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The role of virtual and augmented reality in occupational health and safety training of employees in PV power systems and evaluation with a sustainability perspective

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ABSTRACT

The problems of foreign dependency in energy and the orientation towards national/international environmental policies encourage investments in renewable energy systems. In renewable energy systems (RES), photovoltaic (PV) systems based on solar energy are increasing every year. This situation reveals the need for qualified employees whose working area is photovoltaic systems. This study has conducted a literature search on occupational health and safety (OHS) issues in PV power systems. At the same time, field studies and expert interviews were conducted to examine the OHS practices and training received in the work areas. In this direction, the importance of OHS requirements and training for OHS success in PV power systems has been emphasized. The importance of training has been expressed to increase OHS's performance and success in the PV power system fields. In this study, sample gamification scenarios were created for two different activities in working at height during the installation of the PV. Algorithms have been developed for improving VR/AR applications in OHS training with the sample gamification scenarios created and to support the dissemination of these training applications. In this way, it is aimed to explain the necessary information for VR/AR technologies at an academic level and to contribute to content developers, researchers, relevant institutions and organizations from a sustainability perspective.

1. Introduction

In the world, especially in the fight against global warming and climate change, the orientation to clean energy sources and consequently to renewable energy sources (RES) is inevitable. At this point, research has shown the worldwide tendency toward PV systems will increase, and PV systems will create a wide employment area for the renewable energy sector (European Commission, 2019). The trend towards PV systems causes an increase the need and employment of qualified workers in this field. According to the International Renewable Energy Agency IRENA, 2019, renewable energy and employment report, the number of people working in the renewable energy sector is expected to exceed 20 million by 2030 (IRENA, 2019). That's why, sustainability and safety in PV systems, which are becoming widespread day by day, is ensured by effective OHS management applied in work areas and healthy, high-awareness and qualified employees.

Occupational health and safety have a key role in minimizing any damage, accident/loss and similar situations in PV power systems and ensuring the deploy of qualified personnel. Duroha and Macht (2021), through their literature review, stated that there are no specific accident reports for PV installers and installation (Duroha and Macht, 2021). Also, attention was drawn to the scarcity of studies investigating accidents in the PV industry and their causes. In addition, it is emphasized the dangers of working at height, electricity, thermal stress, and manual handling. Infrastructure Health and Safety Association (IHSA) (2018), it has been stated that there are risks such as falling from a height and electrical accidents in PV power systems. It has been determined that working at height and working with electricity are among the causes of injury (Infrastructure Health and Safety Association, 2018), and these hazards can be reduced with the appropriate trainings to be given to the employees. The New South Wales (NSW) in Australia government has

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Abbreviations

AR	Augmented Reality
CNVVF	Italian National Fire Rescue and Service
GS	Gamification Scenario
IHSA	Infrastructure Health and Safety Association
ILO	International Labour Organization
IRENA	International Renewable Energy Agency
LOTO	Lock Out Tag Out
NSW	The New South Wales
OHS	Occupational Health and Safety
OSHA	Occupational Safety and Health Administration
PV	Photovoltaic
RES	Renewable Energy Systems
SDGs	Sustainable Development Goals
VR	Virtual Reality

produced guidance on OHS hazards and risks in PV installation work (NSW, 2021) (The New South Wales (NSW) in Australia, 2021a). In this guide, it has been pointed out that employees face the risks of death and injury. In this respect, it stated that training is necessary in order to protect employees in the PV industry from OHS hazards and risks. In the guide, it is included contents for training and OHS subjects in PV systems, detailed information about OHS training. The importance of planning, roof access methods, fall prevention systems, safe working management, electrical risks, and manual handling in PV installations were emphasized. In the prepared guide, about the problems encountered in providing OHS efficiency in PV study areas; attention was drawn to the lack of knowledge, training and supervision. The government has prepared a checklist for identifying hazards and risks, ensuring safety management and implementing control list in the areas of PV power systems (NSW, 2020) (The New South Wales (NSW) in Australia, 2021b). Ramali et al. (2022) drew attention to the risk of fire in PV power systems and work areas in the article and stated that academic studies on fire safety were insufficient. Accordingly, it is determined that only 20 of the 264 academic studies reviewed were “closely related” to the fire risk in PV systems. It has been shown that only 3 of these studies directly focus on fire safety in PV systems (Ramali et al., 2022a). Yusri (2018) has identified and evaluated the existing/possible hazards during the installation processes of PV systems. In this context, working at height, use of lifting equipment, electricity, welding work, thermal stress and waste management were emphasized. The importance of providing appropriate trainings and the results of risk assessments in order to combat dangers and risks are emphasized. Interviews were conducted with two executives who are experts in their fields and involved in OHS studies. In the interviews, it was concluded that there is a need for special regulations for OHS conditions in PV power system sites and that they especially encounter electrical accidents (Yusri, 2018). Occupational Safety and Health Administration (OSHA) has published guidance on the hazards, risks, work to be done, and requirements that must be met for PV systems. In this guide, all processes from PV production to waste management are included in the assessment. In the prepared guide, a basic checklist has been created on chemicals, ergonomics, manual handling, working at height, electricity, fire, waste, etc. (OSHA and European Agency for Safety and Health at Work, 2013).

In terms of OHS, especially when the data on occupational accidents are examined, it is seen that human errors and unsafe behaviors are the basis of the accidents. This situation shows the importance of trained employees, awareness of safety culture, and the precautions to take in work environments. Many personal and occupational factors, such as age, gender, education level, occupational status, or lifestyle, have been associated with the risk of a fatal occupational injury (Mirabelli et al., 2003; Richardson et al., 2004; Villanueva and Garcia, 2010). Kaplan and Çallı (2019) examined the relationship between demographic characteristics of employees with work-related accidents in Turkiye between 2007 and 2011 examined the relationship in the study (age, gender, and education). The study determined that the higher the education level, the lower the accident rate (Kaplan and Çallı Kaplan, 2019). Saleh and Pendley have provided a training model to understand system safety and reliability in engineering education. They have found that it is possible to understand the causes of multidisciplinary accidents, identify system errors, and what needs to be done to correct them with proper occupational safety training (Saleh and Pendley, 2012).

Cerev and Yıldırım (2018) state that basic education and vocational training are effective on occupational accidents and diseases, and education is an important factor in combating work accidents and occupational diseases. Also, they reveal the analysis that as the education level of the employees’ increases, the probability of encountering a work accident decreases. In this context, they stated that the main factor in providing a safe work environment to the employee regarding occupational health and safety is the culture of occupational health and safety. For this reason, it has been emphasized that the education system should transfer safety awareness to individuals from an early age (Cerev and Yıldırım, 2018). Li and Zhu (2021), with the 64 articles they reached as a result of the literature research, showed that the trainings using VR/AR technologies had a positive effect on safety management and rescue efforts on challenging issues such as emergency management. The findings have emphasized the success of VR/AR technologies in safety training. In this direction, the trainings carried out with VR/AR technologies increase the cooperation by making a positive impact on the safety culture and awareness of the employees (Zhu and Li, 2020). Santamaria-Bonfil et al. (2020) used VR technology especially in the safety training of personnel working on live-line to prevent accidents in electrical work. As a result, it was determined that 1399 trainees, who participated in 329 different trainings between 2008 and 2016, increased their knowledge and skill levels and their success in safety training (Santamaria-Bonfil et al., 2020). Rey- Becerra et al. (2021), drew attention to the low use of VR technologies in work at height training. In this context, 21 directly related articles from 658 related studies between the years 2010–2021 were evaluated. As a result, it was stated that VR trainings have a positive effect for high-risk jobs such as working at height. However, it has been determined that researches should be increased and applications should be developed in order to increase the effectiveness of safety training in working at height (Rey--Becerra et al., 2021). Research has revealed the importance of education in preventing occupational accidents and losses that may occur due to these accidents. The variability of factors such as workload, age, experience level in the studies carried out for the prevention of accidents affect the success of OHS training and increase its importance (Zhao and Lucas, 2015).

Today, despite developments in sustainability and combating climate change, common policies for healthy and safe working conditions are not adopted. Therefore, policies on OHS issues in renewable energy technologies are not widely implemented, as are investments and incentives. However, adopting new technologies without analyzing possible results and ignoring the relationship between sustainability and safety can lead to more hazards consequences (Nawaz et al., 2019). Even, the carbon emissions of PV systems in supply and transportation are also a matter of human health and environment (Guo et al., 2019). On the other hand, the International Labor Organization (ILO) emphasized the importance of OHS studies in the renewable energy sector. In this respect, it has been pointed out that the definition of “green jobs” which includes the renewable energy sector, does not mean “safe work”. However, it has been stated that employees may be harmed due to dangers and risks if special studies are not carried out on the systems. In green jobs, the integration of OHS practices, OHS experience and training have great importance. In this way, increasing the awareness of employees against hazards and risks according to changing conditions, developing technologies, working areas and conditions contributes to

achieving the goal of "decent work" (Valenti et al., 2016). In this direction, support and projects are needed for vocational training in PV power systems supported by investments and incentives. Increasing investments in vocational and technical training and sustainable processes will contribute to the reduction of occupational accidents (Monteiro et al., 2017). It emphasizes the impact of the benefits of PV systems over traditional energy systems on sustainability. However, it draws attention to the need for an impact assessment in terms of environment and people, and that a full determination of this impact can also resolve concerns regarding PV power systems (Philips J, 2013).

This study specifically focuses on OHS issues in solar energy-based PV power systems, one of the renewable energy sources that contribute to goals such as "Accessible and Clean Energy", "Climate Action", "Sustainable Cities and Communities". In this context, in addition, it aims to contribute to the goals of "Health and Well-being", "Quality Education", "Decent Work and Economic Growth" by evaluating OHS issues with a sustainability perspective. In this study, which is specific to PV power systems, the necessity of incentives for innovative training methods such as VR/AR technologies supported by gamification scenarios and the importance of sector-specific solutions in terms of OHS are emphasized.

