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Mixed Reality Applications for Safety Trainings in Wind Energy Sector: A Case Study

By

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Abstract

The international renewable energy agency (IRENA) forecast that the wind industry will grow at an exponential rate in the coming decades. This enormous growth has created the need and demand for qualified workforce which includes engineers, technicians, and managers in the wind energy sector. Thus, the wind energy training sector needs to implement some innovative technologies in both safety and technical trainings to meet the growing industry demands and to create a qualified workforce. However, before finalizing on any innovative solution for safety training, the challenges that the wind energy training sector faces need to be analyzed. The biggest challenges for the wind energy training sector is to train the workers to work safely with large scale wind turbine structure and its components, working safely with high voltage and working in harsh marine environments. Wind power workers are often exposed to hazards that can result in fatalities or serious injuries due to these challenges. Therefore, the implemented innovative technology must ensure safety and improve efficiency of operations by being aware of the risks associated. However, the wind energy training sector is searching for cost effective solution especially related to remote training, when the technician is not able to attend the training physically. Moreover, the wind energy training sector is also looking for technology that can reduce human error and also reduce cognitive workload.

Therefore, the use of innovative technology like mixed reality (MR) might provide potential benefits. MR includes the use of both the virtual reality (VR) which is a simulated immersive experience and the use of augmented reality (AR) which allows the person to see the real world, additionally overlaid with digital graphics and information in real time. However, there is a lack of clarity on how to effectively design mixed reality technologies in safety training of wind sector. There are technical challenges and gaps to identify the suitable hardware platform, suitable software platform and the associated tracking techniques.

The purpose of this thesis is to develop: (1) the workflow, (2) the framework which will help to design mixed reality technologies in safety training of wind sector. Also to develop, (3) flowchart and (4) worksheet which will help to identify the critical training modules/scenarios and to identify the suitable type of technology (AR/VR/MR) needed for a particular scenario along with the suitable hardware platform, suitable software platform and associated tracking technique. Finally, to develop (5) demo MR model to demonstrate and validate the developed workflow and to understand the associated practical challenges like complexity of such mixed reality technologies and user familiarity.

In order to achieve the purpose of this thesis, a six-step methodology was applied which includes: (1) system analysis, (2) use case analysis, (3) conceptualize, (4) computerize, (5) construct and (6) verify, validate and visualize. The case study started with system analysis which mainly deals with extracting the industrial needs and requirements. The system analysis includes two sub steps. First, is to perform a detailed systematic literature review (SLR) to understand the state of art in VR/AR/MR in the wind industry and other relevant industry. Second, an empirical exploration were the author attended a 5day GWO wind safety training at the Eigersund energy hub to personally experience and understand the training scenarios which will be crucial and beneficial to have a mixed reality application from both technician and company perspective. The use case analysis deals with the creation of the case context which includes selecting the critical training module based on accident data from literature review and to identify one similar framework in other engineering industry. The conceptualize step involves in classifying the selected critical module into training tasks and to identify the risk

associated with each training tasks. It also involves in performing the concept study before building the MR model and to develop the scenario modelling chart. The computerize step involves in developing the actual 3D model and the demo MR model. The construct step involves the creation of the flowchart, worksheet, workflow and the framework and the sixth step is to validate and verify the research outputs.

Consequently, as the result of the six-step methodology this thesis has provided new knowledge regarding four concepts: (1) sequence or workflow (2) the need for continuous and iterative process to design mixed reality (3) the logic and the rules for the selection of technical specifications (4) worksheet to classify the scenarios and to define training complexity.

The thesis concludes that the safety training provider needs to rigorously follow the developed (1) mixed reality analysis (MRA) workflow, (2) mixed reality analysis (MRA) framework, (3) mixed reality technical specification (MRTS) flowchart and the (4) mixed reality technical specification (MRTS) worksheet. The MRA workflow provides the sequence that can enable the industrial practitioner to design MR application in a cost-effective and fit for purpose manner which includes screening out low risk scenarios. The MRA framework clearly indicates that the design to implement MR is an iterative process based on user needs and user level of familiarity. The MRTS flowchart provides the logic to identify the suitable type of technology for a particular scenario, along with the suitable hardware platform, suitable software platform and associated tracking technique. The MRTS flowchart must be used along with the MRTS worksheet which can help to identify the critical training modules/scenarios and further classify them to check if implementation of mixed realities is needed or not.

In future, the complexity associated with such technologies must be studied after implementing in real-time. Based on the case study AR/VR should be designed to make work simpler and error free. However, in some cases if using the technology is creating unintended consequences and complexity, then the technology might not be used in such cases.

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Table of Contents

Abstract	iii
Acknowledgements	v
Table of Contents	vi
List of figures	viii
List of tables.....	x
List of appendixes	xi
List of abbreviations.....	xii
1. Introduction.....	13
1.1. Background and Problem Presentation	13
1.2. Research Question.....	17
1.3. Research Objectives	18
1.4. Research Relevance.....	19
1.5. Methodology	20
1.6. Thesis Scope.....	23
1.7. Project Plan	25
1.8. Thesis Structure.....	25
1.9. Systematic Literature Review (SLR).....	27
2. Research Methodology and Design.....	33
2.1. Research Design.....	33
2.2. Research Design Statement	34
2.3. Research Techniques.....	36
2.4. Traceability Check Methodology Steps and Research Objective.....	38
2.5. Research Reliability and Validity statement	39
3. Relevant Theory.....	40
3.1. Concepts: Type of Technology	40
3.2. Mixed Reality Hardware Platforms.....	43
3.3. Mixed Reality Software Platforms	45
3.4. Mixed Reality Tracking Techniques	47
3.5. Evolution of AR and VR.....	48
3.6. Application areas of AR/VR	50
3.7. Application areas of MR	52
3.8. Technical challenges of MR.....	53
3.9. Verification and Validation Techniques.....	54
3.10. GWO Safety Training Concepts.....	56
3.11. Safety Training and MR Benefits.....	57
3.12. Software's Used	57
4. Data Collection	59
4.1. Case Company	59
4.2. Data Collection Methods.....	60
4.3. Qualitative Primary Data Collection	60
4.4. Qualitative Secondary Data Collection	61

4.5.	Quantitative Data Collection	66
4.6.	Data Collection Reliability Check.....	66
4.7.	Traceability Check Data Collection Techniques and Research Objectives	67
5.	Data Analysis and Results.....	69
5.1.	Systems Analysis.....	69
5.2.	Use Case Analysis.....	73
5.3.	Conceptualize.....	77
5.4.	Computerize	89
5.5.	Construct Flowchart,Worksheet,Workflow and Framework.....	102
5.6.	Verify, Validate and Visualize	110
6.	Discussion	113
6.1.	Discussion: Systematic Literature Review (SLR).....	113
6.2.	Discussion: 5 Day GWO Training:	114
6.3.	Discussion: Systems Analysis	116
6.4.	Discussion: Use Case Analysis	118
6.5.	Discussion: Conceptualize	119
6.6.	Discussion: Computerize and Develop MR model	121
6.7.	Discussion: Construct Flowchart and Worksheet.....	122
6.8.	Discussion: Construct Workflow and Framework	123
6.9.	Discussion: General Observations.....	124
7.	Conclusion	127
	References.....	129
	Appendices.....	132

List of figures

Figure 1: Wind Installed Capacity (IRENA, 2019).....	13
Figure 2: Onshore Wind Turbine (WT) Additions and Replacements (IRENA, 2019)	14
Figure 3: Offshore Wind Turbine (WT) Additions and Replacements (IRENA, 2019)	14
Figure 4: Visual WT Size vs Output Mega Watts (MW), (IRENA, 2019)	15
Figure 5: Accident Stages (Asian et al., 2017).....	15
Figure 6: Key Features to Implement MR.....	21
Figure 7: Research Methodology	22
Figure 8: Thesis Project Plan	25
Figure 9: SLR Steps (Booth et al., 2016)	28
Figure 10: Search String Oria	29
Figure 11: Research Philosophy and Methods (Neuman, 2014)	33
Figure 12: Scope and Scale of Research	35
Figure 13: Mixed Reality Domain (Rokhsaritalemi et al., 2020).....	41
Figure 14: Mixed Reality Characters (Rokhsaritalemi et al., 2020).....	42
Figure 15: Surgeon Using HoloLens (Left) and (right) Image from HoloLens (Tepper et al., 2017).....	44
Figure 16: Virtual Reality (VR) Technology Integration (Poyade et al., 2021).....	45
Figure 17: Augmented 3D Drawing of the Machine Fault Simulator, UiS Lab (El-Thalji et al., 2020).....	46
Figure 18: Video Mixing Technique (Snap from Demo MR Model, by author)	46
Figure 19: Image Projection (Lalanne et al., 2009).....	47
Figure 20: Commonly used Software and Hardware Platforms (Dini & Mura, 2015).....	47
Figure 21: Commonly used Tracking Techniques (Palmarini et al., 2018).....	48
Figure 22: Evolution of AR and VR Technologies (Muñoz-Saavedra et al., 2020).....	48
Figure 23: AR/VR Areas of Application and Work Environments.....	50
Figure 24: AR for Performing Oil Checks (De Crescenzo et al., 2011).....	51
Figure 25: AR in Underground Piping (Schall et al., 2009).....	51
Figure 26: Blade repair offshore Source: https://www.altitec.co.uk/services	52
Figure 27: Architecture of Mixed Reality (Rokhsaritalemi et al., 2020).....	53
Figure 28: Model Development Process (Sargent, 2013)	54
Figure 29: Fall Factors (Bentsen, 2021).....	56
Figure 30: MR in Safety Training (Poyade et al., 2021)	57
Figure 31: Safety Gears (Me at GWO training)	62
Figure 32: Fall Protection (Left) and Quick Evacuation (Right).....	63
Figure 33: Free Fall Loads	63
Figure 34: Safety Hook (Left), Ladder Safety Precaution (Right).....	64
Figure 35: Rescue Techniques	65
Figure 36: GWO Training Tower (Left), Selfie Inside Tower (Right).....	65
Figure 37: SAFER Workflow Process (K. Torgeirsen, personal communication, 19 April 2021)	70
Figure 38: Question 1 (Interview with Managers)	71
Figure 39: Question 3&4 (Interview with Managers).....	72
Figure 40: Question 5 (Interview with Managers)	72
Figure 41: WT Accident Data (Wind Turbine Accidents Data, 2021).....	75
Figure 42: DMAS Framework (Gupta & Varghese, 2020).....	76
Figure 43: 3D Development DMAS Framework (Gupta & Varghese, 2020).....	77
Figure 44: Flowchart Critical Module Classification	78
Figure 45: Risk Analysis Steps (Aven, 2015)	80
Figure 46: Risk Matrix (Aven, 2015).....	81
Figure 47: Scenario Modelling Chart.....	85
Figure 48: Safety Gears Planned for Animation	86
Figure 49: Safety Climbing Protocol	87
Figure 50: Anchoring Device (NS-EN 795).....	87
Figure 51: Milan For Controlled Descent	88
Figure 52: Carabiner Hooks & Fall Dampener	88
Figure 53: Add Basic Shapes Blender.....	90
Figure 54: Edit Shapes	90
Figure 55: Edit Vertex.....	91
Figure 56: Edit Face.....	91
Figure 57: Edit Edge	91

Figure 58: Individual Props Modelling	92
Figure 59: Material Nodes	93
Figure 60: Material Nodes for 3D Model.....	93
Figure 61: Texturing	94
Figure 62: UV Mapping	94
Figure 63:Character Modelling	95
Figure 64:Character Safety Props Modelling	95
Figure 65:Character Face Modelling.....	96
Figure 66:Character Face UV Mapping	96
Figure 67:Final Character after Texturing.....	96
Figure 68:Rigging Character	97
Figure 69:Controlling Movements	97
Figure 70:Animation Reference	98
Figure 71:Lighting Locations.....	98
Figure 72:Lighting Effects	99
Figure 73:External Environment.....	99
Figure 74:Camera Locations	99
Figure 75:Unreal Engine	100
Figure 76:Unreal Node Groups	101
Figure 77:Preview Game Development	101
Figure 78:Game Bug Correction	101
Figure 79:MRTS Flowchart	103
Figure 80: MRA Workflow.....	106
Figure 81:MR Model Development Chart	107
Figure 82:MRA Framework.....	109
Figure 83: Presentation at Science meet Industry Webinar 26 th May 2021	126

