. In this article we will give an attempt to present study on this subject, with a use of exemplary factors and their impact on the environment. Supported by Virtual Reality (VR) simulation existing surroundings and analysis factors which have an influence on people will be presented.**

I. Introduction

The aim of this paper is to demonstrate the possibilities of using VR technology in identifying the areas of occupational hazards in the work environment. The use of the above technology makes it possible to better observe phenomena related to the influence of a given factor, which in consequence allows for better management of occupational risk in workplaces in construction [1]–[3]. In addition, we implement factors into the 3D environment to observe their impact on the building environment. In this case, the most important problem is the quality change of life of people in the vicinity of construction site, related to the construction works. The aforementioned group of disease agents causes effects in the human body that are visible only after some time. The most important factors that can be classified in this group (according to [4]) are: physical (eg, noise, vibration), chemical, biological, and psychonetics. After the investment process, the building's environment does not return to its original state, which can also adversely affect human. This is related with the change of acoustics space or strength of traffic in the area. Such changes can negatively affect progressive diseases and the quality of human life.

II. Virtual Reality Environment

Research and analisis of building construction in 3D enviroment is being in phase of very dynamic development. Engineers, constructors and architects are using different tools and programs to create, visualize, and simulate their concepts and ideas. These tools help in optimizing their design in the early stage of the project. Possiblities have very wide range. For example "Iris VR" software is compatible with 3D modeling tools such as Rhino and Grasshopper, Google SketchUp and Autodesk Revit. It gives possibility to enter enviroment of created 3D model of building by using Oculus Rift and Touch. Furthermore we can examine given 3D model for suitable day-lighting exposure. Other examples of VR and 3D development and simulations for construction industry are research and advanced practice in areas of energy simulation, airflow and natural ventilation, thermal comfort, lighting and daylighting, acoustics, and more. [5]

Virtual Reality technology is commonly used in game and entertainment industry. Although it is very atractive, users have to meet high specifications of software producers to take full advantage of Virtual Reality technology. To run games it requires to have powerful hardware e.g. graphic card NVIDIA GeForce GTX 980 or better; procesor: Intel i7-4770 or better; Memory: 16 GB RAM. Its not equipment for everybody because its overall costs, but as its development goes further, more companies are intrested in research and development.

VR is also the basis for scientific research such as the remote co-operation of people in different physical places in virtual reality. It is possible thanks to the growing network of broadband Internet access, enhanced by the Internet. [6] System of high level of cooperation between people and intelligent agents in virtual reality. Create virtual worlds with Newtonian physics simulation and visualization as a human interface. [7] The foundations of a unified international co-operation system based on 3D Internet are also being created. [8]

A. Development tools

The analyzed issue required the use and interrelation of several programs and tools, which were briefly described below:

Autodesk Revit [9] is a Building Information Modeling (BIM) program that includes architectural, building and construction design, and MEP design. Building Information Modeling (BIM) is a process that involves the generation and management of a digital building model that incorporates the physical and functional characteristics of a building. Thanks to this we get a three-dimensional model of the object, enriched with a static-strength, material, functional-utility features, as well as the time and costs necessary during the construction phase. For the purpose of the analysis, the above program, Revit 2017 version, was used to model a multi-storey reinforced concrete building - Fig. 1.

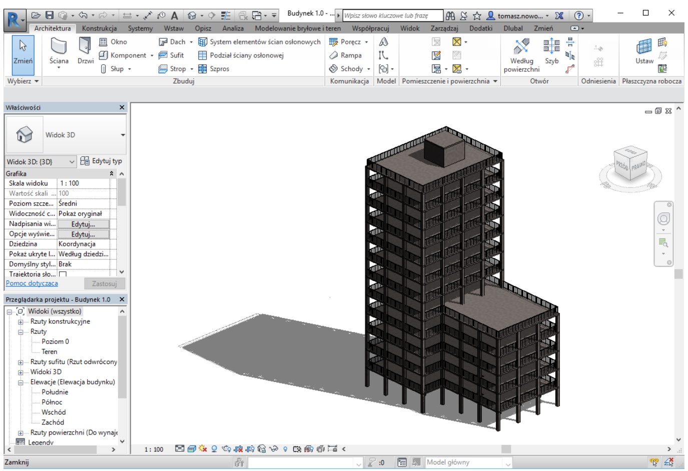

Fig. 1. 3D model of construction used in our analyze - Autodesk Revit 2017

The program used to create a research environment in VR is the Unity (Game Engine) - integrated environment for creating 3D and 2D computer games or other interactive content such as visualizations or animations. It works on Microsoft Windows, OS X, and Ubuntu operating systems and allows you to create applications for web browsers, personal computers, video game consoles, and mobile devices. It was first shown at the 2005 Apple's Worldwide Developers Conference [10].