In this study, hazards and risks for working areas and conditions in PV power systems are determined. For this purpose, especially between the years 2012–2022, articles related to OHS in direct PV systems, related or supportive articles were examined. Observations were made at different PV sites. The training needs of employees involved in different processes such as PV power systems installation, testing and commissioning, operation, maintenance and repair were investigated. Interviews were conducted during the field studies. In this direction, interviews were held not only with OHS professionals, but also with stakeholders of the PV power system sector with different responsibilities (manager, technician, engineer, project consultant, PV installation company, PV maintenance and repair company). Today, studies that increase immersion in education by supporting with gamification scenarios have been examined. The contribution of VR/AR technologies in education has been investigated. In the literature, the importance of gamification scenarios and VR/AR applications in terms of training activities on OHS and related subjects, which are developed for the purpose of increasing the knowledge and awareness of the participants, such as safety training, and to prevent loss and damage, and expressed as "serious games", have been examined. After all; With the obtained information, evaluations and experiences, sample gamification scenarios for hazards and risks were created. Algorithms, which are the basis of VR/AR applications, have been created to support academic studies, to guide content developers, to encourage innovative training methods in OHS and vocational training. In this way, by training employees with high OHS awareness in PV power system fields; It is aimed to contribute to sustainable business environments that support a proactive perspective on issues such as healthy and safe working environments, healthy individuals, and environmental safety. Attention was drawn to the importance of OHS management for the type of renewable energy source used. In this study, the basic algorithms required for the development of VR/AR training applications in PV power systems were created with the gamification scenarios prepared for "working at height", which is one of the most important hazards encountered in PV power systems. In this way, the algorithm flow for VR/AR training, which is lacking in academic studies, is presented.

2. Material and method

This study investigates the current status of OHS legal regulations that need harmonization for future "green jobs" professions, especially PV power systems. Fig. 1 shows the main stages of the workflow plan implemented in this study.

2.1. Literature review

The academic literature was reviewed between the years 2012–2022 in order to show the place and importance of this study and especially to consider the studies on OHS in PV systems. At the same time, investigations were made on the relevant/closely related activities of national/international organizations. In Fig. 2, the keywords and main titles used during the literature studies are shown.

2.2. Field observations

The installation areas of PV power systems differ (see Fig. 3). For this reason, working environments and conditions are also changing. In this study, field observations were made in order to understand the activities carried out by the working personnel. During the field observations, different activities such as maintenance, repair, cleaning and assembly were followed in addition to the routine works. As a result, common and different points have been determined in terms of OHS studies carried out in the study areas.

Interviews were held in order to understand the OHS hazards and risks in PV power systems and to examine the situation in the field from the perspective of the stakeholders of the PV industry. In this direction, field work was carried out on different PV power systems in Turkiye that produce less than 1 MW. In field works; OHS consultants, OHS managers, solar energy systems project consultants and maintenance/repair technicians were interviewed. In the interviews, information was obtained about the overview of OHS problems in PV systems, assessment, activities and difficulties experienced. The interviews were carried out in the form of interviews and the answers were taken in written form with an interview form. In this context, the contribution of VR/AR applications to OHS effectiveness has been examined, considering the hazards and risks of employee groups operating in PV power systems.

2.3. Training studies: VR/AR

Countries have legal regulations covering the rules regarding vocational training and OHS training of employees. These regulations determine the basic framework such as training subjects and duration. For this reason, legal regulations regarding training and investments in training vary. In addition, there are no legal regulations supporting innovative approaches to education methods. This situation makes education investments a subject at the initiative of institutions.

In OHS trainings, there are main arrangements related to classroom training. In the training of PV system employee, core technical information is given in the classrooms or fields of vocational qualification institutions. There are costs such as the duration of the training and the equipment needed in the classroom or in areas such as workshops and laboratories. At this point, VR/AR applications that allow it to be applied at almost any point with time, space and ease of application provide an advantage. VR/AR applications allow employees to get to know and experience their workplace before entering the field.

In this study, the basic steps to be taken into account in order to

Fig. 1. Material and method flow plan.

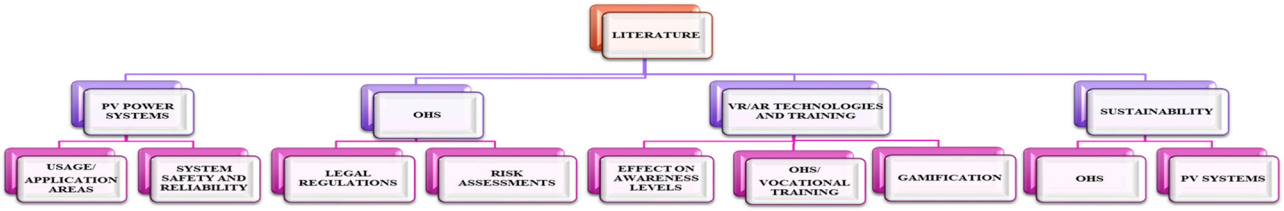

Fig. 2. The academic literature research topics and keywords.

a. Façade type application b. Roof application c. Land application

Fig. 3. Systems where observation and/or interviews are made.

create a training model that will support OHS and vocational training have been determined in line with the hazards and risks identified on the facade type system, land application and the roof integrated PV system, which is becoming widespread today. As a result, basic algorithms covering training requirements and limits for content developers were created.

3. Results and discussion

3.1. Literature overview

Towards keywords that may be related to the subject of this study, the literature researches between the years 2012–2022 are grouped under four main headings:

- ➢ Solar and/or PV systems and OHS,
- ➢ Training requirements in OHS,
- ➢ OHS training and sustainability,
- ➢ The effectiveness/importance of VR/AR training.

The articles that cover the subjects that form the focus and basis of this study have been selected. Among these articles, articles that directly emphasize the dangers and risks in terms of OHS in PV systems, the training of employees, the importance of innovative training methods in OHS issues and a sustainability perspective have been evaluated. As a result, a detailed table of 12 articles was prepared and a general framework was drawn. Among the available sources, studies that are directly related to this study are given in the Table 1.

3.2. Evaluation of field observations

In field observations, it was seen that PV systems should be evaluated gradually in terms of OHS issues. According to the activities, these stages are; installation works (including pre-installation), testing and commissioning, maintenance-repair activities, and cleaning activities. In addition, at every stage, employees may face encounter dangerous behaviors during their activities.

During the field studies, 2 project advisors (medium and large scale), 1 PV installation company employee, 1 PV maintenance and repair company employee, 5 OHS advisors, 1 electrical technician were interviewed.

Interview questions:

Question 1: What are the prominent issues regarding hazards and risks in the PV industry?

Question 2: What are the challenges faced in OHS activities in PV power system sites?

Question 3: What are the causes of the most common accident/injury/loss etc. results in the fields of PV power systems?

Question 4: Are vocational and OHS trainings sufficient for groups working in PV power system fields?

During and after field observations, the questions used in the interviews with employees in different fields of expertise in PV power systems and the findings obtained as a result of these questions are shown in Table 2 . According to the results of the interviews conducted with a total of 10 experienced people who have different roles in PV power systems but work/should work in cooperation in the relevant processes (seeTable 2).

As a result of the interviews, the risk factors accepted by at least 2 of the total employees in different employee groups and in responsibility are given in Table 3. Despite the fact that employees have different knowledge, duties and responsibilities, the fact that they have determinations in terms of OHS and have the same opinion on at least one point draws attention to the importance of cooperation and exchange of views in the same work area.

At the end of the interviews, the prominent causes of problems, losses, or accidents in terms of OHS can be listed like:

- ➢ Lack of training
- ➢ Necessity of applied training
- ➢ Differences of employee groups
- ➢ Changing working conditions and working areas

As a result of the interviews, the prominent problems seen in the work areas in terms of OHS are:

- ➢ Use of insufficient/incorrect PPE
- ➢ Vehicle traffic in the field
- ➢ Failure to act in accordance with instructions

Table 1
Examples of related articles obtained from literature research.

Classification	Title	Authors	Subject	Year
Solar/PV&OHS	1) The photovoltaic industry on the path to a sustainable future- environmental and occupational health issues	1) Bakhiyi et al.	1) Physical and chemical risks have been identified as a result of research on OHS issues in PV systems. In addition to physical hazards such as traffic accidents, working at height, fire and electrical hazards, attention was drawn to issues such as waste management and chemicals. (Bakhiyi et al., 2014)	2014
	2) Hazard Identification and Evaluation in Solar Photovoltaic Installation Process of a selected energy solution provider company	2) Yusri	2) As a result of field studies, research and interviews on OHS issues in PV systems, an evaluation was made with a holistic perspective. After all, hazards and risks are explained when working at height, with electricity and waste management, etc. (Yusri, 2018)	2018
	3) Occupational Safety and Health in Solar Home Systems (SHS) by Brazilian Standards	3) Castañon et al.	3) Hazards to employees and users in terms of OHS in SHSs have been investigated. Examples of causes of hazards and risks are given. In this context, the importance of OHS for the health and well-being of all stakeholders, such as employees, users and businesses, was emphasized as a result of research conducted specifically for SHS (Castañon et al., 2019).	2019
	4) Solar Installations & Their Occupational Risks	4) Duroha and Macht	4) Duroha and Macht, pointed out that occupational accidents for PV installers and installers were not reported. Expressing that there are hazards and risks in the PV installation stages and the absence of industry-specific accident reports makes it difficult to understand the causes of occupational accidents, they investigates the causes of accidents (Duroha and Macht, 2021).	2021
	5) Development of fire safety best practices for rooftops grid-connectedphotovoltaic (PV) systems installation using systematic review methodology	5) Ong et al.	5) The causes of fires in PV systems and the things to be considered for the prevention of fires are emphasized. He especially drew attention to fires caused by connection errors that may occur during the installation of the system and electrical hazards that may occur during or after the installation of the system. As a result of the research, a checklist has been prepared for the prevention of fires in PV systems (Mohd Nizam Ong et al., 2022).	2022
Training requirement in OHS and PV power systems	1) Brazil Market Outlook for Photovoltaic Solar Energy: A Survey Study	1) Monteiro et al.	1) While supporting the encouragement of investments in PV systems, it emphasizes the need for incentives and projects for vocational training. In this study, points out that occupational accidents can be reduced by investing in technical training and sustainable processes. (in the Brazil) (Monteiro et al., 2017)	2017
OHS/OHS training and sustainability	1) Towards a greener labour market: occupational health and safety implications	1) Valenti et al.	1) It draws attention to the importance of integration with OHS practices, OHS experiences, knowledge and training against new hazards and risks for those working in green jobs. They states that training is necessary in order to increase the OHS awareness of the employees and in this way, it will contribute to the target of "Decent Work". (Valenti et al., 2016)	2016
	2) Emerging OSH Issues in Installation and Maintenance of Floating Solar Photovoltaic Projects and Their Link with Sustainable Development Goals	2) Sen et al.	2) In this article, OHS issues in floating solar photovoltaic energy (FSPV) systems are highlighted and sustainability perspective is added. It has been emphasized that the sustainability of an industry/sector can be achieved with a healthy and safe workforce. OHS is a prerequisite for achieving Goal 3 "Health and well-being" and Goal 8 "Decent Work", which are among the SDGs (Sen et al., 2021),	2021
The effectiveness/ importance of VR/AR trainings in the OHS	1) Educational Application of Virtual Reality in Safety Training	1) Cavalcanti et al.	1) It is stated that the current training methods in safety trainings of employees are lacking and the success in VR trainings and safety trainings will increase. (Cavalcanti et al., 2017)	2017
	2) The Enhancement of OSH Training with an Augmented Reality-Based App	2) Kamal A.A. et al.	2) Along with the developments in training, it has been stated that new methods and technologies should be applied in OHS trainings. Kamal et al., emphasized that with AR technology and gamification methods, the success of employees in OHS training and safety management have increased. (Kamal et al., 2021)	2021
	3) Learning analytics for student modeling in virtual reality training systems: Lineworkers case	3) Santamaría-Bonfil et al.	3) Santamaría-Bonfil et al., points out that the success of the students who will/can take part in high-risk jobs such as live line maintenance activities will increase with VR technologies and the losses due to human error will decrease. (Santamaria-Bonfil et al., 2020)	2021
	4) The effectiveness of virtual safety training in work at heights: A literature review	4) Rey-Bacerra et al.	4) Rey-Bacerra et al. emphasized that there is a need for new methods and measurement evaluation methods in safety training. In this context, attention was drawn to VR technologies, which is a risk-free and immersive training method, especially in dangerous activities such as working at height. However, it was emphasized that the literature and studies should be improved in this context. (Rey-Becerra et al., 2021)	2021

