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Workflow and concept study to design mixed reality assisted safety training in the wind energy sector

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Abstract. Mixed reality Technology creates new environments and visualizations to teach, train, and facilitate work, either offline or remote online. The aim is to provide effective learning and training sources and reduce human errors and cognitive workload. However, the concept study to design mixed reality (MR)-assisted training lacks the workflow process. Therefore, the purpose of this paper is to develop a workflow to design MR-assisted training together with a worksheet that can be used to prioritize training tasks that should be virtualized and augmented. The workflow is demonstrated with the help of safety training for wind turbine towers. The results show that the proposed workflow has identified 4 out of 8 tasks to be critical for virtualization and augmentation. The proposed workflow is helpful to screen and identify critical training and work scenarios and tasks, besides the ability to determine the technical specifications of the required virtualization and augmentation.

1. Introduction

The international renewable energy agency estimated that the wind industry would exponentially grow in the coming decades [1]. The expected rapid and colossal growth in the wind energy sector needs and demands a trained and qualified workforce. There should be a game-changer to train such a huge expected workforce, which cuts down the time to train (TOT) and increases the training quality. Moreover, training are usually provided in large-scale facilities and offline mode. There is also a need to provide training in online and remote modes, especially during pandemics, since large scale facilities are limited and require travelling and expensive resources. For example, one of the biggest challenges for wind energy is to train the workers to work safely with large scale wind turbine structures and components at high heights, i.e. 100 to 150 meters, with high voltage and finally working in harsh marine environments. One of the game-changer technologies in the training sector is virtual and augmented reality technology. Virtual reality (VR) is helpful to create virtual training environments and support self and remote training modes. Whereas, Augmented reality (AR) provides virtual objects together with the physical training environment, either to illustrate physically hidden objects, provide access for detailed information, e.g. documents, provide reminders and alarms to ensure quality and error-free training. AR can also be used at the site and even by experienced workers as an assistant tool. Wind power workers are often exposed to hazards resulting in fatalities or severe injuries due to working at high heights, high voltage, harsh environment and human errors [2].

It is worth highlighting that mixed reality (MR) includes the use of both VR and AR. VR provides a simulated immersive experience when a person is completely displaced to another location. Then, AR allows the person to experience the real world, additionally overlaid with digital graphics and information in real-time [3]. MR enables the wind technician to experience the real working conditions and at the same time see responsive virtual objects. For example, when the technician is in an offshore wind turbine, there is a need for rescue operations (cognitively demanding). MR headsets like that of Microsoft HoloLens [4] will virtually connect him to a medical professional (onshore land), and the technician receives real-time instruction to carry out the rescue operation.

VR and AR technologies are seen as game-changers for training and high-quality site-working. It is expected that VR and AR would facilitate any training content to be more effective, enable remote and online modes, reduce human errors and cognitive loads. There are several studies on the effectiveness of VR head-mounted displays in the professional training industry [3, 5, 6].

Portability and usability ambiguity of the mixed reality hardware components are identified as the current gaps in MR technology. It also indicates the technical challenges and gaps to determine the best hardware platform, either a tablet or a headgear, for prolonged and stress-free usage even in low lighting conditions. Furthermore, the know-how to design mixed reality applications that fit into the training scenarios is clearly indicated for future research works [7]. Regarding the complexity of mixed reality technologies, Renganayagalu et al. [5] highlighted the level of user familiarity with the technology as a fundamental challenge. In summary, the literature is partially helpful for training providers to design their AR applications. However, there is a need for an exploration method to identify the technical specifications for safety training to be virtualized or augmented.

Therefore, the purpose of this article is to propose a workflow and worksheet to identify the critical training modules/scenarios and determine the technical specifications for MR application, e.g. hardware platform, software platform, and tracking technique. The article is based on a case study performed in Innovation Energy AS, where safety training for wind energy workers is provided. The safety training is a five-day training with several training scenarios. Innovation Energy AS tried to explore how MR technology can enhance their training performance. Developing MR application is done through a six-step methodology (1) analyze the system of interest, e.g. in our case is the wind tower, (2) analyze the training use case scenarios, (3) conceptualize the most critical training use case scenario(s), (4) computerize the virtual and augmented objects (5) construct the MR application, (6) verify and validate the performance of the developed MR application. This article is related to step 2.

In the following section, the case study and the six-step methodology are presented. The third section presents and describes the main results, i.e. workflow, worksheet, and work-frame. Finally, some conclusions are drawn up based on the studied training scenario.