List of tables

Table 1: WT Human Cause Accident Data (Asian et al., 2017)	16
Table 2: Thesis Limitations	23
Table 3: Thesis Delimitations, Simplifications and Assumptions	24
Table 4: SLR Purpose	27
Table 5: Article Outcome after IC&EC	29
Table 6: Data Extraction from Selected Articles	30
Table 7: Research Design	34
Table 8: Case Study Research Techniques	36
Table 9: Traceability Check Methodology Steps	38
Table 10: Research Outputs Reliability and Validity	39
Table 11: Comparison of Wearable Computers (Tepper et al., 2017)	43
Table 12: Data Collection Methods	60
Table 13: Quantitative Data Collection	66
Table 14: Reliability Data Collection	66
Table 15: Traceability Check Data Collection Technique	68
Table 16: GWO Training Module Classification	73
Table 17: Critical Module Classification	79
Table 18: Training Risk Picture	81
Table 19: Decision Critical Module Classification	84
Table 20: MRTS Worksheet	105
Table 21: Research Outputs Verification Measures	110
Table 22: Research Outputs Face Validation Measures	111
Table 23: Research Concurrent and Convergent Validation Measure	111

List of appendixes

1. Interview E-mail from Energy Innovation AS, Espeland Energie AS and SAFER Managers (Five Managers).
2. Energy Innovation AS Worksheet: Hazards and Measures Documentation.
3. The Tower 2D Drawings
4. The Validation of thesis outputs mail from Energy Innovation AS Manager.
5. The Animation video produced and upload in YouTube at <https://youtu.be/o5zzT9b630k>
Please accept the cookies request if asked by YouTube. This is a public video, I have not locked it, anyone can view it.
6. The Final desktop game is played and upload in YouTube at <https://youtu.be/6bEqzCGC93Q>
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7. The thesis case study presentation at science meet industry webinar is available online and upload in Teams at (follow the whole webinar, it is available [here](#) :time 2.23.00).
This is uploaded online by the conference responsible person, I hope that the link can be opened.

List of abbreviations

SLR	Systematic Literature Review
VR	Virtual Reality
AR	Augmented Reality
MR	Mixed Reality
IAR	Intelligent Augmented Reality
OSHA	Occupational Safety and Health Administration
SEAR	Speech-Enabled Augmented Reality
2D	2 Dimension
3D	3 Dimension
HMD	Head Mounted Device
KPI	Key Performance Indicators
IRENA	International Renewable Energy Agency
WT	Wind Turbine
MW	Mega Watt
GW	Giga Watt
CAD	Computer Aided Design
GWO	Global Wind Organization
IC	Inclusion Criteria
EC	Exclusion Criteria
QC	Quality Criteria
O&M	Operations and Maintenance
NOWC	Norwegian Offshore Wind Cluster
TBP	Tower Base Panel
DMAS	Decision Making Accident Scenario
HHD	Handheld Display
HMD	Head Mounted Display
MRH	Mixed Reality Headset
UI	User Interface
MRTS	Mixed Reality Technical Specification
MRA	Mixed Reality Analysis

1. Introduction

Chapter Outline:

The chapter starts with a brief explanation about the background of the wind industry, the growth prospects in the wind industry and the future challenges (problems). One potential innovative solution to the problem is explored. The research question is formulated and checked for its relevance from a systematic literature review (SLR). The existing research gaps in this topic are listed with support from a systematic literature review (SLR). Based on the research gaps, five suitable research objectives are formulated and the methodology to achieve these research objectives are described. The significance and the relevance of the research are clearly listed. The limitations and the delimitations of the research are tabulated. The project time plan and the report structure are presented for quick review.

1.1. Background and Problem Presentation

The wind energy sector is one of the fastest growing energy sectors in the world. In the last decade the wind industry has been growing exponentially and it is forecasted to grow further. The international renewable energy agency (IRENA) report (Figure 1) indicates that the installed capacity of onshore wind will increase roughly 10 times from 2018 to 2050 and that of the offshore wind will increase to around 1000 GW by 2050 from mere 23 GW by 2018 (IRENA, 2019). This is mainly due to the innovation and development around the floating foundations, so it becomes easier to explore deeper waters.

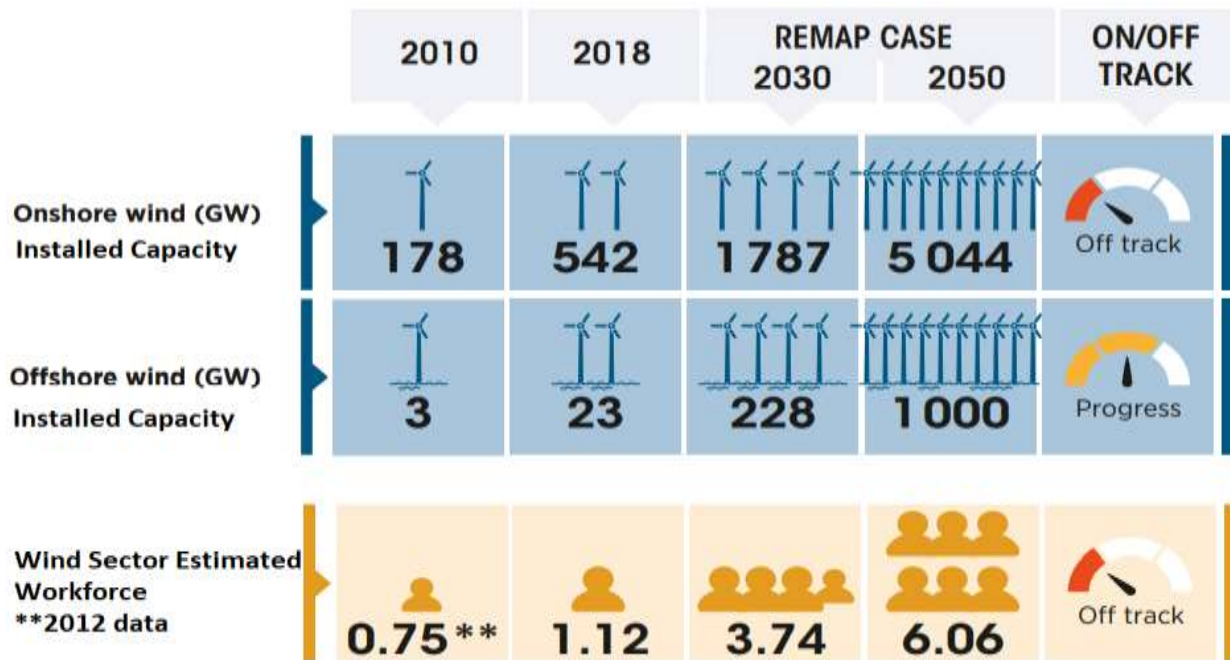


Figure 1: Wind Installed Capacity (IRENA, 2019)

This enormous growth has created the need and demand for qualified workforce which includes engineers, technicians, and managers in the wind energy sector mainly to cater during the installation, operations and maintenance phase which will last around 20 to 25 years in the lifecycle of the wind asset. The Figure 2 clearly indicates the enormous amount of additions of new onshore wind turbine (WT) including the replacements of existing WT components in terms of Giga Watt (GW) globally to match the onshore wind (GW) installed capacity projections for 2050 in Figure 1. Similarly, the Figure 3 indicates for the offshore wind turbine, for example from 2040 to 2050 around 40 to 45 GW equivalent of offshore WT will be added. This is enormous considering the challenging offshore environments.

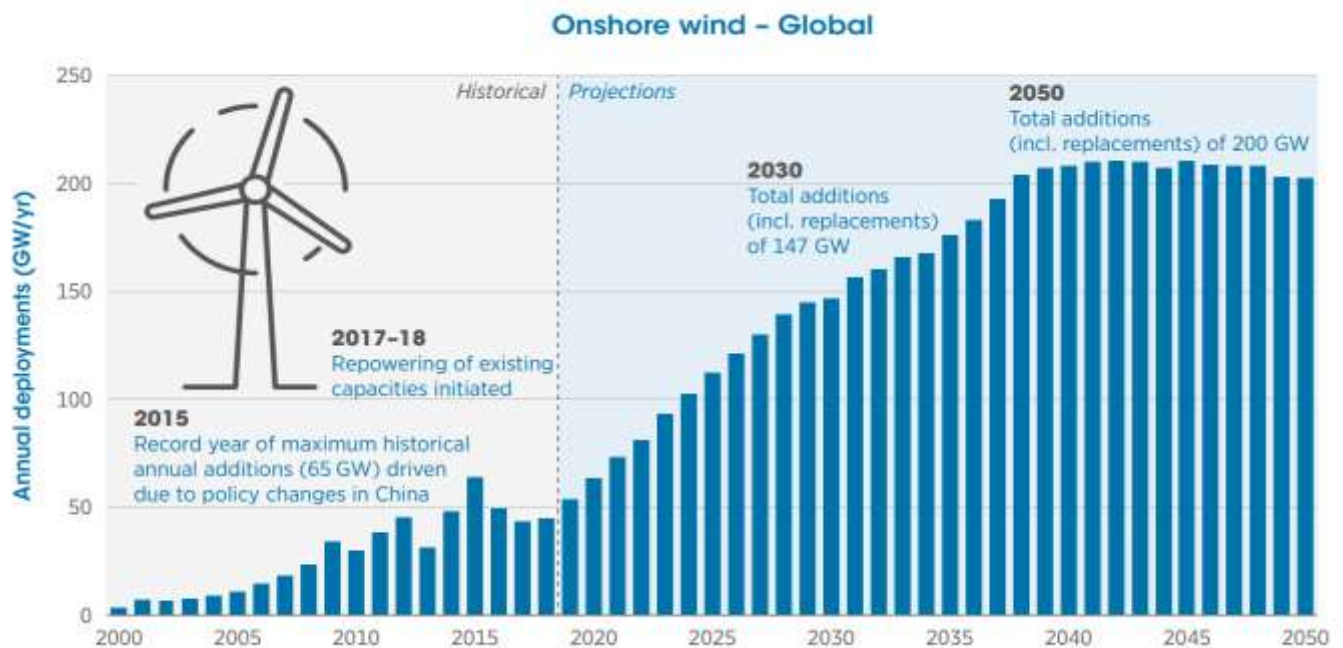


Figure 2: Onshore Wind Turbine (WT) Additions and Replacements (IRENA, 2019)

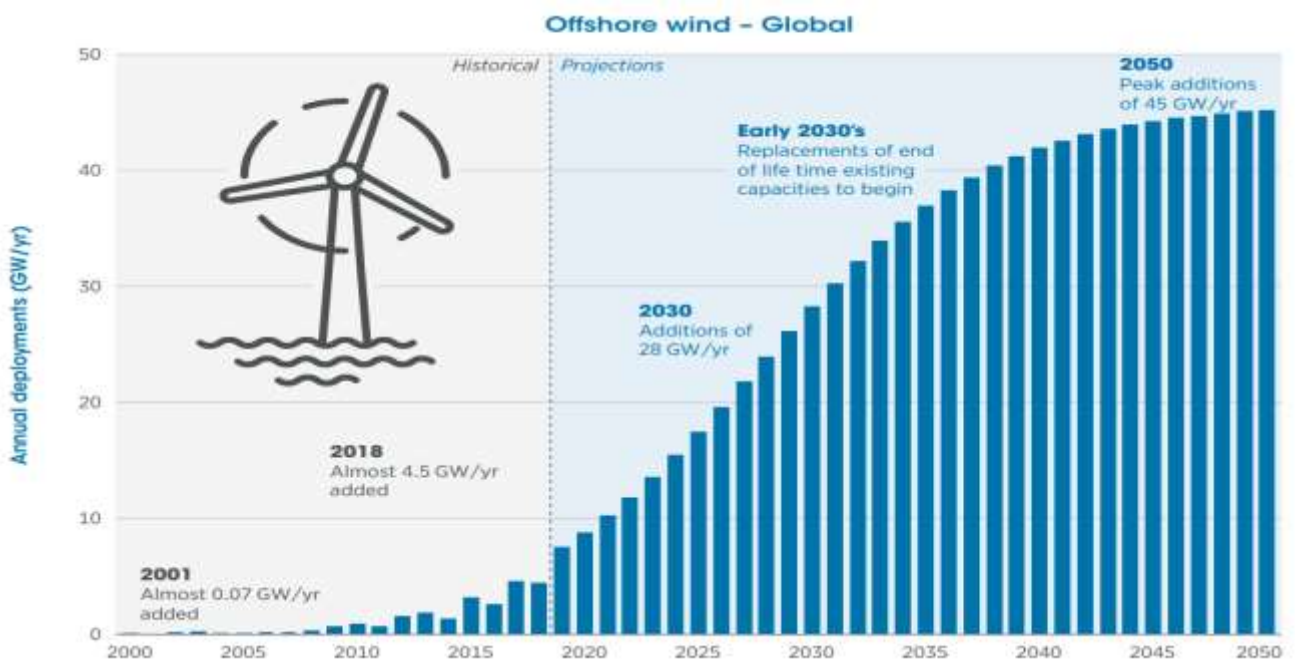


Figure 3: Offshore Wind Turbine (WT) Additions and Replacements (IRENA, 2019)