Table 2
All the answers received in the interviews.

	Project advisors	Installation company employee	Maintenance and repair company employee	OHS advisors	Electrical Technician
Q1	Electrical connection faults, vehicle traffic in the field (forklift, manlift etc.), working at height	Electrical works, working at height, manual handling, thermal comfort conditions, ergonomic	Electrical works, not using LOTO (lock out tag out), working at height, manual handling, working with hand tools, welding, thermal comfort conditions, ergonomic, waste management	Electrical works, working at height, manual handling, vehicle traffic in the field (forklift, manlift etc.), welding, working with hand tools, thermal comfort conditions, ergonomic, incorrect/missing PPE use, waste management, fire	Electrical connection faults, vehicle traffic in the field (forklift, manlift etc.) working at height, working with hand tools, thermal comfort, not using LOTO, ergonomic
Q 2	Lack of adequate work, regulation and cooperation on OHS	Coordination problem when different employee groups work together	- Coordination problem when different employee groups work together - Lack of adequate work on OHS	- Coordination problem when different employee groups work together - Differences in knowledge/experience/demographic structure of employee groups - Lack/incompatibility/non-standardization of legal regulations on OHS in PV systems - Lack of adequate work, regulation and cooperation on OHS - Lack of education - Failure to act in accordance with the instructions on the field	- Lack of adequate work on OHS - Lack of education - Coordination problem when different employee groups work together
Q3	- Lack of adequate work on OHS	- Lack of adequate work on OHS -Lack of adequate work on OHS training	- Lack of adequate work on OHS -Lack of adequate work on OHS training -Changing technique, technology and working fields	- Employees not acting in accordance with instructions, employers not investing enough time or time in training etc., insufficient vocational training, not using LOTO - Changing technique, technology and working fields - Working with a traditional perspective widely in the work areas	- Coordination problem when different employee groups work together - Changing technique, technology and working fields
Q4	I have no direct knowledge of the contents of OHS and vocational training.	The trainings are not given according to the PV power system working areas and changing conditions.	Vocational trainings and OHS trainings are generally taken. However, applied and special training on OHS issues specifically in PV power systems is not provided.	- The trainings are given theoretically in many projects. - No vocational training requirement for direct PV power systems is expected. For this reason, it is considered sufficient for the employees to have training according to the activity they will perform (electricity, welding, etc.). - OHS issues are included in vocational trainings and OHS information is monitored in exams. However, a training method in which real and changing workplaces or conditions are experienced is not used.	I think that applied and more interesting training is necessary in both OHS and vocational training. It is not always possible to adapt to what needs to be considered in real and changing workspaces.

Table 3
Prominent technical risk factors for OHS in PV systems with interviews.

	Electrical hazards	Working at height	Manual Handling	Welding	Ergonomic	Thermal Comfort	Working with hand tools	Waste management	Vehicle traffic in the field
Project advisors	✓	✓							✓
Installation company employee	✓	✓	✓		✓	✓			
Maintenance and repair company employee	✓	✓	✓	✓	✓	✓	✓	✓	
OHS advisors	✓	✓	✓	✓	✓	✓	✓	✓	✓
Electrical Technician	✓					✓	✓		✓

3.3. Establishment of training models

To increase the level of perception in education, it is important to benefit from the sense organs at a high level, develop and use new techniques and technologies, adopt the philosophy of lifelong education, and increase participation. At the same time, it is necessary to choose applicable, configurable training methods according to the needs.

In this study, an educational infrastructure suitable for VR/AR technology is presented, which starts with the selection and use of PPE, one of the OHS training subjects. However, in the success of the trainings, informing the participants before the training is as important as the correct design of the training requirements and algorithms. In this context, the basic issues that should be informed to the employees before entering the VR/AR application are given in Fig. 4.

OHS measures in PV systems and specific solutions in the literature and legal regulations are quite insufficient. This study evaluated the information obtained from literature research and field observations. With the information obtained, the necessary workflow has been composed for creating VR/AR training that will support both vocational and OHS training.

For proper training, it is very important to recognize the work area, determine the needs, the opinions of the employees, field observations, the data obtained and analyze the hazards and risks correctly. On the other hand, choosing the right employee for the job is necessary for measuring the vocational training qualifications, and correctly expressing the expected educational outcomes. Especially, it is essential to decide on the training outcomes to identify the mistakes that can be made and the desired correct behaviors before implementing the training.

In Table 4, some of the basic behaviors expected from the participant in order to evaluate the results and training success in an OHS training specific to PV power systems are given.

The examples of activities in Table 4, in particular, include a basic flow that can be used jointly during installation, connection works, post-installation maintenance-repair, and cleaning.

One of the hazards common to PV system worksites for roof, façade, or terrain applications is “working at height”. All employees who encounter this danger should be informed about working at height. In addition to the technical and/or basic OHS training received by the employees, the training experience they will gain before going out on the field will be able to prevent possible damages.

At this stage, a sample field was determined to create the gamification framework to be used as a training model. The activities of an employee who made measurements in a façade type PV system in Turkiye were examined and showed in Fig. 5. In planned training, the user enters the VR classroom is perform the application with the wireless VR glasses. The hazards that the user is expected to detect/take measure and the number of hazards should be determined according to the training period. Points should be given for each correct behavior and/or detected hazard in the work area, and success should be reported after the application. In addition, users should be able to experience the consequences of their misbehavior (occupational accident, near-miss incident, etc.). Thus the learning activity can be supported. For this reason, there has to be a limitation about the number of wrong choices while creating gamification fiction in training. For example, in this study, the user is deemed unsuccessful in the training if they make an incorrect choice or behavior twice in a row. Each trial right to be given to users will negatively affect learning after a certain point. In other words, users will have made the right choice in the end, not because they have learned, but because their options are eliminated with every mistake. This should be considered when granting the right to continue training and try again. In order to pass each stage of the training as “successful”, a score should be made and reported. In the result report, users should be able to see their mistakes and correctness.

This study prepared two different “gamification scenarios” for two users who will “work at height” in different roles in the same workspace, according to their functional competencies and activities. While creating the scenarios, some assumptions were made for users (employees). These;

- The user has received basic OHS training,
- If necessary, has vocational training,
- The user has a report of suitability for work in terms of health.

3.3.1. General framework used in algorithms

Algorithms; the study is divided into four stages to determine the users’ training success by facilitating the evaluations in the experience stages. These stages are:

- PPE selection
- Steps to be followed before starting work
- Things to consider during work
- Things to do at the end of the work and certification

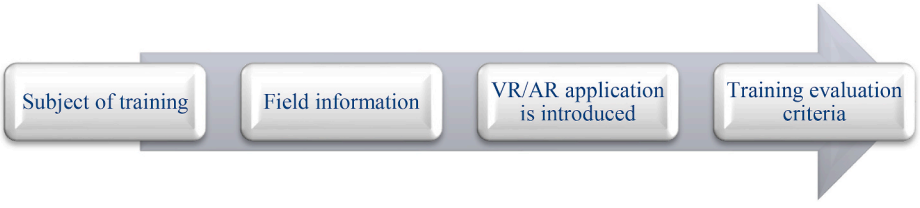

Fig. 4. Requirements for creating virtual reality applications in OHS training.

Table 4
The example activities expected within the scope of OHS in PV systems.

Key activities expected from employees/teams in work areas	• Implementation of work permit procedures • Energy cut off • Implementation of tagging-lockout procedures • Preparation of the work area • Selection of the necessary equipment for the job • Personal protective equipment (PPE) selection • PPE usage • Conducting the activity • Completion of the activity • Energy return • Bringing the working area to the state should be

Fig. 5. Example from field observation of working at height.

3.3.1.1. In the PPE selection section of these stages. Only two attempts are given to the user to make the right choice. This situation can be changed according to preference. However, it should not be ignored that every trial right will reduce the reliability of the training result because the user will continue to choose from the remaining options after every wrong attempt and eventually find the right choice. To complete this tutorial stage, the user must achieve a minimum of 70 points. Otherwise, the training cannot be completed, and training cannot be continued.

3.3.1.2. The steps to be followed before starting the work phase. The user is generally expected to get on the manlift in a controlled manner before starting work and to attach the parachute-type safety belt, one of the most important steps of working at height, to the correct attachment points. As a result of the belt not being properly attached to the manlift and/or lifeline, the user is given a maximum of one trial right. In other words, the training will fail if the user cannot make the correct connection after two attempts. Therefore, the user's training will stop. In addition, to the user occupational accident/near-miss simulations are experience in case of failure to make the connection with the belt or making wrong/incomplete connections.