2. Case study and methods

In this section, the case company and case study are presented. Moreover, the development methodology and the critical theories for the associated methods are illustrated.

2.1. Case study

Energy Innovation AS is located in Egersund, Norway and is considered as a global wind Organization (GWO) certified company. It offers safety and technical training related to the wind energy sector, e.g. 5-day safety training, the wind technicians required that to access both the onshore and offshore wind farms. There are five different modules within the 5-day GWO safety training course, including working with heights, manual handling, fire safety awareness, basic first aid, and sea survival [8].

Energy Innovation AS launched a 30-meter training tower (Figure 1) in May 2018, which can simulate the working conditions in an actual wind turbine. Working at 30 m height, as shown in Figure 1, emphasizes the need for safety and the risk associated. The tower is equipped with lightning protection and is well illuminated.

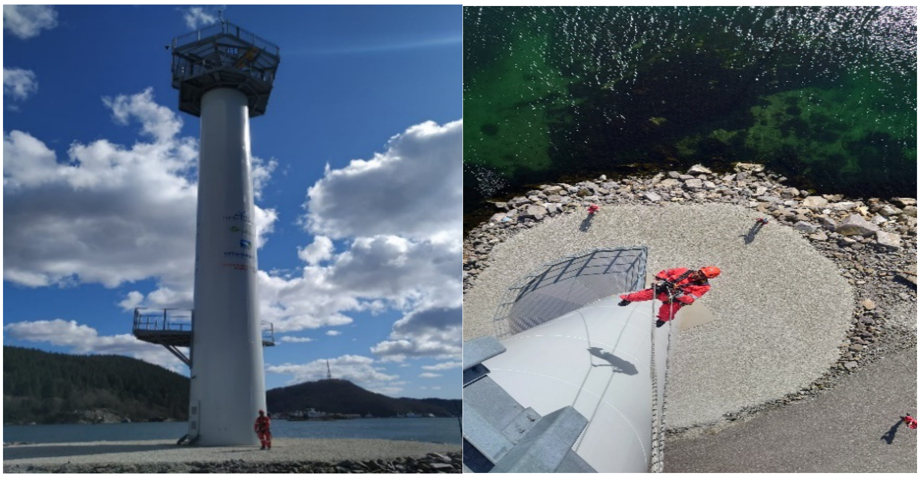

Figure 1. Training Tower (Left) and Safety Trainings (Right)

2.2. Augmented, virtual, and mixed realities

AR technology aims to enable the users to experience the real world with overlaid extra digital information (virtual objects). VR technology aims to allow the users to experience complete immersion in a new virtual environment. However, the user can no longer experience the real world. The purpose of MR technology is to enable the users to experience the real world with additional overlaid digital information and at the same time be able to interact with the virtual objects. However, a full immersive experience is not possible in MR [3]. The most available market devices for AR include handheld devices like iPad and tablets. Google glass was a famous AR device that was discontinued to be available in the market. The most used VR device is Facebook Oculus, and Microsoft Hololens is the commonly available MR device in the market.

Table 1. Comparison of technologies

	AR	VR	MR
Natural surroundings visible	Yes	No	Yes
Virtual objects visible	No	Yes	Yes

2.2.1. Mixed Reality (MR) software/ tracking techniques. Effective tracking of the user's head, hands, and body orientation is required to make the user navigate the MR environment in real-time. Tracking techniques are broadly classified as shown in Figure 2. The vision-based methods are classified into model-based, feature-based and marker-based tracking. Model-based tracking involves creating a 3D model of the real object using computer software and then using the 3D model to track the user movements. Images and Quick Response code (QR) codes of the real objects are used to track in feature-based tracking and marker-based tracking. QR code-based tracking is commonly used in many industrial applications mainly for its simplicity in design and lower cost. However, the main disadvantage of QR code tracking is when the surface is not clean, the tracking is no longer effective. GPS and other sensors like accelerators and gyros are used in sensor-based tracking. The best features of both sensor-based tracking and vison-based tracking techniques are used in a hybrid-based technique *[7]*. It is recommended to use hybrid tracking for MR applications.