B. Oculus RIFT + Touch

Virtual reality Oculus RIFT [11] virtual goggles on Fig. 2 were released on March 28, 2016. With two 1080 x 1200 pixels with a refresh rate of 90 Hz, two screens can be seen stereoscopic. Goggle tracking uses a sensor with built-in infrared camera tracking the movement. In addition, you can extend the device by two touch controllers to handle and move around the created world present on Fig. 3.

III. Hazard Factors & Construction Environment

Construction is one of the most dangerous branches of the economy. According to statistics, every year there are thousands of accidents on construction sites around the world, of which 60,000. About the fatal consequences [13], [14]. This is due to the fact that every day, construction workers

Fig. 2. VR goggle of Oculus RIFT - equipment of VIMed Laboratory in Wroclaw University of Science and Technology

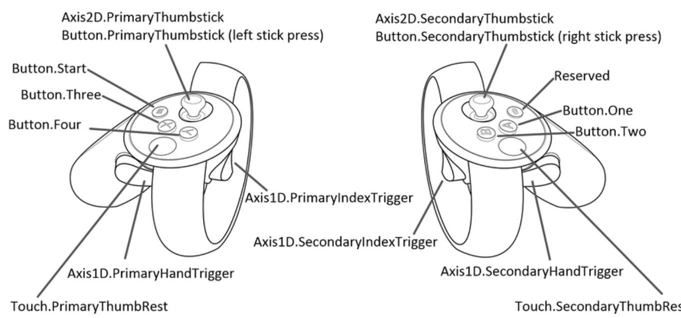

Fig. 3. Touch Controllers [12]

are exposed to a number of factors that endanger their health and life. These factors can cause adverse effects in a sudden or long-term manner. In the first case we are talking about the so-called. ”accident factors” and ”disease factors” in the other [15]. Prolonged exposure in the affected disease area increases the likelihood of occupational disease. For example, in a work environment where noise is present, workers are exposed to hearing-related illnesses. If the employee is exposed to vibration, then the probability of its occurrence on the so-called ”vibration team”.

According to the definition, the factor is ”a circumstance, fact or effect that contributes to a result.” In analyzes of the state of safety of work by the factor, it is necessary to understand all types of material and non-material activities that directly or indirectly affect construction workers, causing accidents at work and occupational diseases.

Hazardous factors in the construction environment are the subject of detailed research, among others. [16]–[27]. Their overall division, due to the type of threat, was proposed, among others. In [15]. Occupational hazards are classified as dangerous, harmful and cumbersome. Each of these groups can cause illness and accidental effects on the human body [4].

The classification of risk factors for the health and living conditions of employees and their relationship are presented on Fig. 4.

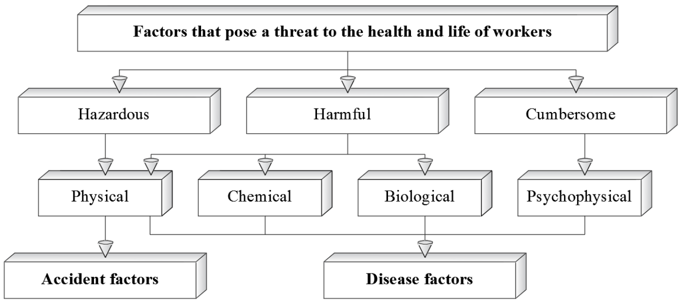

Fig. 4. Scheme of the classification of factors that pose a threat to the health and life of employees (own work, based on [4])

According to Polish regulations [28], the occupational exposure is in situations where workplace exposure exceeds the maximum permissible concentrations (MPC) for chemicals and dusts and maximum permissible intensities (MPI) for noise, vibration, microclimate and radiation.

A. *Noise as a risk factor*

Noise is the most common harmful factor in the work environment. Its source can be machinery and equipment used during work, technology used and work organization. According to research [29], [30] about 35-40% of workers employed in mining, mining and construction are exposed to its negative effects. In addition, some workstations located on site are in particular exposed to repeatedly exceeding the maximum permissible intensities (MPI). For this purpose, the so-called. MPI overrun indicator, expressed by pattern (1):

$$K = 10^{0.1(L-MPI)} \tag{1}$$

where:
L - value of the parameter characterizing the sound - calculated on the basis of measurements,
MPI - value of the highest permissible sound intensity.