3.3.1.3. The things to consider during the work phase. In this study, it is assumed that the work area is designed to do the job and that the employee is also suitable to do the job. It is also assumed that the user has received training on ergonomics, the equipment to be used and the work to be done. The score required to complete the training is expressed in accordance with national regulations, as the fieldwork is done in Turkiye. Thus, to complete this tutorial stage, the user must achieve a minimum of 70 points. Otherwise, the training cannot be completed, and training cannot be continued.

3.3.1.4. Termination of activities and certification. From the user; is expected to terminate the activity carried out in the work area, make the belt connections correctly and apply the finishing procedures by getting off the manlift in a controlled manner. In addition, the lifting equipment used in the work area has been determined as a manlift. However, content developers can change their equipment (with cranes, etc.) according to the need and the area to be worked. It is assumed that the authorized and/or user knows the work permit procedures in the algorithms prepared at this stage. At this stage, the user must get at least 70 points. If the user gets a lower score, he cannot complete the training and is considered unsuccessful. Therefore, the certificate is not issued. The user who arrives at the last stage of the training by fulfilling the required behaviors and/or exceeding the limit score determined will be considered successful in the training.

The minimum score required for the user to be successful throughout the training was accepted as 70. Accordingly, the user must receive at least 70 points. The score required to complete the training has been considered in the "Occupational Health and Safety Law No. 6331″ in force in Turkiye and the "Regulation On The Procedures and Principles Of Employee's Occupational Health And Safety Training" issued by this law. For this reason, the requirement for employees in the relevant legal regulations to receive at least 70 from OHS training has been considered and used in the algorithm.

While creating algorithms, at some stages, the employee must be disqualified from training and considered unsuccessful. In some stages, scoring should be done for the choices made and the success of the education should be evaluated according to the attainment of the determined score at the end of the training. These criteria depend on the risk significance level of the expected outcomes in the training, the evaluation team or the people who will participate in the training, etc. should be determined by the circumstances. For example, the knowledge/

experience level of the occupational safety specialist and the occupational physician or other team members is important.

3.3.2. Gamification scenarios and algorithms

Gamification scenario 1 (GS1); Let's assume that a cleaning worker from within/outside the institution who has received basic OHS training needs to work at height to clean a Façade type PV system. In this gamification scenario, it is planned for the user to clean the PV panels that are contaminated by weather conditions, dust, etc. Accordingly, when compared to technical staff, an employee who lacks technical knowledge about PV fields needs access to the PV system. Accordingly, the user had to work at height in the Façade type PV system site, whose energy was cut off. Therefore, a manlift was preferred as the lifting equipment for working at height. It is accepted that the operator who will use the manlift has the necessary driving documents. Situations where the user can be considered unsuccessful in training:

- Not getting the specified limit points for completing the training,
- Not making parachute-type belt connections (as this step is one of the most critical steps of working at height, those who do not make the connection correctly cannot proceed to the next step),
- Failure to fulfill the right choice, working procedure, and code of conduct within the given trial rights,
- Failure to comply with OHS rules to the expected extent.

In the Fig. 6 the general algorithm of the VR/AR training that this employee will enter before working at height (Fig. 6):

- The user chooses the right personal protective equipment (gloves, work shoes, hard hat, vest, parachute type safety belt, goggles when necessary (in a dusty area, etc.))
- If the user does not get a score of 70 or higher at the end of the selections, they can try their PPE selections again. In this case, it returns to the PPE selections step of the algorithm.
- If the user cannot reach the specified score at the end of the second attempt, the training will fail, and the next step cannot be started.
- The user, who completed the PPE selection, gets on the manlift according to the operator's control and instructions when user enters the field.

In the Fig. 7:

- The user exits the manlift with the operator command.
- The parachute-type belt is first attached to the manlift.
- The user fastens the parachute-type seat belt correctly and at the appropriate points.
- The manlift will rise to the required height if the belt is fastened correctly.
- The belt is attached to the lifeline. It is assumed that the lifeline exists here.

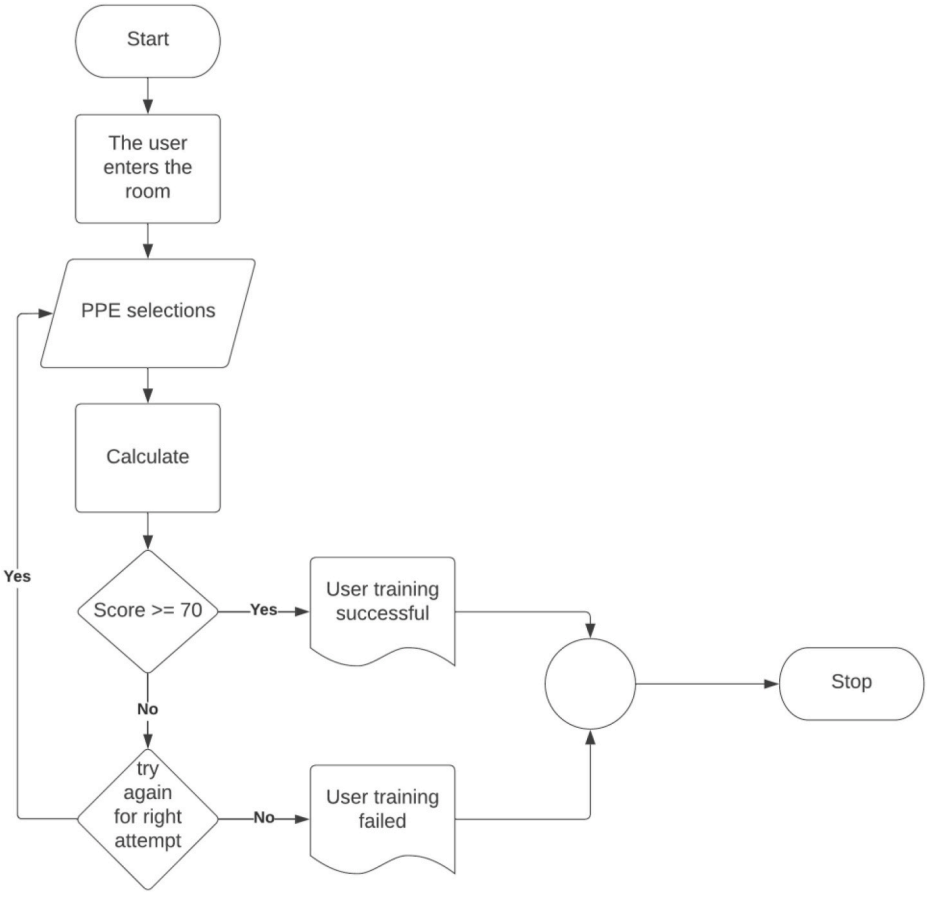

Fig. 6. Algorithm 1 - PPE selection.

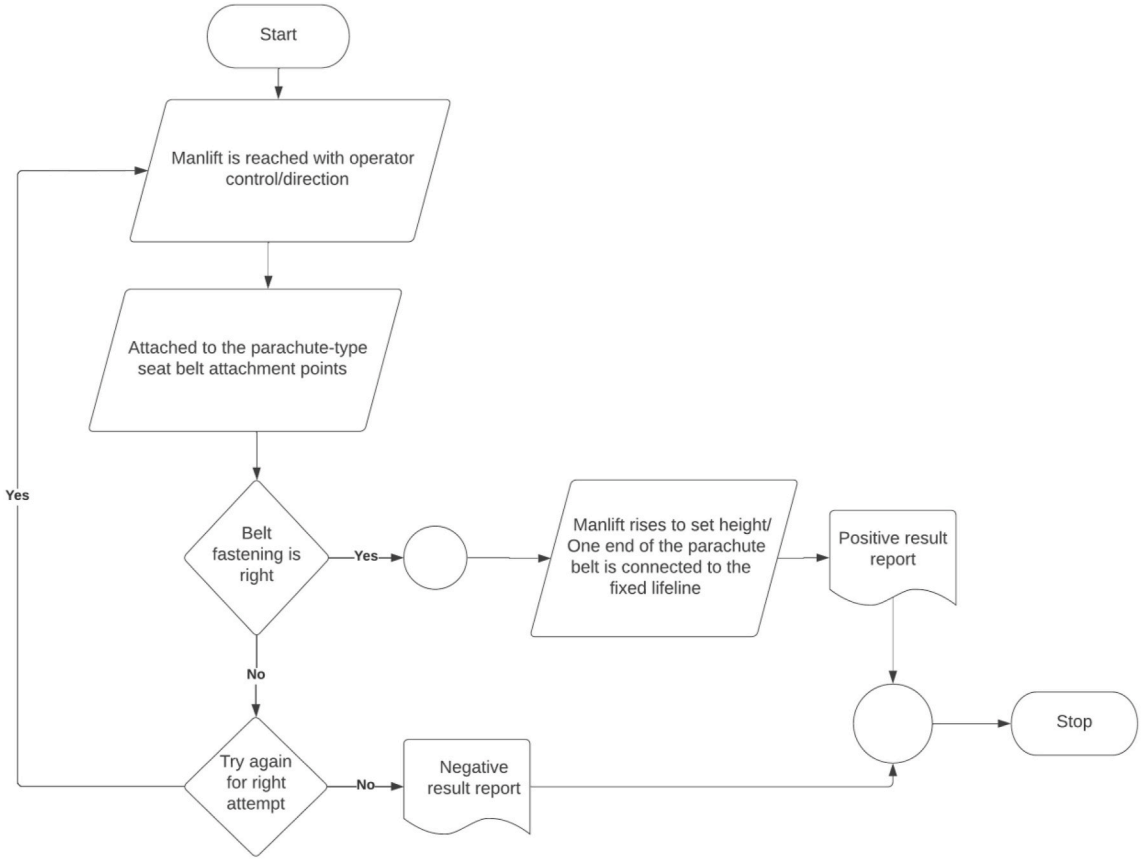

Fig. 7. Algorithm 2- Steps to be followed before starting work.

- ➢ If the parachute-type belt connection is not made correctly, the user can try again.
- ➢ The training is considered unsuccessful if the user cannot make the parachute type belt connection correctly after the second attempt.

In the Fig. 8:

- ➢ The user starts work.
- ➢ The user must comply with ergonomic rules (such as body posture and hand-arm reach distances) throughout the work.
- ➢ The user must have all equipment to be used during maintenance/ repair complete and complete.
- ➢ The user must use the equipment he needs during work according to its purpose.
- ➢ Only users who can score at least 70 points in this section are considered successful.