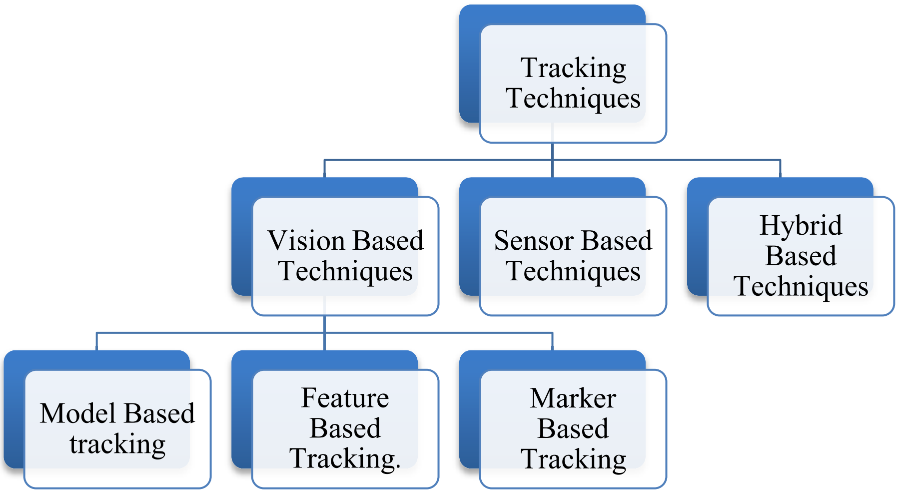

Figure 2. MR tracking techniques [7]

2.3. *Methodology*

Developing MR application is done through a six-step methodology, as shown in Figure 3 : (1) analyze the system of interest, e.g. in our case is the wind tower, (2) analyze the training use case scenarios, (3) conceptualize the most critical training use case scenario(s), (4) computerize the virtual and augmented objects (5) construct the MR application, (6) verify and validate the performance of the developed MR application.

2.3.1. System analysis. This step focuses on finding the requirements and industrial needs. This is done by carrying out interviews with managers from three different companies like SAFER, Espeland Energie AS, and Energy Innovation AS. All the managers stressed that the wind sector is about to experience drastic growth in the next decade and that a qualified workforce is required to match this growth. The primary requirements for safety training in the wind sector are: (1) to make the workers understand and be aware of the risks and challenges associated with the wind industry, (2) to emphasize the safety procedures and standards while working in harsh offshore environments and at heights and with high voltages, and (3) to make the workers understand that deaths or severe injuries result from unsafe work practices.

The safety training industry is showing video documentaries during the safety training to emphasize the above facts. The managers feel if an MR model is used, it will help in a better way. For example, Energy Innovation AS manager feels that MR is ideal to be used for remote safety training activities and inspection purposes. For instance, in case of visual inspection of blade cracks, the MR glasses equipped with Artificial intelligence (AI) can help the technicians classify the level of damage by analyzing the picture of the damage.

2.3.2. Use case analysis. The use case analysis aims to analyze the five use case scenarios (heights, manual handling, fire safety awareness, basic first aid, and sea survival) and determine the most critical scenario to be virtualized and augmented. Wind turbine accident data from [9] presented in Figure 4 shows that the human factor (represented in blue) is the most crucial cause for transport accidents, injury, and death. The reason can be heavy cognitive workload and human error at work. Therefore, working with the heights module is selected as the most critical module due to its high criticality. Any human error while working at heights could lead to severe injuries and deaths.