To create such a qualified workforce the safety training and technical education in the wind sector needs to implement innovative methods to meet the requirements and to cater to installation, operations and maintenance of the wind turbines in a safe manner. However, before arriving at any innovative solution for safety and technical trainings, the challenges that the wind sector faces need to be analyzed. The biggest challenge for the wind sector is the sheer size of the wind turbine. Figure 4 gives us a visual representation of how big the wind turbine of the future is going to look like. The main challenge is the need for maintenance to be done safely on top of the tower (in nacelle) roughly 100 to 150 m high and the inspection of the turbine blades, where size of some offshore wind turbine blades is almost half the length of the football field. Other important challenges are working with high voltage and working in unpredictable weather conditions in offshore wind farms.

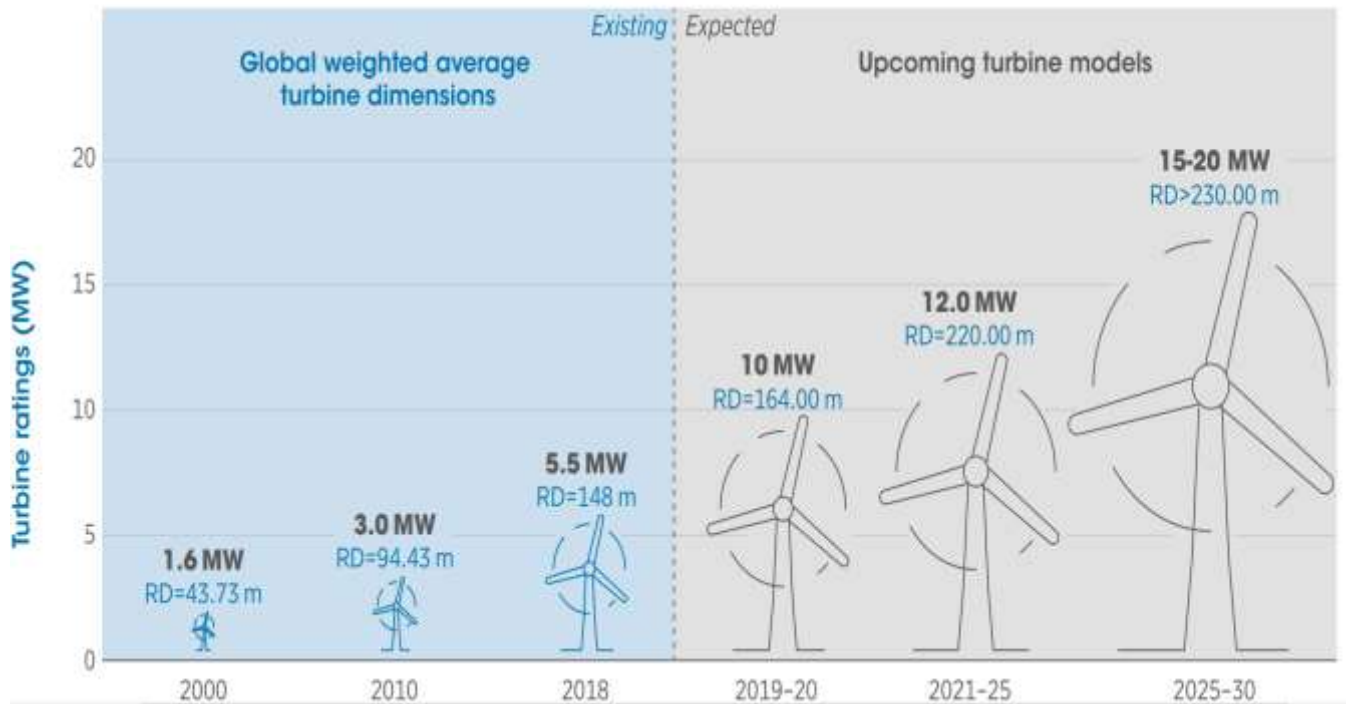


Figure 4: Visual WT Size vs Output Mega Watts (MW), (IRENA, 2019)

The wind safety and technical training sector needs to overcome these risks and challenges which include working at heights (safely) and working with high voltages and working in high wind and wave conditions offshore. Wind power workers are often exposed to hazards that can result in fatalities or serious injuries. The literature review done by (Asian et al., 2017) classify the accidents as shown in Figure 5 occurring across the four stages like transportation, construction, operation and maintenance. The corresponding three accident cause categories such as nature, human and system/equipment and the outcomes resulting in death and in injuries are also reported in the article. The literature review has applied a well-planned data mining approach to study the wind turbine accidents.



Figure 5: Accident Stages (Asian et al., 2017)

Specifically, to the interest of this thesis which is related to the training sector of the wind industry. I have tabulated the accident data caused by the human category (outcome is injury) and spread across three stages like construction, operation and maintenance in Figure 5. This can be justified, since the GWO safety training predominately deals with safe human work practices during installation, operation, and maintenance phase. Even though the article represents the data from year 2017. The seriousness of the issue can be represented and understood clearly.

Table 1: WT Human Cause Accident Data (Asian et al., 2017)

Accident Cause	Count
Human (Negligence)	4
Human (Wrong Action)	4
Human (Interference in control systems)	2
Human (Fall)	1
Human (Heart attack)	1

Note : The human (other) cause, human (transportation) cause and human (plane crash) cause from (TABLE I DISTRIBUTION OF REASONS FOR ACCIDENTS CAUSED BY HUMANS:(Asian et al., 2017)) is not tabulated in Table 1 as the reasons for other cause is not clear and the remaining two causes are related to transportation stage which are not in scope of this thesis.

The article (Asian et al., 2017) provides some useful insights regarding the WT accidents, some of the relevant ones for this thesis are:

- The main accident cause in maintenance stage is human.
- The deaths are mainly reported in the construction and maintenance stages.
- The human cause lead accident is highest also in transportation stage and the authors recommend the use of some virtual reality simulations to reduce human error.

Considering all these factors the wind energy training sector needs to implement some innovative methods of training to equip the workers to be aware of risks, to make the workers understand the relevant standards and safety procedures associated with working at heights and with high voltages and in challenging offshore environment. One such innovative technology could be the use of mixed reality (MR) application for safety and technical trainings in the wind sector.

Mixed reality (MR) application includes the use of both, virtual reality (VR) which is a simulated immersive experience that can be similar to working in a wind turbine in all three dimensions (3D) combined with augmented reality (AR) is when we look at the real-world with either through a tablet or head glass, but it is augmented with extra information or graphics in the view (Brigham, 2017). The prospective mixed reality hardware platforms are smartphones, tablets, head glasses and wearables as they contain the key hardware components for MR technology such as sensors, a processor, an input device, and a display unit. AR/VR technologies are currently being used in various industries such as railways, civil construction, aerospace, and industrial plants. They find their application in fields of maintenance, repairing, training and diagnostic (Dini & Mura, 2015).

The use of virtual reality application (VR) for safety trainings will improve the visualization of working conditions for example in the case of performing a maintenance in the wind turbine. The use of augmented reality (AR) will help the technicians to locate the tasks to perform in a maintenance sequence, thereby improving safety and the work efficiency. “MR is an attempt to combine the best features of both AR and VR”(Brigham, 2017).

The use of mixed reality application for safety training in advanced rescue operations (offshore) in the wind sector adds significant value (saving human life). One relevant example, is the use of head mounted device (HMD) in an AR environment by a rescue worker (offshore) and he/she is connected virtually to a medical professional (onshore) and receives real time instruction to carry

out the rescue operation and the first aid procedures to the injured person (offshore). Energy Innovation AS (Case Company) has already tested this scenario with companies called Bouvet and SAFER.

To sum up, the shareholders of the wind energy training sector has understood the enormous benefits of integrating and using mixed reality applications in their everyday activities and are taking active steps to research and test such models. This master thesis from Energy Innovation AS (Part of the Norwegian offshore wind cluster) in cooperation with University of Stavanger is also one such initiative to get a workflow or framework for implementing mixed realities in training sector ready which can be tested, explored, and improved in the coming years.

1.2. Research Question

The one main research question the thesis aims to answer is: How to effectively design mixed reality application for safety trainings in the wind sector?

To check if the research question is still relevant and not answered before, a systematic literature review (SLR) was done (explained in section 1.9). It was observed while there has been a lot of academic research on implementing the AR/VR/MR in maintenance scenarios and a good literature review was done by authors (Palmarini et al., 2018). However, the authors observe that AR/VR/MR are used the least in the training sector, compared to the repair, inspection, and diagnostic sectors. The authors argue that it can be justified as the aim of using AR/VR/MR in maintenance is to reduce the need for training and improve the maintenance operation in real time. However, I feel and argue when the quality of training is improved by the effective use of mixed reality application, it will have a positive effect while going for real maintenance operations later. Energy Innovation AS (Company) also believes and thinks in this same way, since they already are seeing good results by implementing AR/VR for first aid and advanced rescue safety operation (offshore) with companies like Bouvet and SAFER.

Therefore, it is very evident that none of the literature has specifically focused upon implementing the mixed realities for safety trainings in the wind sector. This makes the research question relevant and encourages to do a case study. Moreover, it was an important industrial requirement from Energy Innovation AS (case company).

The answers to the below sub questions will aid to answer the research question.

Sub-RQ1: How to identify the critical training modules/scenarios which requires implementing mixed reality application?

Sub-RQ2: What is the most suitable hardware platform for implementing mixed reality application in safety training of the wind sector?

Sub-RQ3: What is the most suitable software platform for implementing mixed reality application in safety training of the wind sector?

Sub-RQ4: What is the most suitable tracking technique for implementing mixed reality application in safety training of the wind sector?

The systematic literature review (SLR) also helped to identify the below research gaps.

The most relevant literature found from the search process (google scholar) was a systematic review literature (2021) done on the “effectiveness of the VR head mounted displays in professional training industry” (Renganayagalu et al., 2021). This article relates to training sector. Moreover, this was done in 2021, helping to identify the current gaps.

1. Lack of clarity on how to effectively design such mixed reality technology in training sector (wind tower in this case). The literature review done by (Palmarini et al., 2018) clearly suggest that this gap can be one of the future research works.
2. Ambiguity in the portability and usability of the mixed reality hardware components. There are technical challenges and gaps to identify which is the best hardware platform either a tablet or a headgear for prolonged use and stress-free usage even in low lighting conditions. The articles (Renganayagalu et al., 2021), (Brigham, 2017) and (Dini & Mura, 2015) reports this as a concern regarding such technologies.
3. The article (Brigham, 2017) also reports the challenges associated with the software and gaps to identify which is the best software platform along with the server infrastructure.
4. The challenges associated with identifying the most suitable tracking technique and suitable authoring solutions for implementing mixed reality application are discussed as open issues for further research by (Dini & Mura, 2015) and by (Palmarini et al., 2018)
5. Complexity of such technology. AR/VR must be designed to make work simpler and error free. However, in some cases using the technology itself is creating some complexity than the actual work. The article (Renganayagalu et al., 2021) speaks on level of user familiarity to the technology as important challenge.