In the Fig. 9:

- ➢ The user notifies the operator when the job is finished.
- ➢ The user performs the job completion procedures. In this context, the user collects equipment and securely attaches the parachute-type belt fasteners to the manlift.
- ➢ The user descends under operator control.
- ➢ The user does not leave any equipment on the manlift.
- ➢ Predetermined points are deducted for all wrongdoings.
- ➢ Only the user with at least 70 points is considered successful in creating a certificate.

Gamification scenario 2 (GS2); Let's assume that a technical staff who has received vocational and basic OHS training inside/outside the institution must maintain and repair a facade-type PV system. The user will work in the same workspace and conditions as in gamification scenario 1.

In the GS2, the user is maintenance/repair personnel. Therefore, the user must have a vocational training certificate to enter the VR/AR training application. While the algorithm is being prepared, it is assumed that the user has the necessary professional training.

The algorithms also consist of four stages for GS2. However, updating the basic logic of the first third algorithms wasn't needed. This state has facilitated the creation of the general framework and infrastructure of the algorithms.

The general flow of the VR/AR training that this employee will enter before working at height:

In the first algorithm, the right choices are redefined according to the activities to be selected (see Fig. 10).

In the GS2, in addition to the GS1 (see Fig. 11):

- ➢ Before starting work, the user checks that the power is cut off on the PV power system.
- ➢ The user must stop the work if the power is not cut off.
- ➢ If there is no energy in the PV power system, the user can proceed to the maintenance and repair procedure.

In the third algorithm, ergonomic behaviors are redefined according to the activities to be carried out by the user (see Fig. 12).

In the GS2, in addition to the GS1 (for Fig. 13):

- ➢ The user notifies the operator that the work is finished.
- ➢ The user notifies the authorized person that the maintenance/repair work has ended.
- ➢ Collaborates to implement LOTO procedures. The PV power system is re-energized.
- ➢ The PV power system is tested to be operational.

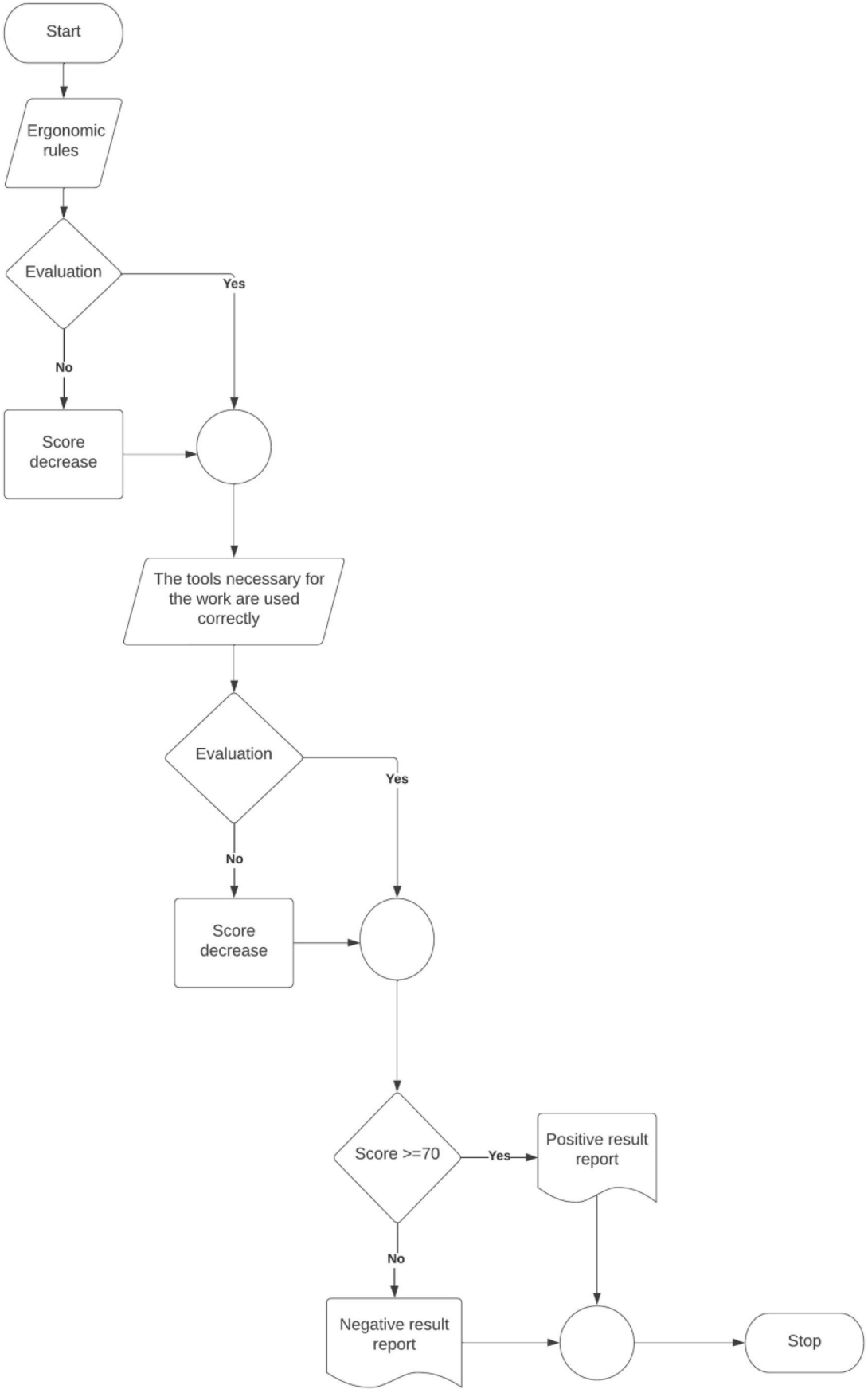

Fig. 8. Algorithm 3- Things to consider during work.

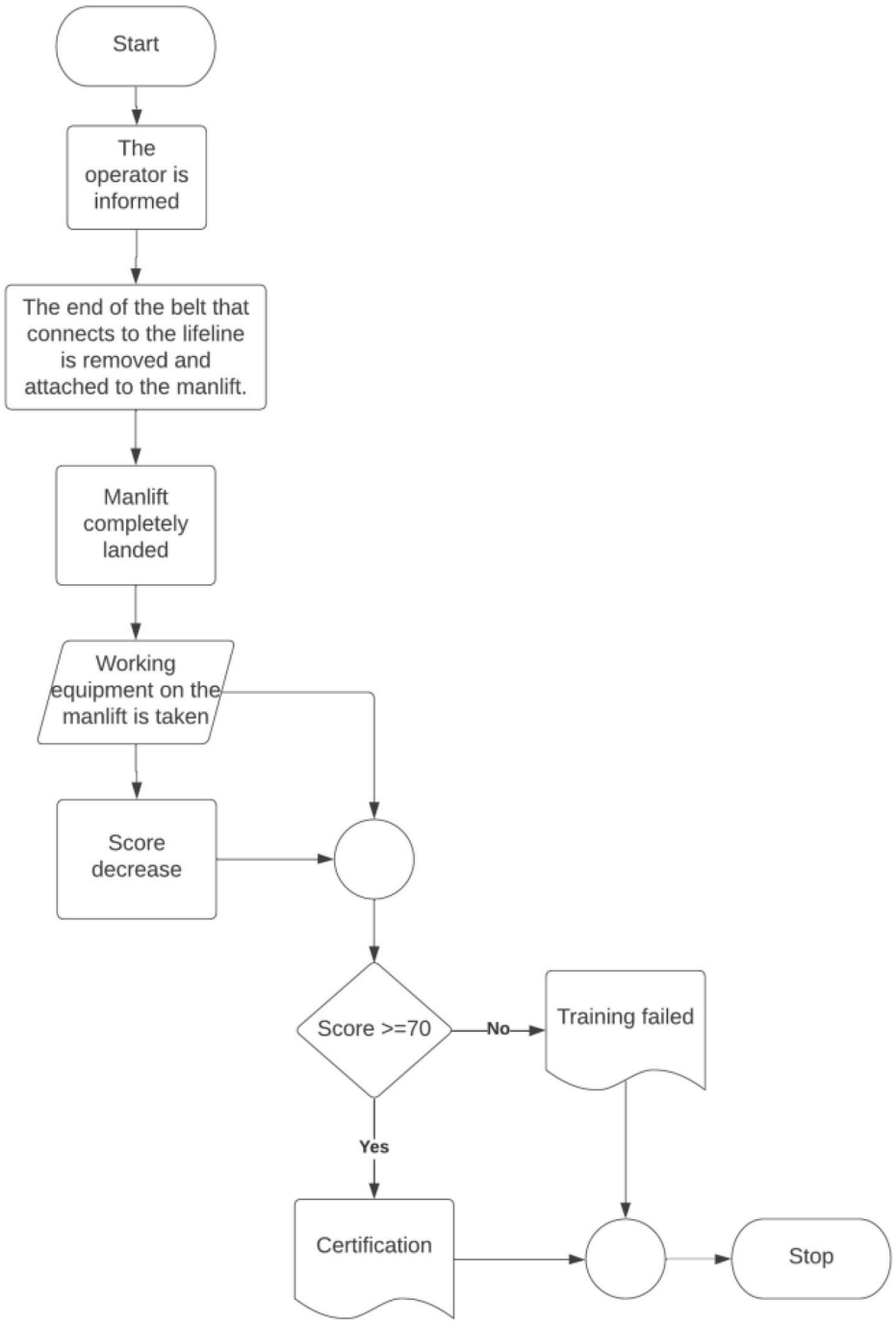

Fig. 9. Algorithms 4- Things to do at the end of the work and certification.

➢ According to the work permit procedures, the relevant persons are notified that the work has been completed.

Finally, only the user with at least 70 points is considered successful in creating a certificate.