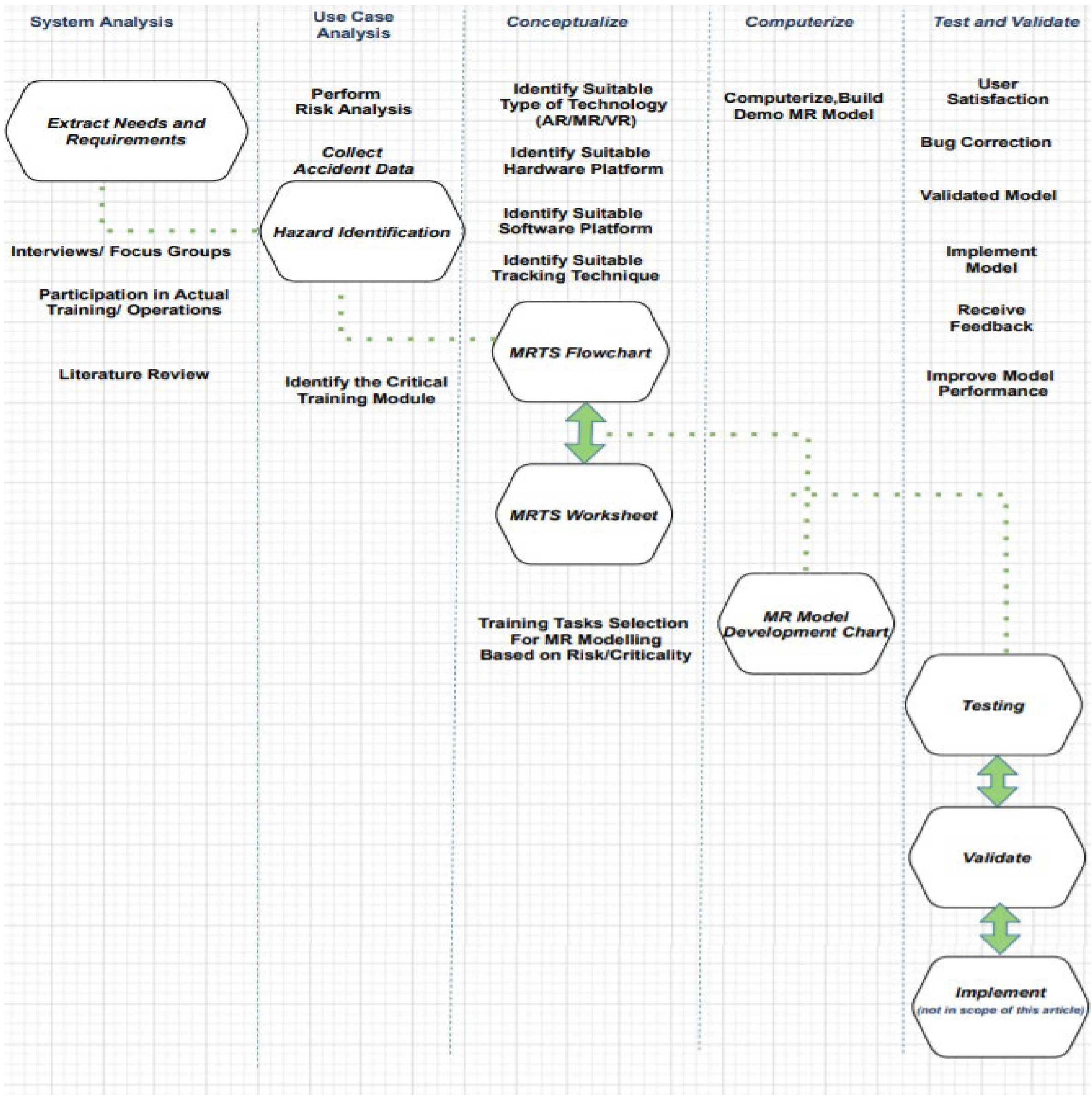

Figure 3. Workflow for developing mixed reality assisted training [9].

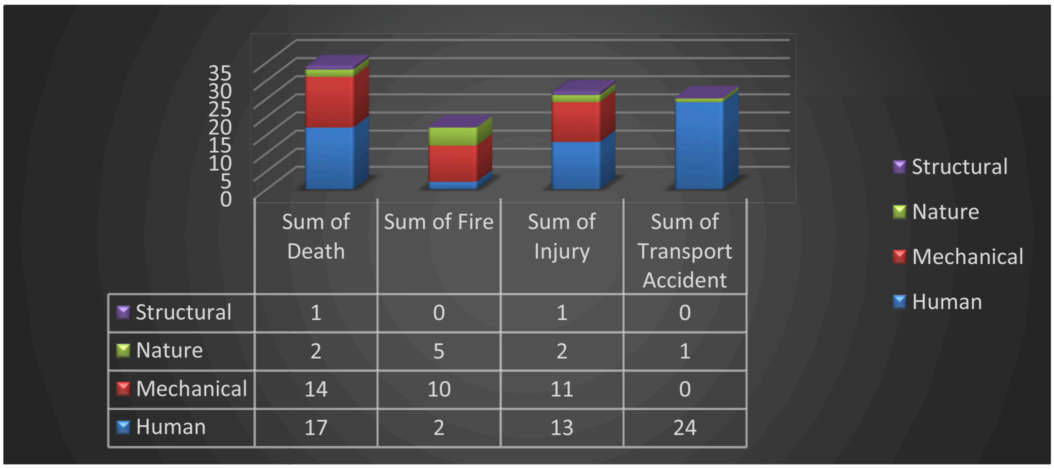

Figure 4. Wind turbine accident data [10]

2.3.3. Conceptualize. This step defines the detailed training task for the selected critical module (working in heights) and identifies the risk associated with each training task. The basic coarse risk analysis approach is used in this study, as shown in Table 2. However, any risk analysis method can be used based upon the industry and the subject area concerned. This article emphasizes the importance of doing the risk analysis before deciding to implement mixed reality technologies. The classification categories are low/medium/high. The risk is estimated for each of the training steps. The likelihood rating and the impact rating used in the risk matrix (presented in Table 2) are decided after talking with industrial experts in the training field and with the author's personal experience from the 5-day GWO training. This type of risk classification will help check if mixed reality must be implemented, which saves cost.

