

Virtual Reality-Based Simulation Design for Hazardous and Toxic Waste Management in the Cement Industry

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Abstract

Businesses with activities that impact the environment must conduct environmental protection and management for the waste and emissions resulting from their operations. Provisions regarding this matter are stated in Government Regulation Number 22 of 2021. Environmental management must be appropriate according to the type of waste produced, including hazardous and toxic waste. Hazardous and toxic waste has specific methods for storage and management, as detailed in the Regulation of the Minister of Environment and Forestry Number 6 of 2021. However, many companies still violate these regulations and must understand the proper storage techniques for hazardous and toxic waste. Therefore, with the advancement of current technology, we can create interactive technology for education and awareness, one of which is virtual reality-based simulation. Hence, the researcher designed a virtual reality-based simulation for hazardous and toxic waste management in the manufacturing industry.

Keywords: *Environmental Management, Hazardous dan Toxic Management, Manufacutring, Virtual Reality*

1. Introduction

Hazardous waste management in industrial business activities, especially in the manufacturing industry, is a concern because environmental issues are a concern for many governmental and non-governmental organisations [1]. Government Regulation Number 22 of 2021 explains that Environmental Approval, as referred to in Article 2, must be owned by every business and/or activity with a significant or non-significant environmental impact [2]. Data from the Ministry of Environment and Forestry states that around 1.12 million square meters of land were contaminated with Hazardous and Toxic Waste until 2019. This indicates that many workers and business activities still do not understand the management of hazardous and toxic waste.

Mismanagement of hazardous and toxic waste poses significant risks to the environment. Environmental pollution from these materials can adversely affect human, animal, and plant health and disrupt the delicate ecological balance of air, water, and soil [3]. The East Java Provincial Environmental Service oversees environmental management within the province's industries. One such industry is PT. X, a cement manufacturer. PT. X possesses a technical detail document that permits the storage of hazardous and toxic waste. This document serves as a vital framework for the company's waste management procedures and forms the basis for developing virtual reality simulations in this research.

Engineering education is experiencing the most dynamic changes due to the rapid introduction of new technologies and the application of modern educational methods, which impact students' learning methods and ability to succeed in engineering education. Various learning techniques are being improved to enhance learning and hands-on experience and increase interest in science and technology [4].

Education is an essential aspect of building the quality of human resources. Therefore, improving the quality of resources from time to time must also be up-to-date and able to adapt to current developments. Virtual reality media has been proven to improve student learning outcomes from 25% of students who complete to 90% of students who complete to achieve Minimum Completion Criteria. One solution that can be done is to design learning media in the form of simulations. Simulations can make learning easier because users will be brought into the world of Reality like the real world. So that with this media can create interactive learning. Virtual Reality is a technology that can make the virtual world seem to be in the real world. Users can also interact with it [5]. Virtual technology offers a more immersive learning experience than traditional learning materials. VR/AR allows students to delve deeper into concepts, objects, and processes through headsets, haptic gloves, and motion sensors. This immersion allows for experimentation with realistic environments and inaccessible objects [6].

Based on previous research, VR is very popular among students, students and workers who are enthusiastic about using virtual reality media. With the problems and developments in technology and previous research, the author is driven to develop and produce innovative

learning media to enhance the management of hazardous and toxic waste within industrial businesses, particularly those with high waste generation rates.

2. Research Methodology

The data used is data on the management of hazardous and toxic waste produced by PT. X, which is engaged in the Cement Industry. This data was obtained from the author's indirect environmental management supervision reports during an internship at Dinas Lingkungan Hidup Provinsi Jawa Timur (The East Java Provincial Environmental Service). Indirect supervision is the supervision of documents reported by companies or business activities to the East Java Provincial Environmental Service as the company's obligation to implement environmental protection based on the UKL-UPL (Environmental Management Efforts & Environmental Monitoring Efforts) documents. The author developed and designed this virtual reality-based simulation, which took place from September 2 to December 31, 2024. The demo test used Virtual Realty Oculus Quest 2 and the Unity application as a virtual reality game developer application to test whether this simulation could be run properly.