3.4. Discussion

3.4.1. PV and OHS

As in every sector and way of working, PV systems have dangers and risks in terms of the OHS. The environmental friendliness of PV systems does not mean that there is no danger/risk in terms of the OHS in the PV power system sector. For example, in Germany, from 1995 to 2012, 179 out of 400 fire incidents were found to have caused a fire in the PV system, and the majority of it failed within the first year, reflecting a rate of 44.8% (Ramali et al., 2022b). According to a study by the Italian National Fire Rescue and Service (CNVVF) from 2002 to 2015, about 2500 fire events occurred in about 550,000 PV systems (Ramali et al., 2022b; Bonomo et al., 2017). These data draw attention to the possibility of damage/loss in PV systems due to fire (Ramali et al., 2022b; Coonick et al., 2018; Mohd Nizam Ong et al., 2021). In addition, Wang et al. (2014), were made risk assessments with Hazard and operability analysis (HAZOP) and Fault tree analysis (FTA) methods in terms of OHS, especially in devices or parts (such as panels, batteries, inverters) involved in electricity generation and conversion in PV power systems (Wang et al., 2014). Kamenopoulos and Tsoutsos (2015), presented a

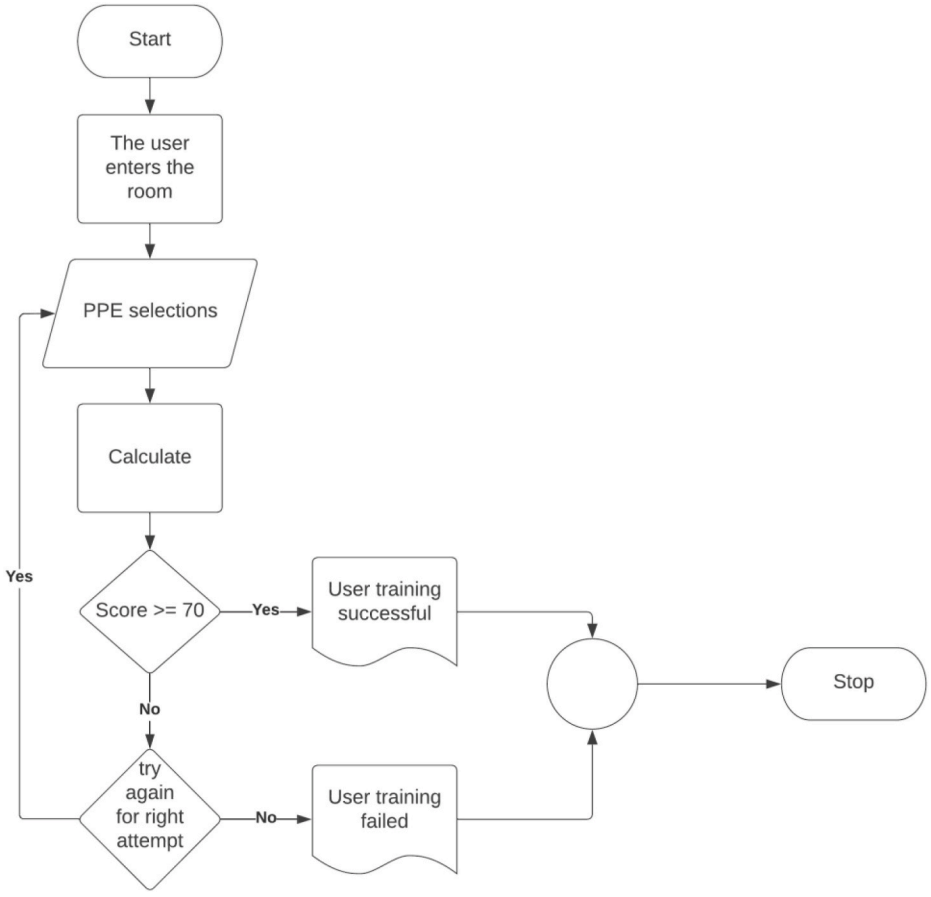

Fig. 10. Algorithm 1 - PPE selection.

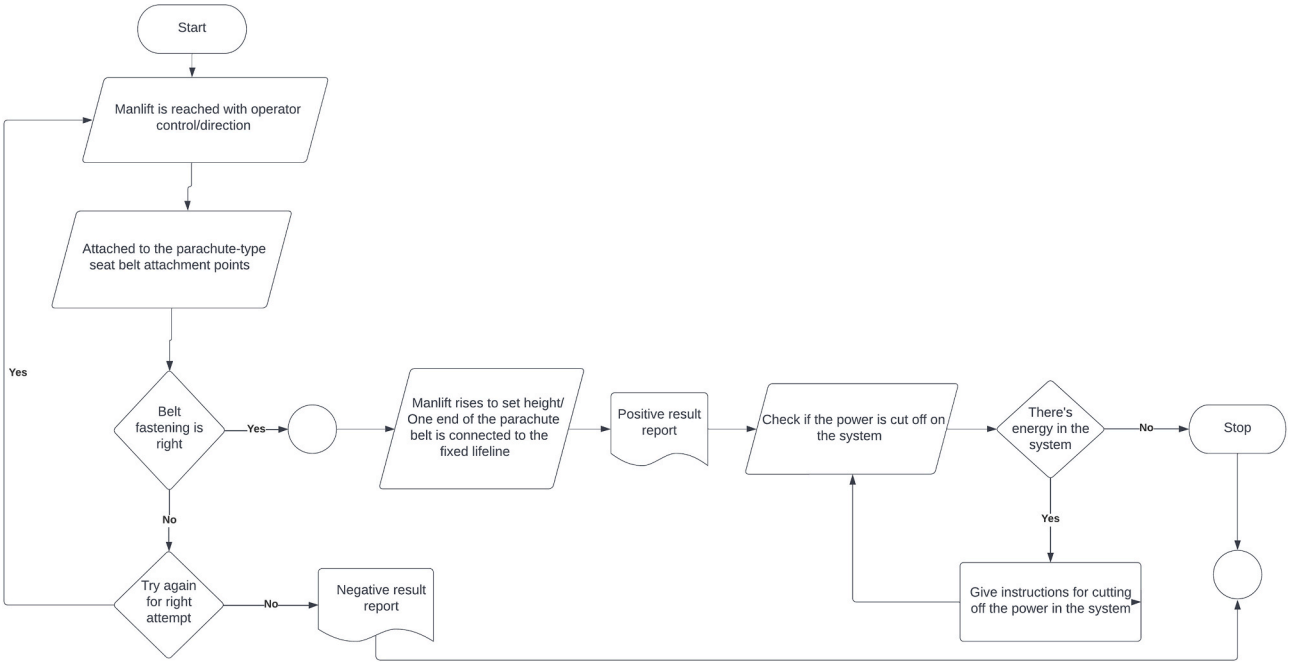

Fig. 11. Algorithm 2- Steps to be followed before starting work.

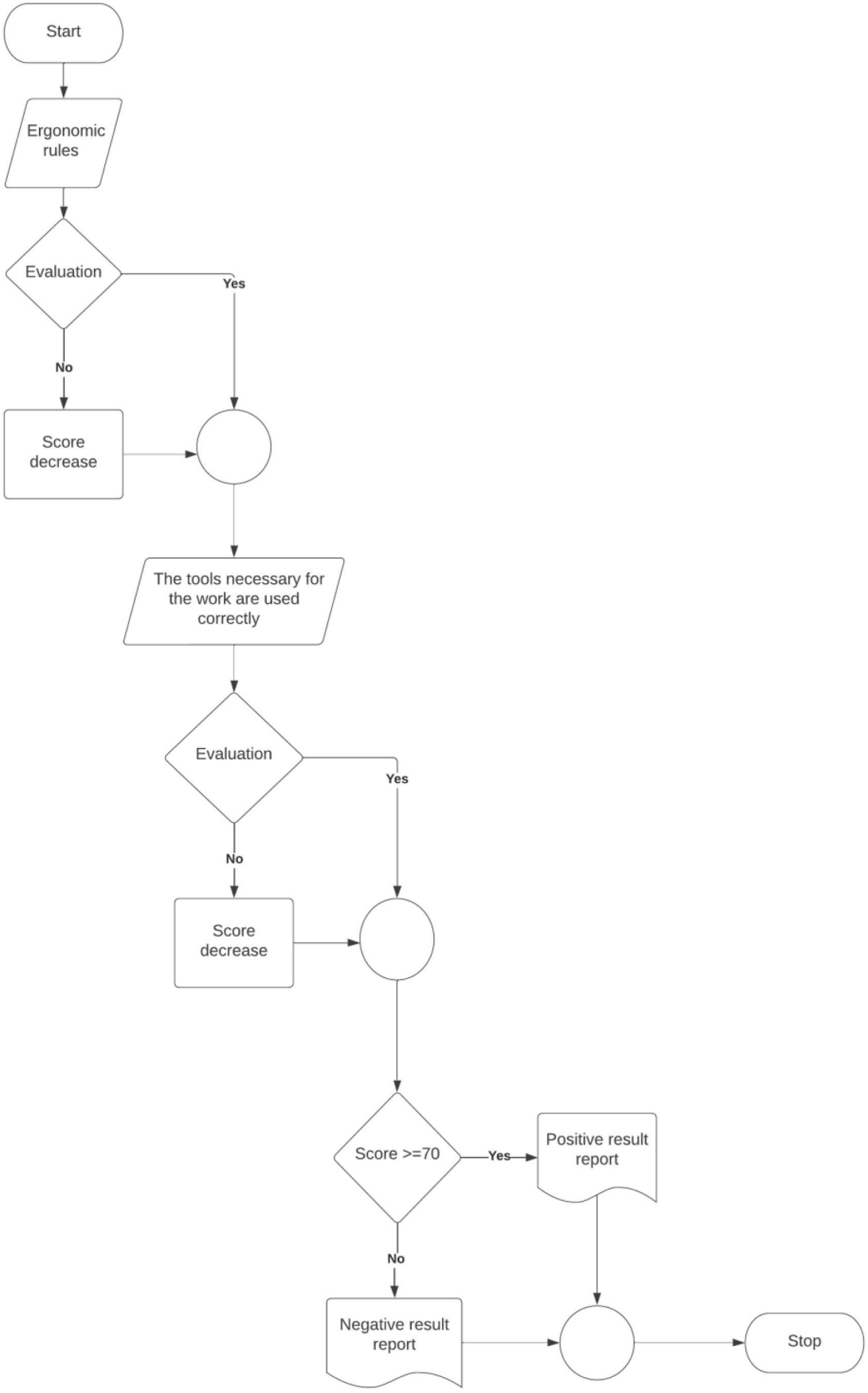

Fig. 12. Algorithm 3- Things to consider during work.