The industrial requirements from Energy Innovation AS are:

1. The need to classify which safety training scenarios (example, safety while working at heights) are essential to be modelled as AR/VR as it is not imperative to have all the training scenarios modelled as a mixed reality application.
2. The need to have a demo MR model based on the workflow, so it can be used to further expand the work when needed.

1.3. Research Objectives

Based on the above-mentioned research gaps. The objectives of the thesis are:

1. To develop a worksheet to identify the critical training modules/scenarios and further classify them to check if implementation of mixed realities is needed or not?
2. To develop a workflow which will help to implement mixed reality technology into training activities of the wind sector.
3. To develop a flowchart which will help to recognize the technical specifications like the suitable hardware platform, suitable software platform and relevant tracking technique.
4. To develop a framework which will capture the method to implement mixed reality technology.

5. To design and create a demo MR model based on the workflow developed in order to validate the workflow and understand the associated practical challenges like complexity of such mixed reality technologies and user familiarity.

Moreover, such a workflow, framework or a flowchart can also be adapted to help implement similar technologies for maintenance, repair, and inspection activities in the future.

In order to achieve the research objectives, the following methods were followed.

- A six-step methodology was applied which includes: (1) system analysis, (2) use case analysis, (3) conceptualize, (4) computerize, (5) construct and (6) verify, validate and visualize.
- The state of art in VR/AR/MR in the wind industry and other relevant industry was studied from academic literature and any similar existing frameworks in other industry was analyzed.
- The SLR done for this thesis indicated, there are no framework/flowchart currently available for wind training sector. Thus, a case study was undertaken to achieve the above research objectives.
- During the case study I attended a 5day GWO wind safety training at the Eigersund energy hub to personally experience and understand the training scenarios which will be both crucial and cost beneficial to have a mixed reality application from both technician and company perspective.
- To create a demo MR model on one specific training scenario. I learned software's like Blender (3D Modelling) and Unreal software (Game Environment).
- The University of Stavanger, asset lab invested on oculus quest 2 headgear which is a VR gear.
- Interview managers from industries like Energy innovation AS, Espeland Energie AS and SAFER.

The fact that mixed reality application (MR) is in early design and development stage in the training sector of wind industry presents an opportunity to explore the gap. The methodology used to develop this framework will take us one step forward in closing the existing gaps and satisfying the industry demands. This case study can be used as a starting point for future research and development of implementing mixed reality application in the wind energy training sector.

1.4. Research Relevance

The significance and the relevance of this research is that it will help to

1. Provide a guideline to implement mixed reality application for safety training in the wind sector.
2. Provide some guidelines to classify which scenarios in global wind organization (GWO) safety training are crucial to be modelled into a mixed reality application.
3. To illustrate the steps to create MR model.
4. Provide a flowchart to select the required type of technology (AR or VR or MR).

5. To identify which is the best hardware platform (tablet or headgear) for prolonged and stress-free usage.
6. To identify the software platform and relevant tracking technique required to create such mixed reality applications.
7. Provide a critical review of such mixed reality application based on the potential unintended consequences of having such a technology. The optimal tradeoff considering both the risk and the ambiguity. The level of constraints such technology will have on operations. What's happens if something goes wrong. What is the backup.

The literature study done on this area by (Dini & Mura, 2015) have indicated that mixed reality applications have the following advantages

- Using AR, we can impose extra graphically information on real objects.
- VR provides an Immersive experience.
- Easier to understand and interpret technical and procedural information.
- Easier to share the files. It is a paperless technology, so document management is efficient.
- The work processes become easier to follow. In simple words, it provides a check list digitally

Additionally, in the theory part of this thesis, the advantages and disadvantages of AR/VR/MR have been explored.

The theoretical relevance of this case study is that it can be used as a starting point for future research and development for implementing mixed reality application in the wind energy training sector. The practical relevance of this case study is that it will help Energy Innovation AS to identify the training scenarios which are crucial to be simulated using AR/VR/MR to help reduce human error and ensure overall safety.

1.5. Methodology

The first goal of this thesis is to identify the training scenarios which are crucial to be simulated using AR/VR to help reduce human error and ensure overall safety. To identify those training scenarios, I personally took part in the 5day GWO wind safety training at the Eigersund energy hub to understand the scenarios which will be both crucial and cost beneficial to have a mixed reality application. The workflow was developed by studying the training needs and the requirements of the wind sector. A 3D model of the training tower was created in a software called Blender. One crucial training scenario was identified, and a MR of the scenario was created using the Unreal software and oculus quest 2 headgear.

To implement mixed reality technologies in this case study, three main key features are identified (Figure 6)

1. The real environment (in this case study, the training tower) must be convert into virtual one like a digital twin. (done using Blender Software).
2. The way the user (technician) interacts with the system (digital training tower) was done using Unreal Software.
3. The feedback from the system (digital training tower) to the user.

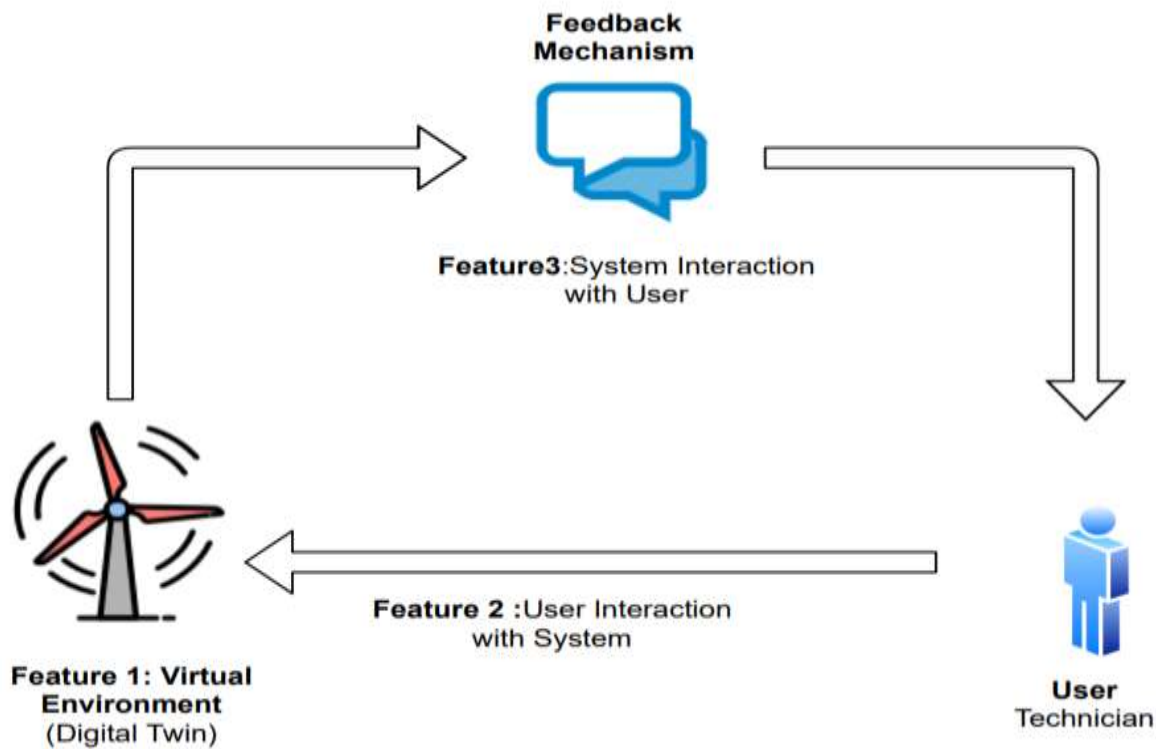
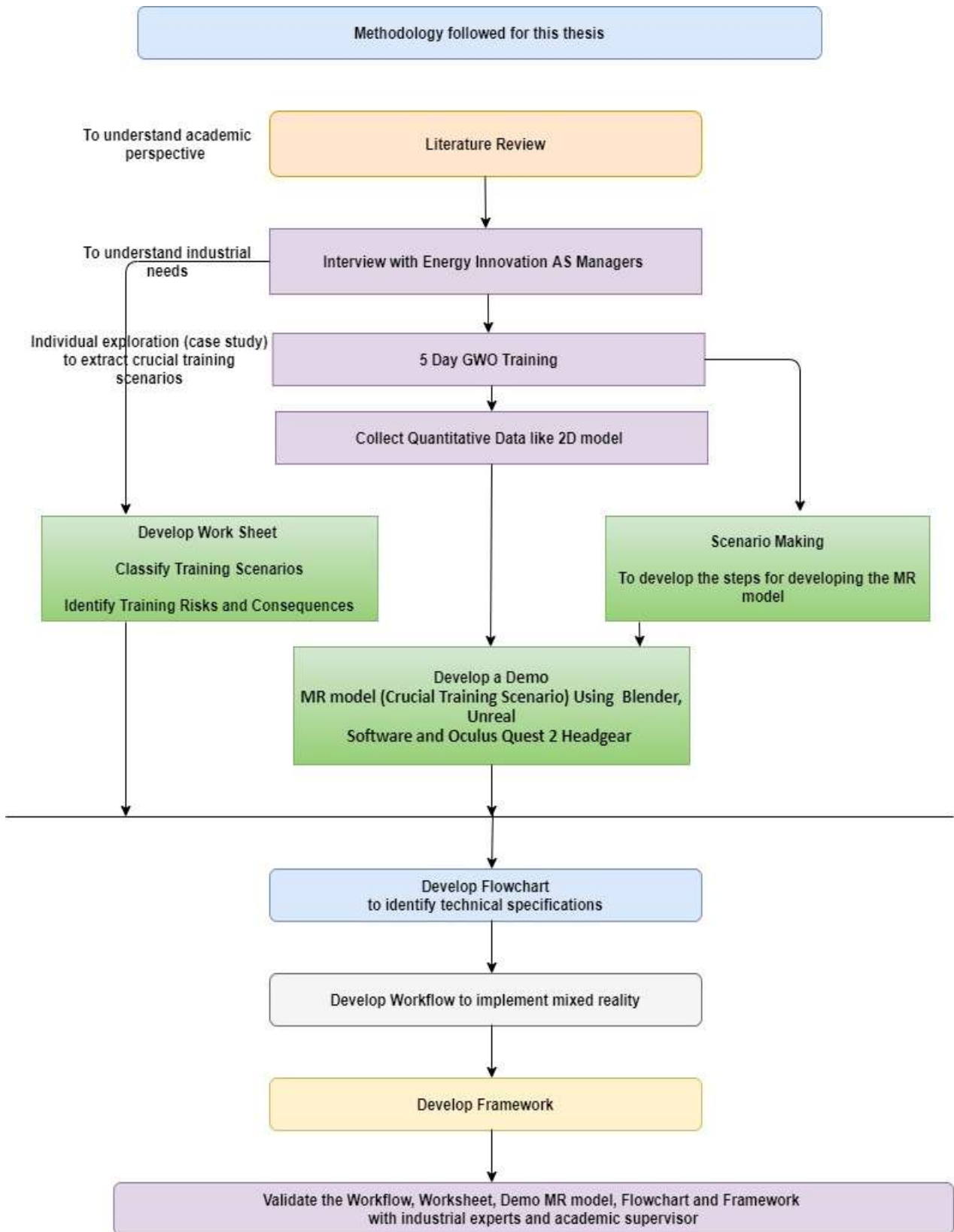


Figure 6: Key Features to Implement MR

The methodology described in Figure 7 was constantly checked to ensure the reliability and the validity of the research. To build a reliable framework, first an extensive literature review was done (section 1.9). Second, I participated in GWO training to understand the crucial scenarios for a period of 5 days. Meanwhile to ensure the validity of the demo MR model created, it was reviewed with relevant industrial experts.

The methodological approach mentioned in the Figure 7 conveys steps followed in the research process of this thesis. The overall approach to collect and analyze data which aid to create the demo MR model of one crucial training scenario and aid to answer the research questions and thereby helping to achieve the research objectives are presented detail at Chapter 4 and Chapter 5.



Energy Innovation AS, SAFER, Espeland Energie AS

Figure 7: Research Methodology

1.6. Thesis Scope

This thesis will focus only on implementing the mixed reality applications for safety trainings in wind energy sector.

The scope of the thesis includes achieving all the objectives (mentioned in the section 1.3) in order to answer the research question. However, there are some delimitations, assumptions, simplifications which are taken to achieve the required results with the given limited time and budget.