The development of this virtual reality-based simulation has several stages. Planning is the initial stage before making a simulation. The design aims to provide direction to the author to achieve the research objectives with the right steps. At the analysis stage, the data collection process is carried out, where the author conducts observations and interviews with environmental monitoring officers at the East Java Provincial Environmental Service to obtain information related to regulations and binding rules about environmental management, especially hazardous and toxic waste. Then, the information received will be a reference for making virtual reality-based simulations. The design stage is the modelling stage, namely creating all objects made, such as temporary storage places for the waste, packaging places for the waste, storage facilities and other things that are needed. Finally, the implementation stage is to integrate all objects that have been designed using the Unity application to be implemented into Virtual Reality.

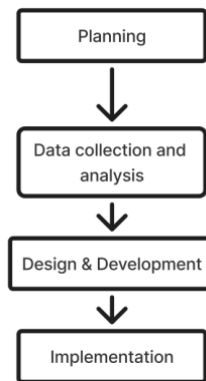


Figure 1: Research Flow

2.1. Planning

The concept determines the simulation concept, title, platform, genre, interactivity, features, etc. The concept is presented in table 1.

Table 1: Concept Simulation VR Based

No	Concept Simulation VR Based		
1	Title	:	Virtual Reality-based Simulation Design for Hazardous and Toxic Waste Management in the Cement Industry
2	Goal	:	Implementing virtual reality technology for hazardous and toxic waste management is anticipated to enhance knowledge and understanding of waste management practices within industrial and business settings.
3	Genre	:	Simulation
4	Platform	:	Desktop
5	User	:	Single User
6	Interactivity	:	<ul style="list-style-type: none"> • Menu Option • Walk in a virtual • Can rotate 360°
7	Dimension	:	3D
8	Feature	:	<ul style="list-style-type: none"> • Operational permit document for temporary storage of hazardous and toxic waste • Symbols and Labels for hazardous and toxic materials • Observation/surrounding the storage area for hazardous and toxic waste

2.2. Data Collections and Analysis

Each business activity produces waste depending on the industry, production process, machines, and other operational activities. Thus, the author took a case study at PT. X, which is a cement industry, has details of hazardous and toxic waste produced as follows:

Table 2: List of hazardous and toxic waste produced by PT. X

No	list of hazardous and toxic waste materials			
	Types of Waste	Characteristic	Amount	Description
1	Used Battery	Corrosive	2 pcs/th	A102d

2	Waste from laboratories containing hazardous and toxic materials	Poisonous	600 kg/yr	A106d
3	Waste contaminated with hazardous and toxic materials	Poisonous	100 kg/yr	A108d
4	hazardous and toxic materials laboratory equipment	Poisonous	2 pcs/yr	A338-2
5	metal sludge (grams contaminated with hazardous and toxic materials)	Poisonous	20 kg/yr	A345-2
6	used packaging for hazardous and toxic materials	Poisonous	300 kg/month	B104d
7	Used lubricating oil	Flammable liquid	300 kg/month	B105d
8	Electronic waste (used lamps, used cartridges)	Poisonous	20 pcs/yr	B107d
9	used filters from noise pollution control facilities	Poisonous	5 pcs/yr	B109d
10	used rags and similar	flammable solid	200 kg/yr	B110d
11	used rags and similar	Poisonous	2 kg/yr	B323-4
12	Used toner	Poisonous	2 pcs/yr	B353-1

2.3. Design & Development

At the design stage, the author creates an object for packaging the waste according to the data that has been obtained. From the results of the author's interview with environmental supervisors at the East Java provincial environmental service, hazardous waste must be packaged in closed packaging so that air and the like do not quickly enter the waste. In addition, closed packaging can protect the surrounding environment from exposure, spills, and other dangers from hazardous waste.