Below you will find information on selected workstations in the construction industry that have experienced audible noise [31]:

- soil compactor operator - K = 4.1,
- construction worker - K = 4.8,
- welder - K = 10.5,
- angle grinder operator - K = 30.0.

Parameters characterizing the noise and their limit values are given in Table I.

A different issue is the impact of noise on the surrounding environment. With excessive noise level, not only employees but also people living in the vicinity of the construction site are exposed to its negative impact. In this respect, the Polish regulations [32] define acceptable noise levels in the environment, depending on the type of site and noise sources, related to the different exposure periods. They were identified by the following indicators:
L_{DWN} - allowed long-term average level A in dB - time interval equivalent to all days of the year,
L_N - acceptable long-term average sound level in dB - time interval equivalent to all nights,
L_{AeqD} - permissible sound level in dB - time interval equivalent to 16 hours,
L_{AeqN} - permissible noise level in dB - time interval of 8 hours.

TABLE I. PARAMETERS CHARACTERIZING THE NOISE AND THEIR LIMIT VALUES MPI ACCORDING TO [28]

Parameter characterizing the noise	MPI limit value
Noise exposure level related to 8-hour daily working hours	85 dB
Daily exposure	3.64 x 103 Pa^{2}s
Noise exposure level related to the average weekly working time	85 dB
Weekly exposure	18.2 x 103 Pa^{2}s
Maximum sound level A	115 dB
Peak sound level C	135 dB

In Table II, the permissible values of indices for selected types of land where the noise source is the construction work of the building.

TABLE II. ALLOWED VALUES OF INDICES FOR SELECTED TYPES OF LAND ACCORDING TO [32] - NOISE SOURCE, AMONG OTHERS. CONSTRUCTION WORKS

Type of terrain	Noise Indicators [dB]			
	L_{DWN}	L_N	L_{AeqD}	L_{AeqN}
Single-family housing developments	50	40	50	40
Residential areas of multi-family housing and collective housing, residential and commercial buildings and in urban areas of cities over 100,000 residents.	55	45	55	45

B. *Mathematical description of noise*

Noise is a sound wave that, in a free environment (without obstacles), is roughly spread in the form of a sphere of increasing radius with distance from the source. The intensity decreases in proportion to the distance from the source in acc. Pattern 2.

$$I_1 r_1^2 = I_2 r_2^2 \tag{2}$$

where:
I_1, I_2 - intensity of the sound in the radius r_1 i r_2,
r_1, r_2 - distance from the source.

Surrounded by obstacles, the sound wave, when encountered by the object depending on its structure, can be reflected, absorbed or penetrated by the object. The properties of the material are determined by 3 factors (reflection, absorption of penetration), the sum of which is equal to 1.

IV. EXPERIMENT

The subject of the study was the analysis of the selected area for the propagation of cumbersome and dangerous acoustic waves, which originate at the potential site. The analysis was aimed at exploring the possibilities of using a virtual reality tool to visualize a selected dangerous factor, which in reality can not be observed - after the introduction of the mathematical model of the propagation of sound waves and their interactions with baffles. It also gives visual possibilities for estimating their radius and spectrum from the source - fig. 4.

A. Create VR model

The Unity 3D environment was used for the experiment, which implemented the actual 3D models of the buildings within the scope of the study. The area under analysis is laid out by the streets of Powstancow Slaskich, Zielinski and the vicinity of the office and residential tower Sky Tower in Wroclaw, Poland. This made it possible to create this part of the city in virtual reality, and when using the Oculus Rift + Touch VR, it allowed you to navigate around the environment you created - Fig. 5