First to implement mixed reality technologies, three main key features are identified (Figure 6)

1. The real environment (in this case study, the training tower) must be convert into virtual one like a digital twin. (done using Blender Software).
2. The way the user (technician) interacts with the system (digital training tower) was done using Unreal Software.
3. The feedback from the system (digital training tower) to the user.

The scope of this thesis is however limited to the first two features. The limitations and the delimitations are presented in Table 2 and Table 3.

Table 2:Thesis Limitations

Limitations	Description
Time (From Feb 1,2021 to June 15,2021).	<p>It was only possible to design and validate the research outputs and the demo MR model.</p> <p>It was very difficult to convince the managers to implement and test the demo MR model and workflow in this short time.</p> <p>As described in research relevance, the industry might use this case study as a starting point for further research with more master thesis in the years to come. They plan to use the demo MR model to present to their industrial partners to check the opportunity to develop a full-scale MR model.</p>
Budget	Project budget only for GWO basic offshore course (NOK 21000). Not for advanced rescue, enhanced first aid, pole climbing courses.
Facilities:	<p>The Training facilities are located at Egersund which is 1 hour from University of Stavanger UiS.</p> <p>MR Software lab and 3D model is new to UiS (Experimental basics)</p>
Restrictions (Covid)	<p>Until mid-February restriction to use the lab due to covid restrictions and again by April to May,2021.</p> <p>Only student version of both 3D model and Animation software.</p>

Table 3: Thesis Delimitations, Simplifications and Assumptions

<p>Delimitations</p>	<p>One crucial training scenario will be selected, and a demo MR model will be created using the Unreal Software.</p> <p>The delimitations for the demo MR model developed for this thesis are the C++ scripts are not individualized for many actions in the game. Therefore, there is lot of movement mismatch in the game and bug corrections was time consuming and certain bugs was not rectified fully. The development of mobile application is not in the scope of the thesis as it involves third party virus and quality checks to be performed and it requires payment of money. There will not be any sounds in the game.</p>
<p>Simplification</p>	<p>3D model of the training tower does not include the helipad on the top, as its not relevant for the selected scenario. However, the total height of the tower modelled is including the helipad.</p> <p>The worker animation will have only the important safety gears in the harnesses which are relevant for the crucial scenario to be modelled.</p> <p>The demo MR model character will not have any safety gears into it.</p>
<p>Assumptions</p>	<p>The purpose of the demo model is to illustrate how MR can be implemented. For example, in which situations VR is ideal and in which situations AR is ideal. The demo MR model can be used to build confidence for investing in such technology by Energy Innovation AS.</p> <p>The demo MR model is developed for only one crucial scenario, so it's very difficult to do a cost benefit analysis for that particular situation. Meanwhile in the future, when Energy innovation AS realizes the potential for implementing MR for the entire training modules (all crucial scenario's), then surely a cost benefit analysis will be carried out.</p> <p>This is agreed with the Managers. It is assumed the scenario is cost beneficial.</p>

1.7. Project Plan

The project timeline for the thesis is described in the Figure 8.

PROJECT NAME		PROJECT DURATION	PROJECT START DATE	PROJECT END DATE																								
Mixed Reality Application		4,5 months	February 01,2021	June 15,2021																								
					Month																							
					Feb				Mar					Apr				May				June						
Task ID	Task Description (weekly)	Task Duration	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24						
1	Problem understanding and description	2 week																										
2	Identify/Training Software for 3D model	3 week																										
3	Identify/Training Software for MR model	4 week																										
4	Submit Chapter 1 Introduction	6 week																										
5	Submit Chapter 2 Research Design	4 week																										
6	Literature Review	5 week																										
7	GWO Training	1 week																										
8	Easter Holiday	1 week																										
9	Submit Chapter 4 Data Collection	3 week																										
10	3D model Training Scenario	4 week																										
11	VR model Training Scenario	4 week																										
12	Submit Chapter 5 Data Analysis	4 week																										
13	Research Output Development	1 week																										
14	Validation with Industry and academic	1 week																										
15	Submit Chapter 3 Theory	2 week																										
16	Submit Chapter 6 Discussion	2 week																										
17	Submit Chapter 7 Conclusions	1 week																										
18	Deadline for first submission	1 week																										
19	Thesis revision,academic and technical checks	2 week																										
20	Final submission to university	1 week																										

Figure 8: Thesis Project Plan

1.8. Thesis Structure

The chapter 1 starts with a brief explanation about the background of the wind industry, the growth prospects in the wind industry and the future challenges (problems). One potential innovative solution to the problem is explored. The research question is formulated and checked for its relevance from a systematic literature review (SLR). The existing research gaps in this topic are listed with support from a systematic literature review (SLR). Based on the research gaps, five suitable research objectives are formulated and the methodology to achieve these research objectives are described. The significance and the relevance of the research are clearly listed. The limitations and the delimitations of the research are tabulated. The project time plan and the report structure are presented for quick review.

The chapter 2 helps to identify the research design that will help to answer the research objective of the thesis. The research methodology and design topic start with a brief explanation about the research philosophy and then the research approach is chosen based on the research philosophy. The research strategy and the research techniques are identified. The research methodology steps are defined which helps to define the scope and scale of the research work. The research

techniques which include the data collection techniques, the data source and the data analysis techniques are presented. Finally, the traceability check between the developed research methodology steps and the research objectives is tabulated and the ways to ensure the validity and the reliability of the thesis outcomes are discussed.

This thesis follows a format of explaining the associated theory concepts in the same section where a particular topic is introduced (to improve reader convivence). Therefore, the chapter 3 only focus on relevant theory regarding the concepts associated with technical specifications like type of technology, the hardware platforms, the software platforms, the tracking technique. The evolution of AR and VR over the years is presented to check the history through a hype cycle. Next the application of AR and VR and MR in various industries is mentioned along with the technical challenges in implementing MR. The theoretical concepts of validation and verification of computer modelling is described. One important theory from the 5-day GWO training is briefly explained. The software's that were used to model the demo MR model is described.

The chapter 4 starts with a brief explanation about the case company (Energy Innovation AS) and the modules of the 5day GWO training and the description of the training tower are briefly described. The data collection methods used in the thesis are tabulated and are discussed in detail in the subsequent sections. The quality of the data collected, and the reliability of the data is checked and tabulated. Finally, the traceability check between the data collection techniques and the research objectives is tabulated to check if the progress is in the right direction.

The chapter 5 starts with the systems analysis were the industrial needs and requirement was studied with the help of interview technique. The use case analysis is explained which helps to identify the critical training module in the 5day GWO training program and one similar framework in construction industry is described in detail. The conceptualize phase helps to classify the selected critical module and perform a risk assessment of the training steps. Finally, the scenario modelling is described in detail. The computerize phase explains in detail how to create the 3D model, the safety animation, and the demo MR desktop game. The fifth stage starts with the development of flowchart which will indicate how to identify the relevant type of technology (AR/VRMR) and to identify suitable technical specifications associated with the selected technology. Second the worksheet is developed. Next a workflow is described which will help to implement mixed reality into safety training of wind sector and finally the framework is constructed. The validation of the outputs concludes this section.

The chapter 6 starts with recalling the research objectives and mentioning the steps taken to achieve these objectives. First the systematic literature review (SLR) and GWO training experience is discussed in detail, mentioning the key outcomes, implications, limitations, and some future recommendations. Second the discussion chapter contains the relevant discussions of each of the analysis steps, which is the six-step methodology developed for this case study.

Finally, Chapter 7 outlines the main conclusions and identifies both limitations to the study and recommendations for further research.

1.9. Systematic Literature Review (SLR)

To study the state of art in virtual reality (VR) and augmented reality (AR) in the wind industry and other relevant industry a systematic literature review (SLR) was done. The main purpose for doing SLR for each chapter is given in Table 4.

Table 4:SLR Purpose

Systematic Literature Review for Chapter	Main Purpose	Reference used
Chapter 1: Introduction	<ul style="list-style-type: none"> • To identify research gaps. • To check if the research question is interesting to be explored and if it's not answered so far. • To describe the background information and the problem statement. • To know the advantages and disadvantages of such technologies. 	6
Chapter 2: Research methodology and design	<ul style="list-style-type: none"> • To design the research philosophy, research approach, research strategy and research techniques. 	
Chapter 3: Theoretical background	<ul style="list-style-type: none"> • To describe the theories about the topic. • To describe the theories about the used method. • To describe the theories about the application. 	10
Chapter 4: Data Collection	<ul style="list-style-type: none"> • To find the existing data within the field of study. 	1
Chapter 5: Data analysis and results	<ul style="list-style-type: none"> • To develop conceptual flowchart to select the relevant type of technology and associated technical specifications. • To arrive at the framework by following the six-step methodology developed. • To identify the crucial scenarios and perform scenario modelling in order to develop the demo MR model. 	7
Chapter 6: Discussion	<ul style="list-style-type: none"> • To summarize key findings • To interpret the study results • To check if the results measure what it is supposed to measure • To establish similarity with published articles 	3

Note: There are some articles which are used in multiple chapters, example both in chapter 1 and also used in Chapter 5. However, the article number is recorded in the chapter where it was first used.

The steps that are followed to do this SLR is given in Figure 9 . The SLR methodology used for this thesis is based on the approaches and methods described in the book (Booth et al., 2016)

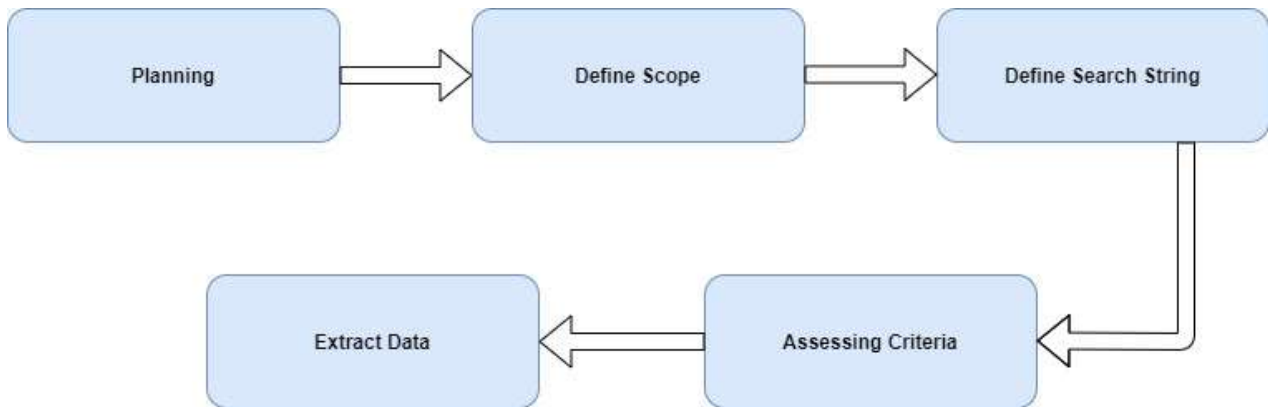


Figure 9: SLR Steps (Booth et al., 2016)

Step-1: Planning:

In the planning stage the search engines which will be used for this systematic literature review (SLR) were selected. Considering the timeframe for this master thesis (5 months). The university search engine and one external search database was selected for the SLR of this thesis.

The main search engines used for the literature search are:

- Google Scholar <https://scholar.google.com/>
- Search Oria (UiS database) www.oria.no

The reference management was done by using Zotero software.

Step-2: Define Scope:

The scope was defined together with the academic supervisor. The method followed in this thesis was to initially start with two important articles provided by the academic supervisor on this area.

The first one, relates to the application of augmented reality in different engineering services (Dini & Mura, 2015). Second, was a detailed SLR done to check the state of art, AR in Maintenance (Palmarini et al., 2018).

The first article helped to understand the application of AR in different industries. The second article helped to identify a few research gaps in implementing mixed reality in training sector. Since the second article (Palmarini et al., 2018) is from the year 2018 several other interesting articles related to the thesis topic was taken from the reference page of this literature review article.

Finally, to further check any latest development in this topic until 2021. I designed a three-step process, which includes the inclusion criteria, the exclusion criteria, and the quality criteria.