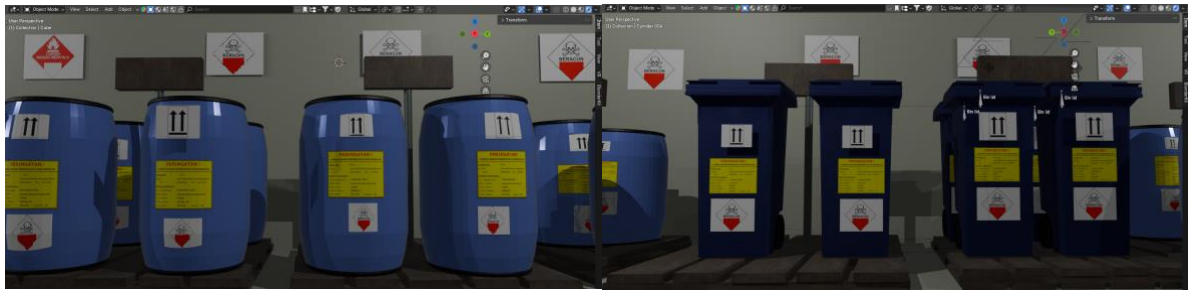


Figure 2: Hazardous and toxic waste packaging using the Blender 3D application

The simulation process will be described in a flowchart to make it easier to understand the simulation process that will be operated through virtual reality. This flowchart can also be called a userflow which is the user's journey during the simulation. Userflow shows users' paths while running an application to complete a task. Userflow is a diagram containing pages or sessions the user will go through [7].

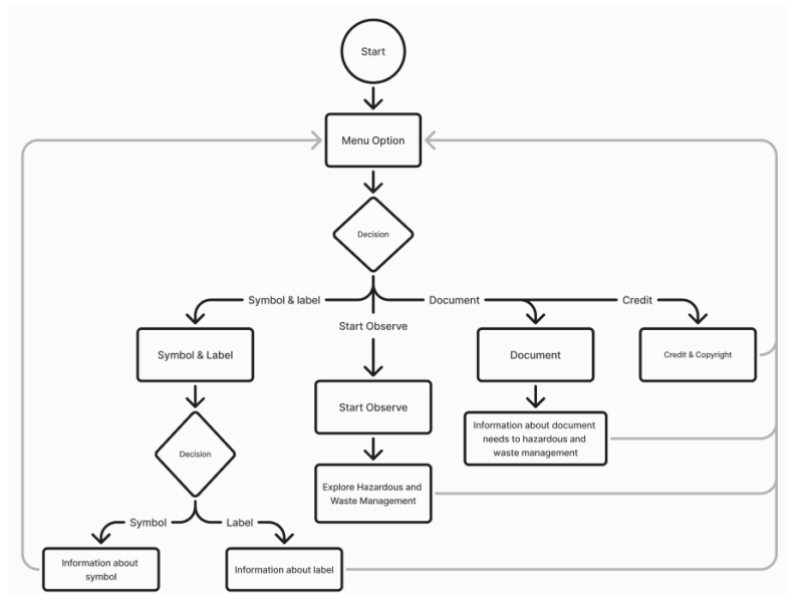


Figure 3: Userflow

3. Implementation

The author developed a simulation using the Unity application in the implementation stage. The author implemented the stages carried out previously in the design process, namely planning, data collection and analysis, design and development. The main menu is displayed on the first display. Users can select start and select several menus, including the symbol and label recognition menu, documents, and user guides, as in Figure 4.



Figure 4: Start Menu and Option Menu

On the symbols and labels page, the symbols and labels regulated in the Regulation of the Minister of Environment Number 6 of 2021 are displayed. These symbols and labels must be attached to temporary storage places for hazardous and toxic waste and packaging for hazardous and toxic waste, as in Figure 5.



Figure 5: Menu Symbol dan Label

The document page contains documents required for operating permits and management of hazardous and toxic waste. One of the documents includes details of hazardous and toxic waste produced by PT. X.