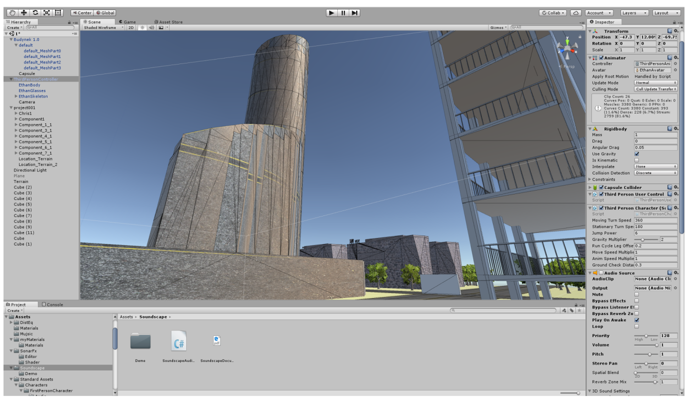

Fig. 5. View on the Sky Tower skyscraper - Unity environment

B. Danger Factors Visualise (Sound Control Function)

In order to visualize the factor which is harmful noise in the virtual reality was used audio script library available in the Unity engine called Soundscape. Real sound was used on construction sites such as drilling, excavating, compacting machines. Initiated noise was investigated by the motion of the person on stage (Fig. 6) Use Oculus (Vision plus Sound) to spread the noise on the virtual construction site. It is possible to delimit the area affected by the sound waves. This provides the basis for further work on visualizing this factor.

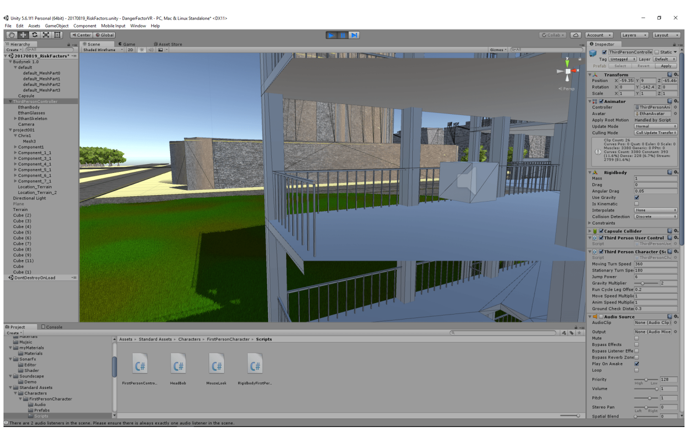

Fig. 6. Sound Source - Unity environment

In addition, analyzes of noise propagation may:

- help to identify areas, on areas with high noise levels,
- enable to analyze the nuisance of noise caused by the construction site on neighboring residential and service buildings,
- gives you the ability to predict and simulate noise from sources such as communication, public or circular transport at your location right at the project stage. Thanks to this, the designer can influence the quality of life and health of the residents.

Other factors can be analyzed, among others: vibration, radiation, and also not discussed here factors related, among others. With the construction machinery and the transport of materials. This gives us the perfect tool for identifying and analyzing the hazards that occur on the construction site and in its vicinity, which help to assess occupational risk at workplaces. In the longer term, implementing this solution in BIM will allow for accurate risk assessment at all stages of the life of the building - from construction, through use to demolition.

V. Results

Throughout the implementation of 3D models built in SketchUp by users (KonZawad and Jojak), the scene of a real fragment of the city of Wroclaw was obtained. Then the scene was imported into a virtual environment based on the Unity engine. This allowed us to navigate, study, and analyze the area of development both from a human and a bird's perspective. Oculus Rift virtual reality goggles (being in the state of the ViMed lab at Wroclaw University of Technology) have allowed for a visual perception of the urban environment (the site and its neighborhood). The Unity and oculus Rift tools allow you to freely move and "teleport" you anywhere to the 3D scene. This allows you to easily explore and analyze the area from any point, which in fact is physically very difficult.

Virtual reality research and analysis have been conducted primarily for noise hazards. In addition, the sunlight was analyzed in the Iris VR development area, before and after the implementation of the newly designed building.

In the developed 3D model, we focused on acoustic analysis and attempted to implement an audio source (path) into it. An audio file emitting the sound of the construction machine (Fig. 6) was assigned to the object experiment. Noise emitted was audible to the user depending on where I was in the scene. Early acoustic reflections, which increase the intensity and reception of noise by humans, have also been pre-implemented.

VI. Conclusion and Future Works

Further work and research into the use of VR for the investigation of dangerous and disruptive factors on the site and its vicinity definitely require further work and development. The authors would like to address issues related to sound propagation, reflection and absorption in a 3D environment. Appropriate implementation of the physical properties and behavior of acoustic waves in the 3D model is needed.

The next step is to try to visualize the noise, its field, and the radius of impact. Translating these acoustic values into visual language to signal zones, areas where noise standards are exceeded, and thus becoming dangerous and burdensome for people working and living in the area. It is also planned to develop research into other factors affecting the behavior, health and quality of human life in the city.

VR gives you the perfect opportunity to analyze and simulate light, acoustics as well as other factors affecting the quality of human life. It allows to visualize and feel the urban environment, analyze its disadvantages and advantages already at the stage of the initial urban and architectural design.

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