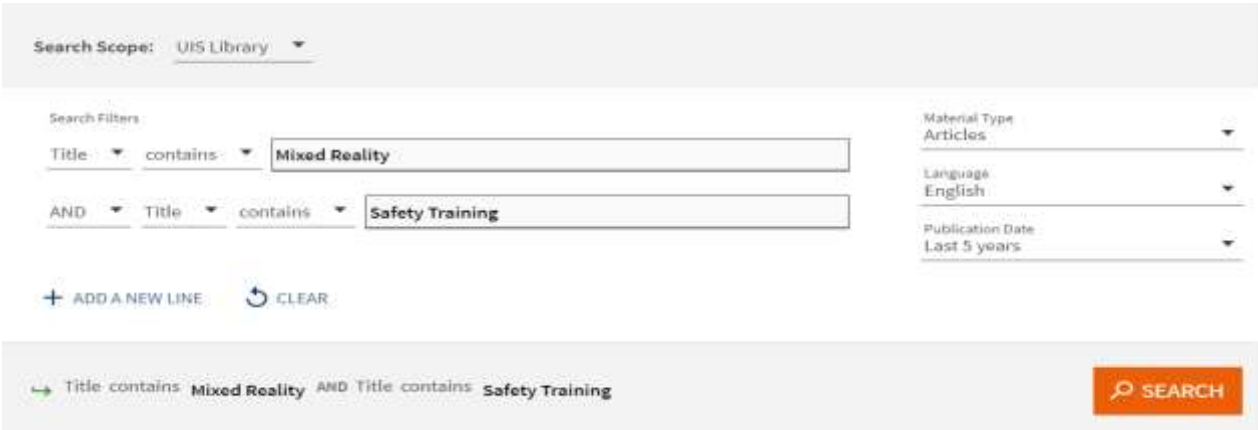
Step-3: Define Search String

The below search string was designed after reading the two previous relevant articles.

1. Key word Combination used: **allintitle:"Virtual Reality" AND "Safety Training"**
2. Key word Combination used: **allintitle:"Virtual Reality" AND "Technical Training"**
3. Key word Combination used: **allintitle:"Augmented Reality" AND "Safety Training"**
4. Key word Combination used: **allintitle:"Augmented Reality" AND "Technical Training"**
5. Key word Combination used: **allintitle:"Mixed Reality" AND "Safety Training"**
6. Key word Combination used: **allintitle:"Mixed Reality" AND "Technical Training"**

The first four search strings will help to identify the state of art around AR/VR in both safety and technical training across different industries. It was planned to check if there are any similar frameworks designed for training sector in any other industries apart from wind industry. The last two strings are directly related to the thesis topic.

The search filter setup to apply for Oria is shown in Figure 10. The keyword combinations are same as mentioned above.



The screenshot shows the Oria search interface. At the top, the search scope is set to 'UIS Library'. Below this, there are search filters. The first filter is 'Title contains Mixed Reality'. The second filter is 'AND Title contains Safety Training'. To the right of these filters, there are additional filters: 'Material Type Articles', 'Language English', and 'Publication Date Last 5 years'. At the bottom left, there are buttons for '+ ADD A NEW LINE' and 'CLEAR'. At the bottom right, there is a 'SEARCH' button. The search query is displayed as 'Title contains Mixed Reality AND Title contains Safety Training'.

Figure 10: Search String Oria

Step-4: Assessing Criteria

The following criteria applies during the search process

Step 1: Inclusion Criteria (IC):

IC1: The study that uses VR/AR in safety training and technical training.

IC2: The words must appear on the title of the article

Step 2: Exclusion Criteria (EC):

EC1: Only from 2015 to 2021

EC2: Only Articles

EC3: Not in English

The number of articles found after applying the IC and EC are given in Table 5

Table 5: Article Outcome after IC&EC

Search String Google Scholar (Filter from year 2015 to 2021)	Google Scholar Articles Found (Final check May29th,2021)	Oria Articles Found Oria Search Figure 10 (Final check May29th,2021)
allintitle:"Virtual Reality" AND "Safety Training"	34	35
allintitle:"Virtual Reality" AND "Technical Training"	2	5
allintitle:"Augmented Reality" AND "Safety Training"	5	5
allintitle:"Augmented Reality" AND "Technical Training"	0	1
allintitle:"Mixed Reality" AND "Safety Training"	2	2
allintitle:"Mixed Reality" AND "Technical Training"	0	0
Total	43	48

All the 43 articles found from the google scholar and 48 articles from oria, was subjected to the quality criteria (QC), which was very subjective. The abstract, conclusion and the articles methodology was read to match the requirements for this thesis

Step 3: Quality Criteria (QC):

QC1: The article methodology includes a framework or flowchart.

QC2: The study results are related to MR/VR/AR in engineering industries.

QC3: The articles provide concrete theory about the application of VR/AR.

QC4: Detailed SLR articles will be selected.

QC5: Choose one article from the duplicate articles from both Scholar and Oria.

The number of articles used in the thesis after applying the QC are given in Table 6.

The most effective literature found from the search process (google scholar) was a systematic review literature (2021) done on the effectiveness of the VR head mounted displays in professional training industry (Renganayagalu et al., 2021). This article speaks about the same hardware I have planned to use in the demo MR model, and it relates to training sector.

Step-5: Extract Data

The final step is to extract the data from the selected articles. Table 6 shows the type of technology and the industry the selected articles represent.

Table 6: Data Extraction from Selected Articles

Article Reference	Type of Technology	Industry	Field of Application	Chapter and Purpose Used
(Dini & Mura, 2015)	Augmented Reality (AR)	Various Engineering Industries	Application of AR in various engineering industries	Chapter 1&3&5: To identify the research gaps To check if the research question is valid. To describe the advantages of mixed realities. To describe the technical specifications associated with AR,VR and MR
(Palmarini et al., 2018)	Augmented Reality (AR)	Various Engineering Industries	Detailed SLR of AR in maintenance across different industry	Chapter 1&3&5: To identify the research gaps To check if the research question is valid. To describe the technical specifications associated with AR,VR and MR
(IRENA, 2019)	Publication	Wind Industry	Outlook about wind industry and renewable industries	Chapter 1: To indicate the background of wind industry and the future prospects.
(Asian et al., 2017)		Wind Industry	Wind turbine accident report	Chapter 1&5: To indicate the occupational hazards of wind industry.
(Brigham, 2017)	Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR)	Various Industries	The usage of MR, VR and AR	Chapter 1&3: To explain the concepts of mixed reality technologies.
(Renganayagalu et al., 2021)	Virtual Reality (VR)	Various Industries	Detailed SLR of VR in training sector across different industry	Chapter 1: To identify the research gaps To check if the research question is valid.
(Rokhsaritalemi et al., 2020)	Mixed Reality (MR)	Various Industries	Describe application of MR.	Chapter 3: Concepts of mixed reality
(Tepper et al., 2017)	Mixed Reality (MR)	Medical Sector	Describe application of MR.	Chapter 3: Concepts of mixed reality
(Poyade et al., 2021)	Virtual Reality (VR)	Chemical Industry	Safety Training	Chapter 3: Concepts of virtual reality
(El-Thalji et al., 2020)	Augmented Reality (AR)	Education Sector	Learning	Chapter 3: Concepts of augmented reality
(Muñoz-Saavedra et al., 2020)	AR/VR	Various Industries	Describe application of AR/VR	Chapter 3: Trends of AR/VR.

(De Crescenzo et al., 2011)	Augmented Reality (AR)	Various Industries	Describe application of AR	Chapter 3: Applications augmented reality.
(Goose et al., 2003)	Augmented Reality (AR)	Various Industries	Describe application of AR	Chapter 3: Applications augmented reality.
(Schall et al., 2009)	Augmented Reality (AR)	Various Industries	Describe application of AR	Chapter 3: Applications augmented reality.
(Costanza et al., 2009)	Mixed Reality (MR)	Various Industries	Challenges	Chapter 3: Applications mixed reality.
(Sargent, 2013)			Verification and Validation	Chapter 3: validation
(Bentsen, 2021)	GWO Training Materials		Describe the training procedures	Chapter 4: To describe the steps of the training
(<i>Wind Turbine Accidents Data</i> , 2021)	Webpage	Wind Industry	Accident data about wind industry.	Chapter 5: To identify the major accident category
(Gupta & Varghese, 2020)	Virtual Reality (VR)	Construction Industry	Describes a similar framework used in construction industry.	Chapter 5: To identify the main elements in a framework.
(Sargent, 2013)	Simulation Model		Describes the verification and validation process	Chapter 5: To guide in verification and validation process.
(Buttussi & Chittaro, 2018)	VR/AR	Multiple Industry	Describes the hardware platforms	Chapter 5: To guide in verification and validation process.
(Checa & Bustillo, 2020)	VR/AR	Training Industry	VR to improve learning	Chapter 5: To guide in validation of Demo Model.
(Suarez-Fernandez de Miranda et al., 2020)		Manufacturing Industry	Life Cycle Engineering 4.0	Chapter 5: To guide in validation of MRA Workflow.
(Sepasgozar, 2020)	Digital Twin and Web-Based Virtual Gaming	Training Industry	Technologies for Online Education	Chapter 5: To guide in validation of MRTS Flowchart
(Jeelani et al., 2020)	Virtual Reality (VR)	Construction	Construction Safety Training	Chapter 6: To guide in validation process.
(Dhalmahapatra et al., 2020)	Virtual Reality (VR)	Multiple Industry	Safety Training	Chapter 6: To guide in validation process.
(Druzhinia et al., 2019)	Virtual Reality (VR)	Construction	Safety Training	Chapter 6: validation process of Demo model.

Note: Personal communication reference used for interviews are not updated in the above table. There are lot of textbook which were referenced, this is not included in the table.

2. Research Methodology and Design

Chapter Outline:

The chapter helps to identify the research design that will help to answer the research objective of the thesis. The research methodology and design topic start with a brief explanation about the research philosophy and then the research approach is chosen based on the research philosophy. The research strategy and the research techniques are identified. The research methodology steps are defined which helps to define the scope and scale of the research work. The research techniques which include the data collection techniques, the data source and the data analysis techniques are presented. Finally, the traceability check between the developed research methodology steps and the research objectives is tabulated and the ways to ensure the validity and the reliability of the thesis outcomes are discussed.

2.1. Research Design

The objective of this thesis is to design and develop a reliable and valid framework, worksheet and flowchart to implement MR in training sector of the wind industry and work processes to design MR model for safety training in the wind sector. The research design that will enable to achieve this objective is discussed in detail.

The research philosophy that is ideal to be followed for implementing mixed reality applications into safety training of wind sector is pragmatism, since it deals with the success of practical application of the demo MR model. However, Interpretivism philosophy was followed to understand the crucial scenarios in safety training by interviewing Energy innovation AS managers. Then while designing the interface between the technician (worker) and the digital tower, critical realism philosophy was followed to capture as many interface details as possible based on my personal GWO training experience (Neuman, 2014).

Based on my research philosophy, which is a triangulation of Interpretivism, pragmatism and critical realism, the research approach for this thesis is abduction research which is a combination of both inductive and deductive research. Inductive research approach involves developing a framework/workflow for implementing mixed realities based on the inputs from Energy Innovation AS and from the literature review. The deductive research approach involves developing a demo MR model based on similar models in other industries like construction industry and then to validate with industrial experts before arriving at the final framework.

The research strategy which is used in this thesis is based on the research philosophy and research approach is a case study approach which involves a detail literature review to check for relevant framework and having interviews to understand the industrial requirement relevant to this topic. and action research approach which involves building a demo MR model and validate it. The research techniques and procedures followed in this thesis are based on data collection and data analysis. The Figure 11 visually summaries the research design.