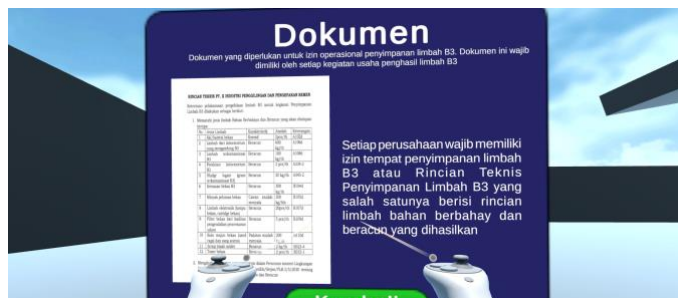


Figure 6: Menu Document

After understanding the symbols and labelling as well as the documents required in the management of hazardous and toxic waste, the user can then observe the environment of the temporary storage area, including what dangerous and harmful waste is produced, along with a description of the waste, a brief explanation of the waste produced, as well as the facilities and infrastructure that must be available at the temporary storage area for the waste, as in Figure below.

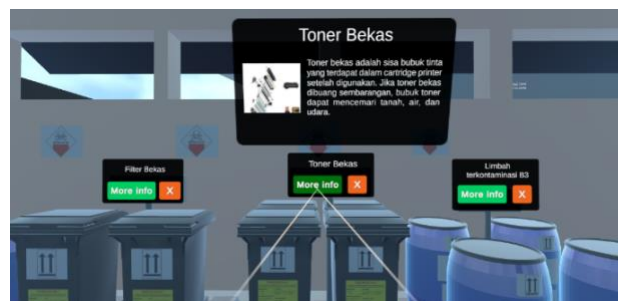


Figure 7: Explore/Observe Section (1)



Figure 8: Explore/Observe Section (2)

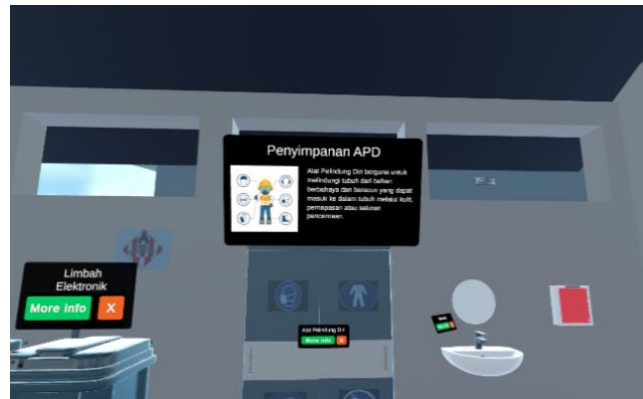


Figure 9: Personal Protective Equipment Facility Information

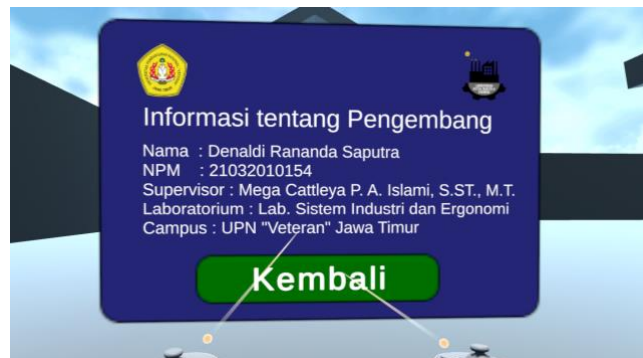


Figure10. Credit Section

The credit page contains information about the application developer to maintain the credibility and originality of the developed application.

4. Conclusion

In this study, a virtual reality-based simulation has been successfully designed and built to introduce hazardous and toxic waste management in the manufacturing industry as a producer of hazardous and toxic waste. Based on this virtual reality introduction it consists of an introduction to symbols and labels that must be attached to dangerous and toxic waste storage and packaging, an introduction to documents required for the operation of hazardous and toxic waste storage facilities, and an exploration of how to manage dangerous temporary and poisonous waste storage facilities based on hazardous and toxic waste management at PT. X, engaged in the cement industry, has complied with the Regulation of the Minister of Environment and Forestry Number 6 of 2021. The test results in the implementation section show that the virtual reality simulation can be run well, display information, and interact with users. With this virtual reality-based simulation, it is possible for workers in the industry, as well as students who want to enter the industrial sector, to learn how to manage the environment according to applicable regulations.

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