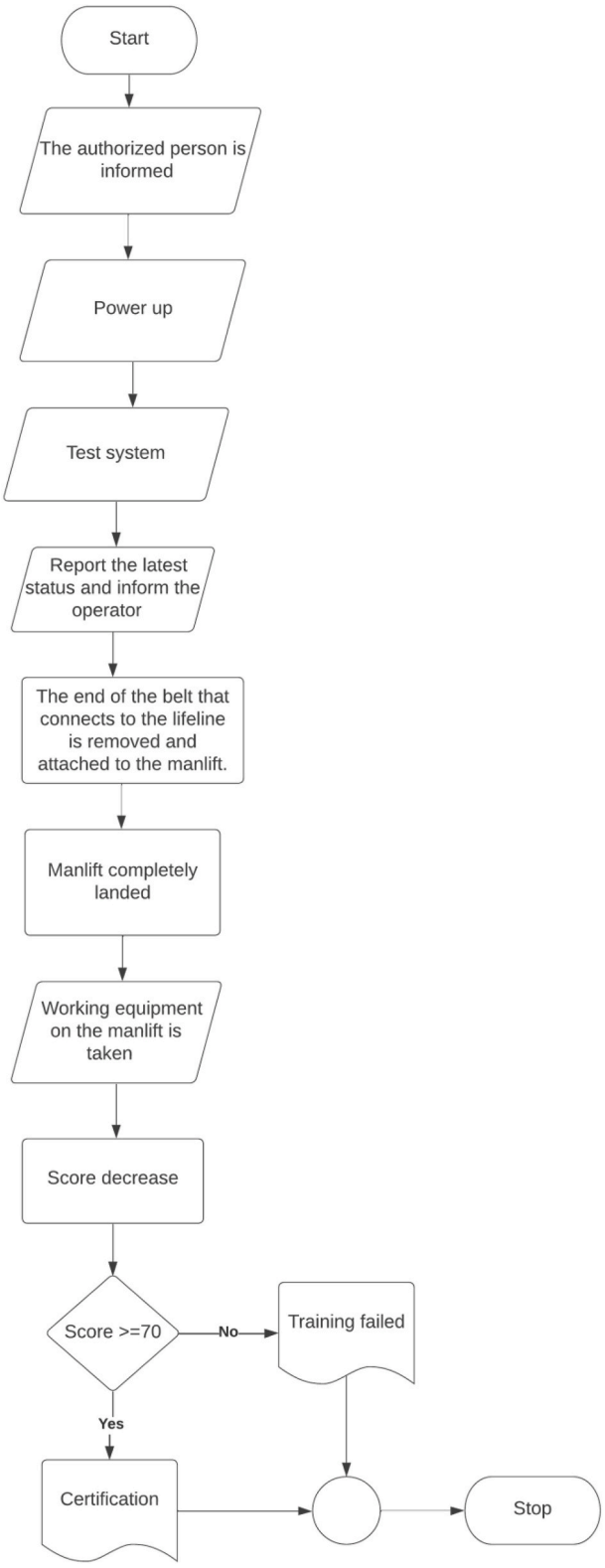

Fig. 13. Algorithms 4- Things to do at the end of the work and certification.

risk assessment with a holistic view of hazards and risks for safe maintenance and repair of PV power systems (Kamenopoulos and Tsoutsos, 2015). Accordingly, the hazards were categorized. Despite this, academic studies, legal regulations and standards on OHS in PV systems have not been sufficiently adapted to current developments. Therefore, there are very few references to offer adequate and effective evaluations or solutions.

In the literature, many studies highlight the contribution of innovative training that industry-specific changes in the success of OHS management accident/loss prevention. However, these have lacked field observations and interviews. In addition, it is seen that studies that approach OHS issues in PV systems holistically are in the form of review articles. This study did not focus solely on identifying OHS problems in PV power systems. In OHS management, human errors have also been taken into account, which are more difficult and variable to control. It has created an education-oriented perspective to minimize human errors. As a result, an innovative training infrastructure that scenarios human errors in PV power systems are offered.

3.4.2. OHS training and VR/AR

The use of VR/AR technologies makes a significant contribution to the safety training to be given to those working in hazardous activities (Seo et al., 2021; Schiavi et al., 2022) such as working with electricity (Li et al., 2017) and working at height (Rey-Becerra et al., 2021). VR/AR training supports the reduction of human error in the safe execution of maintenance work (Benbelkacem et al., 2013). In fact, VR/AR technologies, emergency training (Pinheiro et al., 2019), fire safety training (Zhu and Li, 2020), first aid training (Fromm et al., 2019) to be applied in cases of work accidents (Chryssolouris et al., 2008; Mavrikios et al., 2013; Radhakrishnan et al., 2021; Adami et al., 2021) etc. matters make the difference. These results support the importance of OHS training for healthy individuals, a safe and sustainable system and the environment, and the contribution of VR/AR technologies to OHS training.

The background flow, the algorithm base to be created and the flow must be determined in order for VR/AR technologies to be applied, understood, adapted to the areas needed and gamification scenarios can be created. It has been determined that in almost none of the literature researches, the basic algorithms of VR/AR trainings are not explicitly included. Dianatfar et al. (2021) created algorithms for OHS training for robot-human interactive studies and gave them as a result of their studies. In this direction, in the algorithms they prepared for the safety training needed at the end of their research on the study subjects, only a setup that starts and stops the system is presented (Dianatfar et al., 2021).

In this study, unlike similar studies, the basis of training studies is given with progressive algorithms in order to produce these trainings, not the images obtained in the training results or the training success rates. Algorithms have clearly shown the steps that need to be implemented basically. System definitions vary according to the implementers. This study presents the framework of OHS education to be created with VR/AR technology.

3.4.3. Sustainability perspective

The concepts of green energy and green employment are of global importance under the headings of “Sustainable Development Goals” and “Combating Climate Change”. In this context, it not only increases employment in the highly invested PV sector, but also creates a need for qualified personnel who are open to cooperation with different working areas, changing technology, new techniques and different employee groups.

In literature, specific to PV power systems, effective OHS management, qualified and high awareness individuals and SDGs; Its contribution to the goals of “Decent Work” (Nawaz et al., 2019; Castañon et al., 2019), “Health and Well-being” (Philips J, 2013; Castañon et al., 2019) is emphasized.

In this study, similar articles were developed; The time, cost and educational effectiveness of VR/AR trainings were investigated, field observations and interviews were made, the literature was discussed

with a broad perspective and the relationship between PV systems and OHS was defined. As a result, it was emphasized that the consideration of OHS issues in the orientation to RES and PV power systems contributed to the goals of “Clean and Accessible Energy”, “Sustainable Cities”, “Quality Education".

4. Conclusions

In this study, PV power systems; A perspective is presented with OHS, educational technologies and sustainability perspectives.

- ➢ In the RES, it is an important tool for qualified employees to have sufficient training and experience in terms of technical and professional competence and OHS. For this reason, with a perspective that supports the proactive approach of OHS, a new educational perspective has been expressed with point of view VR/AR technologies that will prevent losses in widespread PV power systems.
- ➢ Framework-oriented algorithms have been determined to improve the integration of VR/AR technologies into OHS trainings in PV systems and to increase the effectiveness of training. Especially VR technology stands out because it is not based on real images of training places and allows for desired editing and change.
- ➢ With the gamification training method, the employee’s desire to be successful, experiencing failure, feeling of competition with himself and/or teammates, etc. supportable.
- ➢ This study supported the necessity of increasing the effectiveness of OHS trainings, as well as providing basic OHS trainings with hands-on practice training and increasing VR/AR applications in vocational training. As a result of this study, gamification scenarios and algorithms, which are lacking in literature research, are given in a clear, applicable and accessible way.

As a result, emphasized the contribution of investments in education and OHS to the SDGs. OHS studies and awareness have a key role in protecting human life and the environment, which is the ultimate goal of all goals such as sustainable cities, clean energy and sustainable systems, quality education, decent work, health and well-being.

CRediT authorship contribution statement

Begüm Erten: Investigation, Methodology, Writing – original draft, Writing – review & editing. **Bülent Oral:** Conceptualization, Methodology, Writing – review & editing. **Melik Ziya Yakut:** Conceptualization, Programming and Algorithm Logic, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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References

Adami, P., Rodrigues, P.B., Woods, P.J., Becerik-Gerber, B., Soibelman, L., Copur-Gencturk, Y., Lucas, G., 2021. Effectiveness of VR-based training on improving construction workers’ knowledge, skills, and safety behavior in robotic teleoperation. Adv. Eng. Inf. 50, 101431 https://doi.org/10.1016/j.aei.2021.101431.

Bakhiyi, B., Labrèche, F., Zayed, J., 2014. The photovoltaic industry on the path to a sustainable future - environmental and occupational health issues,. Environ. Int. 73, 224–234. https://doi.org/10.1016/j.envint.2014.07.023.

Benbelkacem, S., Belhocine, M., Bellarbi, A., Zenati-Henda, N., Tadjine, M., 2013. Augmented reality for photovoltaic pumping systems maintenance tasks. Renew. Energy 55, 428–437. https://doi.org/10.1016/j.renene.2012.12.043.

Bonomo, P., Saretta, E., Frontini, F., Caccivio, M., Bellenda, G., Manzini, G., Cancelliere, P., 2017. Fire safety of PV modules and buildings: overviews, bottlenecks and hints. In: Paper Presented at the 33rd European Photovoltaic Solar Energy Conference and Exhibition, September, 25-27, Amsterdam, The Netherlands.

Castañon, J.A.B., Mendes, M.P., Silva, R.P.T., 2019. Occupational safety and health in solar home systems (SHS) by Brazilian standards. Occup. Health Saf 677–685. https://doi.org/10.1007/978-3-030-14730-3_71.

Cavalcanti, J., Soler- Dominguez, J.L., Raya, M.L.A., 2017. In: Contero, M. (Ed.), Educational Application of Virtual Reality in Safety Training, International Technology, Education and Development Conference, INTED2017 Proceedings, March 6–8, Valencia, Spain. https://doi.org/10.21125/inted.2017.2191.

Cerev, G., Yıldırım, S., 2018. A study on the effects of personal characteristics of employees on occupational accidents and occupational diseases,. Fırat Üniversitesi İİBF Uluslararası İktisadi ve İdari Bilimler Dergisi 2/1, 53–72.

Chryssolouris, G., Mourtzis, D., Stavropoulos, P., Mavrikios, D., Pandremenos, J., 2008. Knowledge management in a virtual lab collaborative training project: a mini-formula student car design. In: Bernard, A., Tichkiewitch, S. (Eds.), Methods and Tools for Effective Knowledge Life-Cycle-Management. Springer, Berlin/Heidelberg, Germany.