Table 2. Applied risk matrix [11]

		Impact		
		1	2	3
Likelihood	3	Low	Medium	High
	2	Low	Medium	Medium
	1	Low	Low	Low

The decision to implement the helpful type of technology for a specific training task depends on:

1. If the risk is identified as high, then a suitable type of MR technology is recommended.
2. If the risk is identified as a medium, then a suitable type of MR technology is recommended only if the situation happens in an emergency.
3. If the risk is identified is low, then the MR technologies is not required.

Finally, the relevant type of MR technology and the useful hardware platform, software platform, and the appropriate tracking technique for each training steps are obtained from Figure 5.

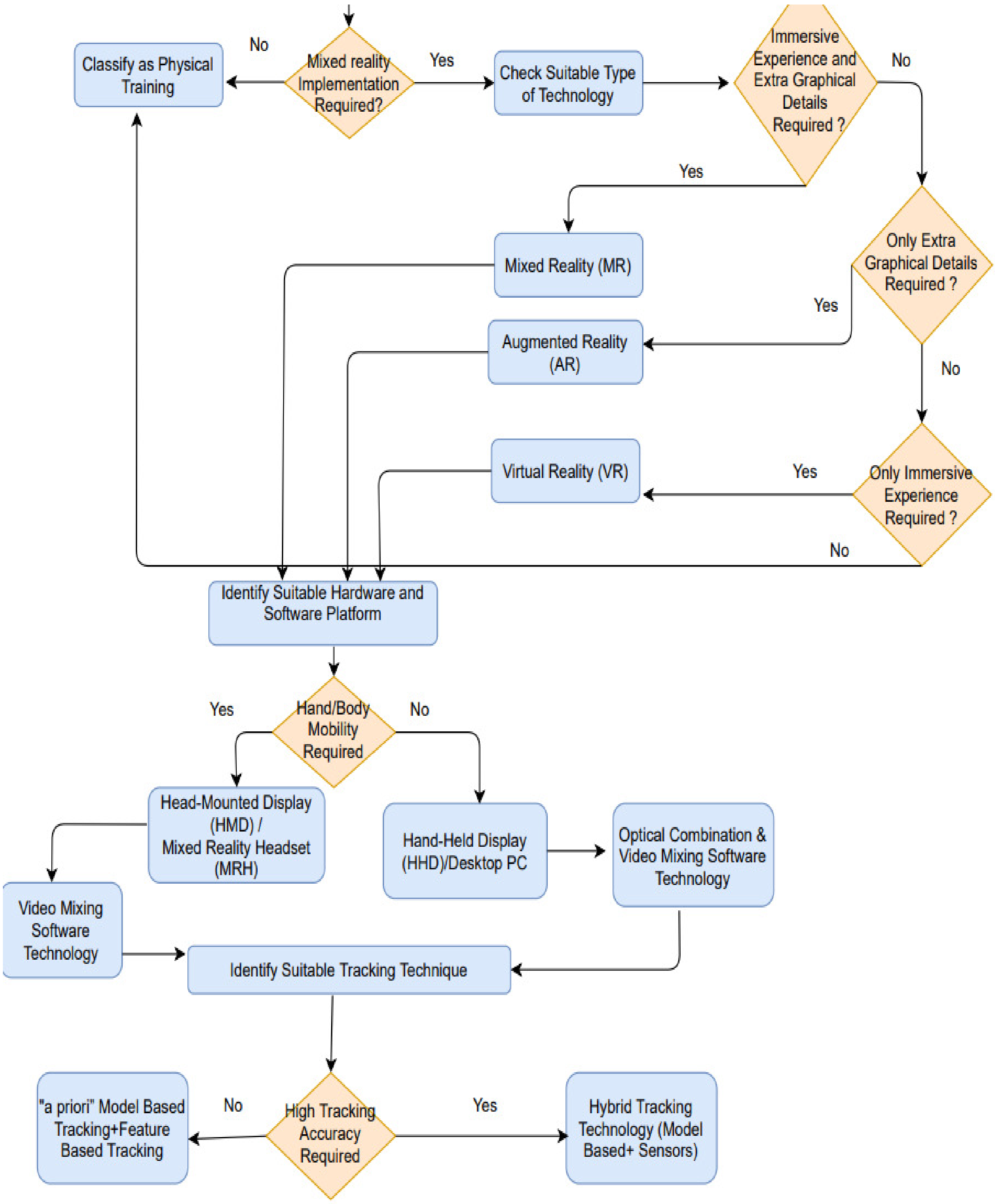

Figure 5. MRTS flowchart [9]