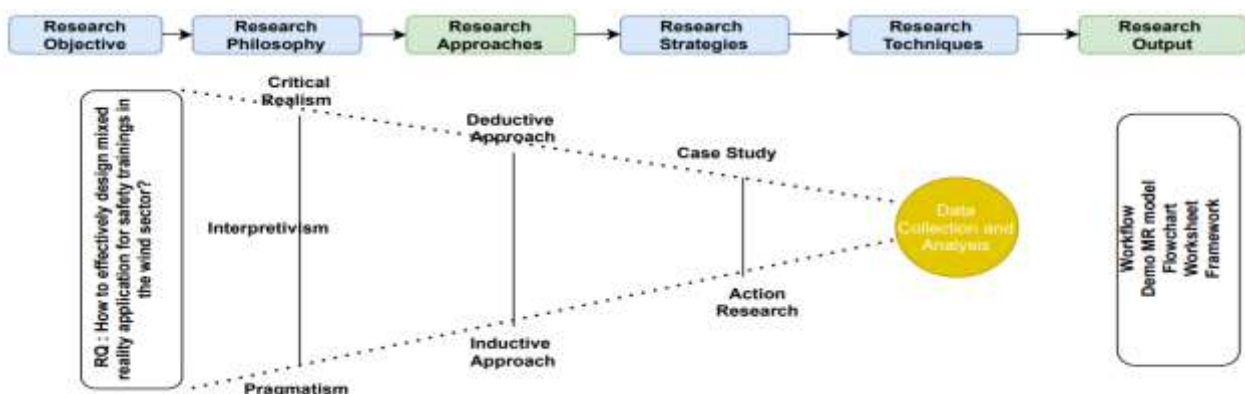


Figure 11: Research Philosophy and Methods (Neuman, 2014)

I acknowledge the fact that the scientific research to create a real-world experience using MR is still not 100% accurate since it involves conceptualizations, generalizations, and predictions that the researcher uses based on his knowledge.

2.2. Research Design Statement

The research design statement is based on the understanding of the core activities to be done to reach the desired research objectives and the associated philosophical view. The objectives and the activities are tabulated below in Table 7. The six methodology steps are inspired and adapted from four step modelling approach by Randers (Randers, 1980).

Table 7: Research Design

Methodology Steps	Aspects	Methods	Philosophical View (Neuman, 2014)	Research Approach and Research Strategies (Neuman, 2014)
System Analysis	Extract industrial needs and requirements	Interviews with Energy Innovation AS	Interpretivism	Inductive research approach and case study strategy
Use Case Analysis	Develop case context	Literature review Case study: 5-day GWO training	Pragmatism	Inductive research approach and case study strategy
Conceptualize	MR concept study: scenario modelling To develop coarse risk assessment and hazard identification	Training criticality classification Manipulate training scenario based on personal experience and expert opinion	Constructivism, Interpretivism	Inductive research approach and case study strategy
Computerize	Build 3D models Construct demo MR models for crucial scenarios	Modelling with Blender and Unreal Software	Positivism Critical realism	Deductive research approach and action research strategy
Construct Flowchart, Worksheet, Workflow and Framework.	Construct and interpret To develop conceptual flowchart to select	Develop workflow	Constructivism Interpretivism	Deductive research approach and case study strategy

	the relevant type of technology and associated technical specifications. Develop worksheet, workflow and framework	Perceptions from other technology developers like Bouvet		
Verify, Validate and Visualize	Check, improve and approve the demo MR model and framework	Verification tests. Validate with Industrial Experts.	Positivism and Interpretivism Postmodernism	Inductive research approach and case study strategy

From Table 7 the flow of work becomes clear and this helps to define the scope and scale of the research work, and where to stop. The research future scenario is visualized in the Figure 12.

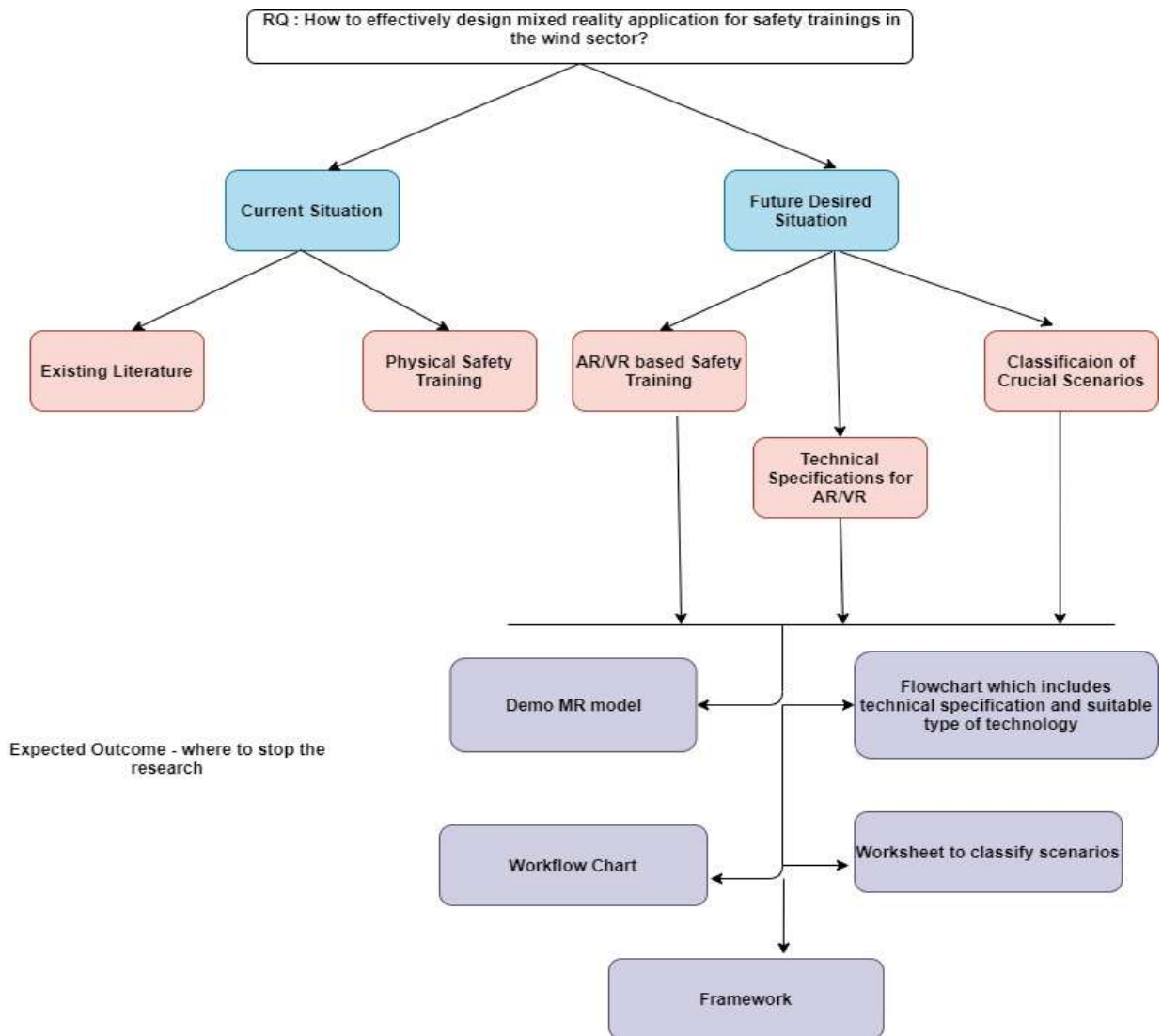


Figure 12: Scope and Scale of Research

The developed research design for this thesis proposes only one iteration of development of the framework, flowchart, workflow. One scenario which is crucial from the safety training perspective is chosen. One Demo VR model is created and validated.

2.3. Research Techniques

The Table 8 gives a brief description of the data source used in the thesis and of the data collection and the data analysis techniques required to satisfy the research needs and the objectives of the thesis.

Table 8: Case Study Research Techniques

Methodology Steps	Methods	Data Sources (what, where, who)	Data Collection Techniques	Data Analysis Techniques
System Analysis	Interviews with Energy Innovation AS managers	Internal safety documents and guideline reports from Energy Innovation AS	Retrieve documents. Interviewing.	Needs and purpose analysis.
Use Case Analysis	Literature review Case study: 5day GWO training	Literature review. Observational data. Expert opinions. Training materials.	Retrieve documents. Observing processes and training scenarios.	Needs and purpose analysis. Perception analysis. Process analysis.
Conceptualize	Training criticality classification Manipulate training scenario based on personal experience and expert opinion To develop coarse risk assessment and hazard identification.	Expert perceptions about criticality of the training modules Perceptions from Energy Innovation AS. Perceptions from other technology developers like Bouvet Personal perception and ideas	Retrieve training documents. Retrieve literature records. Observing. Interviewing	Safety analysis. Risk analysis Sensitivity analysis. Parameter variation analysis.
Computerize	Modelling with Blender	Model input data (dimensions, interactions, MR	Simulating	Simulation analysis.

	And Unreal Software	tracking methods)	Retrieve numerical data (Inputs)	Parameter variation analysis.
Construct Flowchart, Worksheet, Workflow and Framework.	<p>Construct and interpret</p> <p>To develop conceptual flowchart to select the relevant type of technology and associated technical specifications.</p> <p>Develop worksheet, workflow and framework</p>	<p>Technical specifications like hardware and software platforms from literature review</p> <p>Training Materials from Energy Innovation AS</p> <p>Perceptions from other technology developers like Bouvet</p>	Retrieve Documents	Lifecycle Analysis.
Verify, Validate and Visualize	<p>Check, improve and approve the demo MR model and other research outputs</p> <p>Verification tests.</p> <p>Validate with Industrial Experts.</p>	<p>To verify the workflow by the demo MR model.</p> <p>To validate the worksheet, flowchart and framework with industrial experts.</p> <p>To verify the Demo MR model by asking participants to use it.</p> <p>To validate the demo MR model with industrial experts.</p>	<p>Interviewing</p> <p>Performing focus groups</p>	<p>Perception analysis.</p> <p>Comparison analysis.</p>

2.4. Traceability Check Methodology Steps and Research Objective

The traceability check between the six steps methodology developed for this thesis with the research objective of the thesis is tabulated in Table 9. This will indicate if each of the methodology step followed will take us one step further to achieve the expected results. Moreover, a detailed description on the procedure of performing each of the analysis and the quality of the data are discussed in chapter 5 and 4. Furthermore the problems (if any) arising due to the type of analysis method are presented in the Chapter 6.

To recall the objectives of the thesis are:

1. To develop a worksheet to identify the critical training modules/scenarios and further classify them to check if implementation of mixed realities is needed or not?
2. To develop a workflow which will help to implement mixed reality technology into training activities of the wind sector.
3. To develop a flowchart which will help to recognize the technical specifications like the suitable hardware platform, suitable software platform and relevant tracking technique.
4. To develop a framework which will capture the method to implement mixed reality technology.
5. To design and create a demo MR model based on the workflow developed in order to validate the workflow and understand the associated practical challenges like complexity of such mixed reality technologies and user familiarity.

Table 9: Traceability Check Methodology Steps

Methodology Steps	Relation to thesis objectives
System Analysis	Helps to identify the needs and requirements.
Use Case Analysis	Helps to identify if some similar frameworks are available in other engineering industry. Helps to identify the critical training module for which the worksheet is constructed.
Conceptualize	Helps to develop the steps for the worksheet which aids to classify the critical training module and identify if mixed reality is needed to be implemented or not. Helps to develop the steps for demo MR model.
Computerize	Helps to develop the demo MR model.
Construct Flowchart, Framework and Workflow	Helps to develop conceptual flowchart which aids to indicate the relevant type of technology and associated technical specifications. Helps to develop the final Worksheet. Helps to develop the workflow which will help to implement mixed reality technology into training activities of the wind sector. Helps to develop a framework which will capture the method to implement mixed reality technology.
Verify, Validate and Visualize	Helps to validate the framework, flowchart, worksheet, workflow and the demo MR model.

2.5. Research Reliability and Validity statement

The main outputs from this thesis are represented visually in Figure 12. The steps that are planned to be taken to ensure the validity measures which includes collecting valid data and perform a valid analysis method are presented in Table 10. The reliability measures which includes collecting a consistent data sets and performing a reliable method are also discussed.