Coonick, C., Pester, S., Acott, J., Burroughs, M., Clarke, C., Sinclair, C., Weeks, C., Longfield, A., Crowder, D., Cotterell, M., Flanagan, M., Galvin, J., Holland, C., Mansi, P., Parsons, J., Shipp, M., Smith, S., 2018. Fire and solar PV systems-investigations and evidence, BRE national solar centre. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/786882/Fires_and_solar_PV_systems-Investigations_Evidence_Issue_2.9.pdf.

Dianatfar, M., Latokartano, J., Lanz, M., 2021. Concept for Virtual Safety Training System for Human-Robot Collaboration. In: 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021) June 15–18, Athens, Greece. https://doi.org/10.1016/j.promfg.2020.10.009.

Duroha, J.C., Macht, G.A., 2021. Solar installations & their occupational risks. In: Proceedings of the 2021 HFES 65th International Annual Meeting, October 4-7, Baltimore. https://doi.org/10.1177/1071181321651275.

European Commission, 2019. Global PV status report 2019. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC118058/kjna29938enn_1.pdf, 20.02.2022.

Fromm, J., Mirbabaie, M., Stieglitz, S., 2019. The Potential of Augmented Reality for Improving Occupational First Aid, 14th International Conference on Wirtschaftsinformatik, Februrary, pp. 24–27. Siegen, Germany.

Guo, X., Lin, K., Huang, H., Yang, L., 2019. Carbon footprint of the photovoltaic power supply chain in China. J. Clean. Prod. 233,626–633. https://doi.org/10.1016/j.jclepro.2019.06.102.

Infrastructure Health and Safety Association, 2018. Safe Practices for Working on or Around Photovoltaic Systems, A health and safety guideline for workers, supervisors, employers, and designers. https://www.ihsa.ca/PDFs/Products/Id/M072.pdf.

IRENA, 2019. The renewable energy and jobs 2019 report. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Jun/IRENA_RE_Jobs_2019-report.pdf, 20.02.2022.

Kamal, A.A., Junaini, S.N., Hashim, A.H., Sukor, F.Z., Sia, M.F., 2021. The enhancement of OSH training with an augmented reality-based app,. International Journal of Online and Biomedical Engineering 17 (3). https://doi.org/10.3991/ijoe.v17i13.24517.

Kamenopoulos, S.N., Tsoutsos, T., 2015. Assessment of the safe operation and maintenance of photovoltaic systems. Energy 93, 1633–1638. https://doi.org/10.1016/j.energy.2015.10.037.

Kaplan, M., Çallı Kaplan, M., 2019. Analysis of the effects of the demographic properties of employees to the work accidents in Turkey. Journal of Management and Economies Research 17/2, 77–89.

Li, X., Wen, Y., Chi, H.L., Wang, X., Chan, A.P.C., 2017. A critical review of virtual and augmented reality (VR/AR) applications in construction safety,. Autom. ConStruct. 86, 150–162. https://doi.org/10.1016/j.autcon.2017.11.003.

Mavrikios, D., Papakostas, N., Mourtzis, D., Chryssolouris, G., 2013. On industrial learning and training for the Factories of the Future: a conceptual, cognitive and technology framework,. J. Intell. Manuf. 24 (3), 473–485. https://doi.org/10.1007/s10845-011-0590-9.

Mirabelli, M.C., Loomis, D., Richardson, D.B., 2003. Fatal occupational injuries among self-employed workers in North Carolina. Am. J. Ind. Med. 44, 182–190.

Mohd Nizam Ong, N.A.F., Sadiq, M.A., Md Said, M.S., Jomaas, G., Mohd Tohir, M.Z., Kristensen, J.S., 2021. Fault tree analysis of fires on rooftops with photovoltaic systems. J. Build. Eng. 46, 103752 https://doi.org/10.1016/j.jobe.2021.103752.

Mohd Nizam Ong, N.A.F., Mohd Tohir, M.Z., Md Said, M.S., Nasif, M.S., Alias, A.H., Ramali, M.R., 2022. Development of fire safety best practices for rooftops grid-connected photovoltaic (PV) systems installation using systematic review methodology. Sustain. Cities Soc. 78, 103637 https://doi.org/10.1016/j.scs.2021.103637.

Monteiro, N.S.C., Monteiro, R.A.B., Mariano, J.D'A., Junior, J.U., Romano, C.A., 2017. Brazil market outlook for photovoltaic solar energy: a survey study,. Br. J. Appl. Sci. Technol. 21 (5), 1–11. https://doi.org/10.9734/BJAST/2017/33408.

Nawaz, W., Linke, P., Koç, M., 2019. Safety and sustainability nexus: a review and appraisal,. J. Clean. Prod. 216, 74–87. https://doi.org/10.1016/j.jclepro.2019.01.167.

OSHA, European Agency for Safety and Health at Work, 2013. Hazard identification checklist: OSH risks associated with small-scale solar energy applications. https://osha.europa.eu/en/publications/e-facts/e-fact-69-hazard-identification-checklist-osh-risks-associated-withsmall-scale-solar-energy-applications.

Philips J, 2013. Determining the sustainability of large-scale photovoltaic solar power plants. Renew. Sustain. Energy Rev. 27, 435–444. https://doi.org/10.1016/j.rser.2013.07.003.

Pinheiro, A.S., Gouveia, R., Jesus, Â., Baptista, J.S., 2019. The importance of emergency response training: a case study, studies in systems, decision and control, occupational and environmental safety and health, systems research institute, polish academy of sciences, janusz kacprzyk (eds.), warsaw,. Poland 202, 757–764. https://doi.org/10.1007/978-3-030-14730-3_79.

Radhakrishnan, U., Koumaditis, K., Chinello, F., 2021. A systematic review of immersive virtual reality for industrial skills training,. Behav. Inf. Technol. 40 (12), 1310–1339. https://doi.org/10.1080/0144929X.2021.1954693.

Ramali, M.R., Baharudin, R.M., Tharima, A.F., Akashah, F.J., Tohir, M.Z.M., 2022a. A review on safety practices for firefighters during photovoltaic (PV) fire. Fire Technol. https://doi.org/10.1007/s10694-022-01269-4.

Ramali, M.R., Mohd Nizam Ong, N.A.F., Md Said, M.S., Yusoff, H.M., Baharudin, M.R., Tharima, B.A.F., Akashah, F.W., Mohd Tohir, M.Z., 2022b. A review on safety practices for firefighters during photovoltaic (PV) fire, Fire Technology. https://doi.org/10.1007/s10694-022-01269-4.

Rey-Becerra, E., Barrero, L.H., Ellegast, R., Kluge, A., 2021. The effectiveness of virtual safety training in work at heights: a literature review,. Appl. Ergon. 94 (103419) https://doi.org/10.1016/j.apergo.2021.103419.

Richardson, D., Loomis, D., Bena, J., Bailer, A.J., 2004. Fatal occupational injury rates in southern and non-southern states, by race and Hispanic etnicity. Am.. J. Publ. Health 94, 1756–1761.

Saleh, H.J., Pendley, C.C., 2012. From learning from accidents to teaching about accident causation and prevention: multidisciplinary education and safety literacy for all engineering students. Reliab. Eng. Syst. Saf. 99, 105–113.

Santamaria-Bonfil, G., Ibáñez, M.B., Pérez-Ramírezb, M., Pérez-Ramírez, G., Pérez-Ramírez, F., 2020. Learning analytics for student modeling in virtual reality training systems: lineworkers case. Comput. Educ. 151 (103871) https://doi.org/10.1016/j.compedu.2020.103871.

Schiavi, B., Havard, V., Beddiar, K., Baudry, D., 2022. BIM data flow architecture with AR/VR technologies: use cases in architecture, engineering and construction. Autom. ConStruct. 134 https://doi.org/10.1016/j.autcon.2021.104054.

Sen, A., Mohankar, A.S., Khamaj, A., Karmakar, S., 2021. Emerging OSH issues in installation and maintenance of floating solar photovoltaic projects and their link with sustainable development goals. Risk Manag. Healthc. Pol. 14, 1939–1957. https://doi.org/10.2147/RMHP.S304732.

Seo, H.J., Park, G.M., Son, M., Hong, A.J., 2021. Establishment of virtual-reality-based safety education and training system for safety engagement. Educ. Sci. 11 (12), 786. https://doi.org/10.3390/educsci11120786.

The New South Wales (NSW) in Australia, 2021a. Guide to safe solar panel installation. https://www.safework.nsw.gov.au/_data/assets/pdf_file/0008/965861/Guide-to-solar-safe-installation.pdf.

The New South Wales (NSW) in Australia, 2021b. Solar rooftop installation retailers. Safety checklist. https://www.safework.nsw.gov.au/_data/assets/pdf_file/0010/1087453/safe-rooftop-solar-installation-findings-report.pdf.

Valenti, A., Gagliardi, D., Fortuna, G., Iavicoli, S., 2016. Towards a greener labour market: occupational health and safety implications. Ann Ist Super Sanità, Monographic Section 52 (3), ,415–423. https://doi.org/10.4415/ANN_16_03_13.

Villanueva, V., Garcia, A.M., 2010. Individual and occupational factors related to fatal occupational injuries: a case-control study. Accid. Anal. Prev. 43, 127–133. https://doi.org/10.1016/j.aap.2010.08.001, 2011.

Wang, Y., Guo, F., Huang, M., 2014. Analysis and countermeasure study of photovoltaic system fault based on fault tree and HAZOP. Appl. Mech. Mater. 536–537, 1557–1561. http://dx.doi.org/10.4028/www.scientific.net/AMM.536-537.1557.

Yusri, L., 2018. Hazard identification and evaluation in solar photovoltaic installation process of a selected energy solution provider. In: Master Thesis, Engineering Safety, Health and Environment, University of Malaya, Science and Environmental Management, Malaysia.

Zhao, D., Lucas, J., 2015. Virtual reality simulation for construction safety promotion. Int. J. Inj. Control Saf. Promot. 22 (1), 57–67. https://doi.org/10.1080/17457300.2013.861853.

Zhu, Y., Li, N., 2020. Virtual and augmented reality technologies for emergency management in the built environments: a state-of-the-art review,. Journal of Safety Science and Resilience 2, 1–10. https://doi.org/10.1016/j.jnlssr.2020.11.004.