2.3.4. Computerize. In this step, the *MR model is* developed in three steps, as shown in Figure 6. The first *step is t*o create the 3D model of the physical environment, the wind tower, for this use case. Blender Software, or Unity Software, can be used. The second step is to create a game environment. Unreal Software, or Unity Software, can be used. The third step is to extract the game as APK file to support it in android mobile device and configure it with headgear. Then, follow standard procedures to extract the game file to other platforms like iOS.

2.3.5. Construct. This step is to construct and install the computerized (either virtual or augmented objects) application and set up the hardware and tracking instrument.

2.3.6. Verify and validate. The results during each step of this methodology are validated with Energy Innovation AS managers and Bouvet AS (AR technology provider).

Figure 6. MR model development chart

3. Results
The main result of this study is the developed workflow and worksheet to design cost-effective MR assisted training. It is effective as it assists the current training task with either virtual or augmented objects. It is cost-effective as it could identify four tasks out of eight tasks that are critically important for MR assistance, as shown in Table 3.

4. Conclusion
The article explores how to effectively design MR applications for safety training in the wind sector, identify the critical training modules/scenarios, and determine the most suitable hardware platform, software platform, and tracking technique. The article concludes that the safety training provider needs to develop and rigorously apply the following analysis to establish a cost-effective MR application: (1) mixed reality analysis workflow to effectively design MR applications for safety training in the wind energy sector (2) mixed reality design worksheet to identify the critical training modules/scenarios and tasks which requires implementing MR technologies and the (3) mixed reality design flowchart to find the most suitable hardware platform, software platform and tracking techniques.

To conclude the case study, that capturing the risk associated with each training task early in the design helps to classify if the implementation of such technologies is needed for that task or not. Such a risk analysis is a significant cost-saving option for the industry. It can save a lot of money in identifying only the crucial scenarios for which the implementation is needed.

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Table 3. Mixed reality design worksheet, extract from [9].

Module	Safety Training Scenario	Safety Traning Tasks	Complexity of Training	Technology Required	Suitable Technology	Effective Hardware Platform	Effective Software Platform	Suitable Technique of Tracking
Working with Heights	Ideal way to use safety equipment	The technician learns to wear the safety harnesses in the right way and to climb safely using the support belt (safety equipment) and fall arresters (safety equipment).	Low	No	N.A.	N.A.	N.A.	N.A.
		The technician learns how to safely place the self-locking slider (safety equipment) on turbine ladder railings.	Medium	No	N.A.	N.A.	N.A.	N.A.
	Climbing turbine ladder safely	The technician learns how to safely open the turbine ladder hatch and where to locate the anchor (safety) points where he/she shall fix fall arresters (safety equipment) and how to properly close the ladder hatch.	Low	No	N.A.	N.A.	N.A.	N.A.
		The technician learns about fall (safety) factors and how to connect the fall arresters (safety equipment) with 0 (zero) fall factor, meaning lower veritical fall range.	Medium	Yes	AR	Hand devices like-Ipads/ Tablets or PC	Image Projection. The real-object is augmented with-extra digtial images.	Tracking based on Vision and 3D Model.
	Safe Descent	The technician learns to how to safely use the Milan (safety equipment) to descent and to use the evacuation gear to do the emergency evacuation jump.	High	Yes	MR	Headmounted Devices	Computer softwares to mix-digital images and real time motion.	Tracking done by using both real time sensors and 3D Model.
		The technician learns how and where to find the evacuation gear (a set of safety equipments) during an emergency situation.	Medium	Yes	AR	Hand devices like-Ipads/ Tablets or PC	Image Projection. The real-object is augmented with-extra digtial images.	Tracking based on Vision and 3D Model.
	Emergency Rescue	The technician learns how to save an fellow injured technician and to provide basic first aid and make a call for rescue.	High	Yes	MR	Headmounted Devices	Computer softwares to mix-digital images and real time motion.	Tracking done by using both real time sensors and 3D Model.
		The technician learns how to identify hanging trauma symptoms in the injured technician.	Low	No	N.A.	N.A.	N.A.	N.A.

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