Table 10: Research Outputs Reliability and Validity

Thesis Expected Outputs	Reliability Measures	Validity Measures
The Worksheet	The hazard identification is planned to be carried out based on a worksheet provided (attached in appendix) by Energy innovation AS.	The validity of the worksheet is planned to be confirmed with industrial expert opinion from Energy Innovation AS.
The Workflow	The industrial needs and requirements in the framework are planned to be collected from a reliable interviewing technique	The validity of the workflow is planned to be checked by developing a demo MR model.
The Flowchart	Technical specifications of MR technology like hardware and software platforms are planned to be extracted from systematic literature review (SLR).	The validity of the flowchart is planned to be confirmed with industrial expert opinion from Energy Innovation AS, Espeland Energie AS and SAFER.
The Framework	Combines the planned reliable measures of Worksheet, Workflow and Flowchart.	The validity of the framework is planned to be confirmed with opinion from Energy Innovation AS, Espeland Energie AS and SAFER.
The Demo MR model	<p>The steps of MR model will be done only after attending a 5-day GWO training personally.</p> <p>The Training documentation is already approved by GWO.</p> <p>The 2D drawing of the tower is a reliable and valid input data.</p>	<p>The Demo MR model is planned to be validated with SAFER and Energy Innovation AS.</p> <p>Peer debriefing which involves discussing with other students regarding the validity of the demo MR model and the user convenience.</p>

The reliability and the validity of the data collection methods and data analysis are discussed in detail in the chapter 4 and 5. Meanwhile chapter 6, discuss how reliable and valid are the produced results. It discusses the level of consistency and the actual opinions from industrial experts. The shortcomings of the research are also discussed in chapter 6.

3. Relevant Theory

Chapter Outline:

This thesis follows a format of explaining the associated theory concepts in the same section where a particular topic is introduced (to improve reader convivence). Therefore, this chapter only focus on relevant theory regarding the concepts associated with technical specifications like type of technology, the hardware platforms, the software platforms, the tracking technique. The evolution of AR and VR over the years is presented to check the history through a hype cycle. Next the application of AR and VR and MR in various industries is mentioned along with the technical challenges in implementing MR. The theoretical concepts of validation and verification of computer modelling is described. One important theory from the 5-day GWO training is briefly explained. The software's that were used to model the demo MR model is described. Finally, the benefits of using MR in safety is described.

3.1. Concepts: Type of Technology

Augmented Reality (AR)

Augmented reality is a concept where the user can experience the real physical world with inclusion of real time digital content (Brigham, 2017). Some widely known uses and examples are Google glass and Pokemon Go app. Google glass <https://www.google.com/glass/start/> was a device that can be worn on head which looked similar to eyeglasses, it was in use only between 2013 and 2015. These devices allowed wearers to view information on a tiny display above the right eye. The device had features such as reading messages, taking pictures, and recording anything that the wearer could see. Its major use was in the health care industry where it was used for recording patients details during an appointment to improvise health record capturing and for surgeons to monitor patients vitals while still working on an operation (Brigham, 2017).

Virtual Reality (VR)

In this concept of artificial reality, the person is completely displaced to another location, thereby overlapping the natural physical surrounding. These devices are like a headset, with a screen in front of users' eye and headphones with surround-sound effects of the new digital environment. The aim of VR is to immerse the user into a complete difference experience and give a sensation that it is really happening. In its early introduction in 1990s, VR was not successful in entering consumer market due to its high cost and its effect of motion sickness to the users. Though, after nearly 20 years with the invention of Oculus <https://www.oculus.com/quest-2/accessories/>, which had resolved the problem of motion sickness with its research on how to reduce latency. In VR, latency is the difference of time between a user motion and when the virtual image adjusts to the movement. The Oculus Rift combines information from gyroscope, accelerometer, and magnetometer to evaluate head movement, and results in improvisation of user experience (Brigham, 2017).

Since then many new devices such as FOVE, OSVR HDK2, HTC Vive, and PlayStation VR have been in-development due to the renewed interest in VR. Some mobile manufacturers such as Samsung, Google and LG have built their mobiles to support use with VR headsets as displays (Brigham, 2017).

Mixed Reality (MR)

MR was derived both conceptually and historically from virtual reality. MR brings together real physical reality and digital content. In mixed reality you interact with and manipulate both real-world and virtual objects using advanced sensing and imaging technologies. Mixed reality is sometimes considered a type of augmented reality, but its capacity for interactivity between real-world and digital elements paces it further along the virtuality continuum (Lalanne et al., 2009).

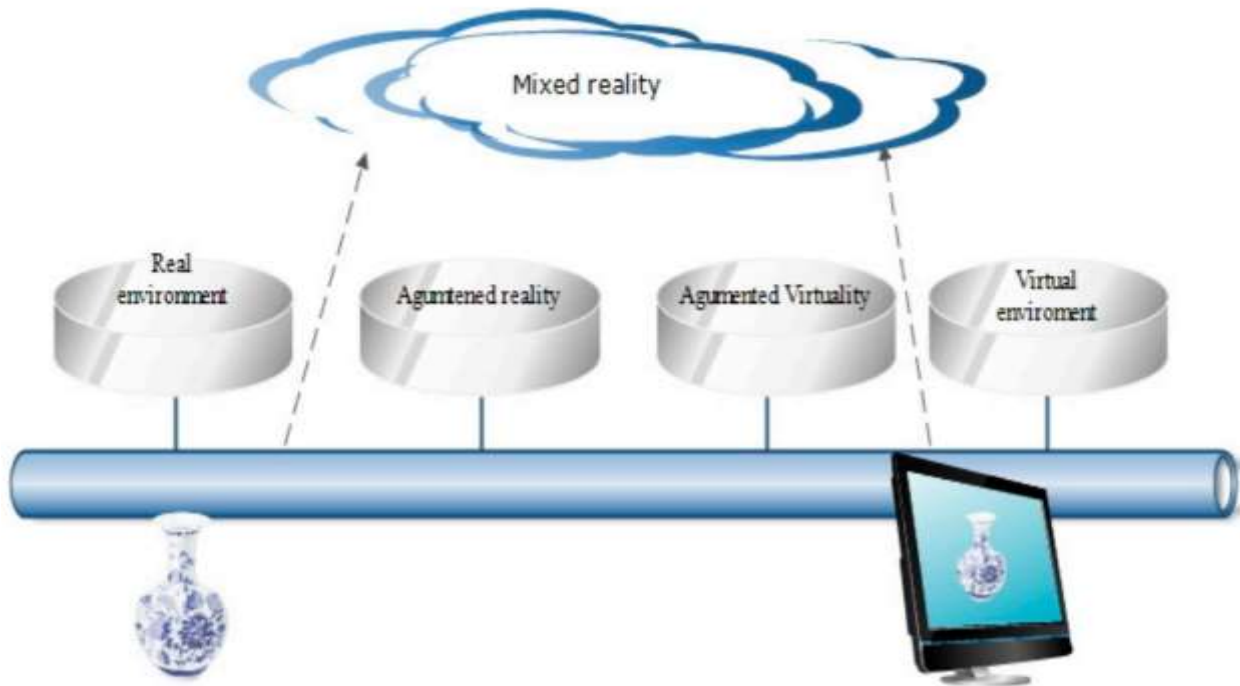


Figure 13: Mixed Reality Domain (Rokhsaritalemi et al., 2020)

Figure 13 represents the mixed reality continuum which is a scale modelling real-world representation of classes based on computing techniques. On the left side of this scale is real environment, on the right-side virtual space and MR is everything between augmented reality and augmented virtuality. Mixed reality is sometimes also referred to as hybrid or extended reality (XR). Using the different medium of user interfaces users can map digital content in physical surroundings and software then uses deep learning algorithms to align digital characters with specific areas of the map (Rokhsaritalemi et al., 2020).

Key Characteristics of mixed reality (MR) for basic understanding (Rokhsaritalemi et al., 2020):

- Mixed reality (MR) aims to achieve maximum user interaction.
- Mixed reality (MR) aims to provide an immersive experience in the same time allows the user to interact with the real environment.
- The tracking of the user space and the 3D object space and the integration of both is the main characteristics and challenge of MR.
- In MR systems, users perceive both the physical environment around them, and digital elements presented through, for example, the use of semi-transparent displays.

Mixed reality (MR) characters are defined using three terms by (Rokhsaritalemi et al., 2020) :

Immersion refers to representation of the user environment in real time. MR tries to achieve real time spatial mapping which means creating a 3D map of the environment in real time. Meanwhile using AR, the user will still be in the real world, but he will see some extra graphics and information. With VR the user is fully in the virtual world. So that real time mapping of user environment is low. The Figure 14 explains this trend. With MR having a high immersion and AR having a medium immersion and AR is fully virtual.

Interaction is very intuitive to understand. It is how the user interacts with the environment (object). In VR domain the user can only interact with the virtual domain and in the AR domain the user can only interact with the physical object, since the user can never enter the virtual world. However in the MR domain (Figure 14) the user can interact simultaneously both in the virtual environment and still be in the physical (real environment).

Information refers to “virtual object being registered in time and space in the user environment”(Rokhsaritalemi et al., 2020). VR will export the user into the 3D space. Meanwhile AR will just annotate the 3D space. There is no correlation to user space in both AR and VR. However, MR offers correlation to user space and thus it is also time persistent.

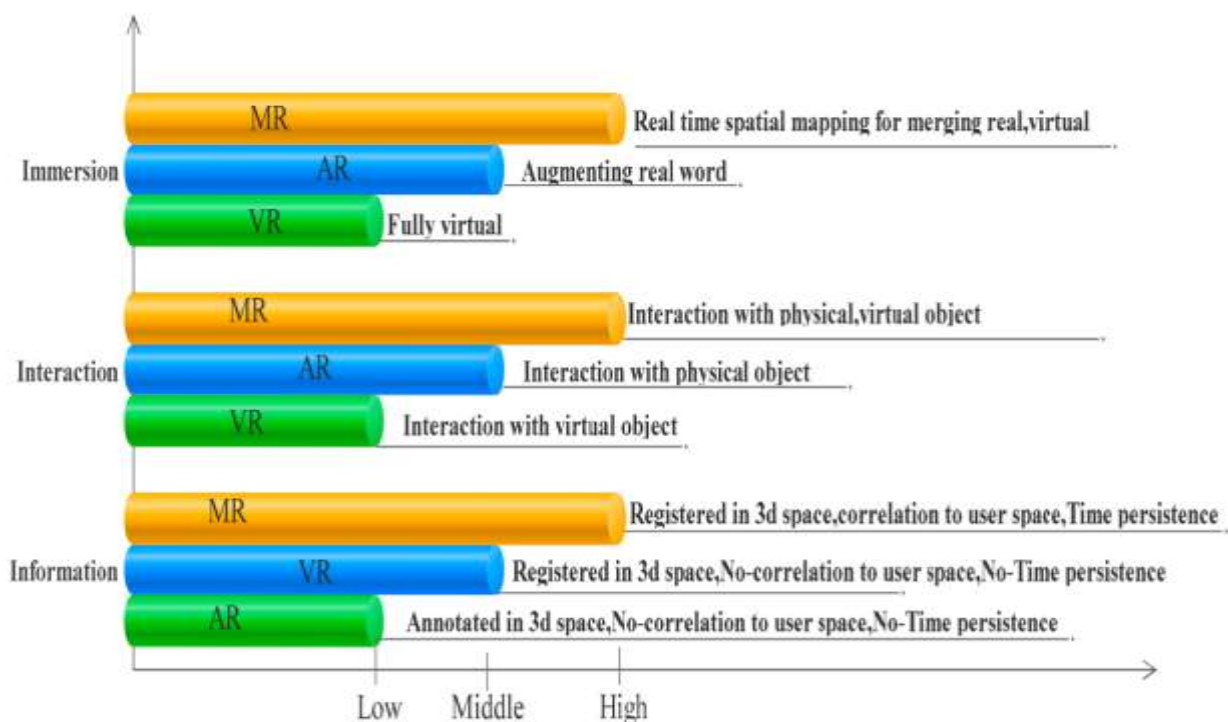





Figure 14: Mixed Reality Characters (Rokhsaritalemi et al., 2020)

The basic difference between AR and MR is that though AR can include virtual objects in a real-world environment, but it does not allow perception of depth and perspective of virtual objects while MR does.

3.2. Mixed Reality Hardware Platforms

Table 11: Comparison of Wearable Computers (Tepper et al., 2017)

Product Description	Google Glass	Oculus Rift	Microsoft HoloLens
			
Technology	Augmented Reality	Virtual Reality	Mixed Reality
Wearability	Eyeglasses-style	Adjustable Headband	Adjustable Headband
Battery Life	1 Hr of heavy use	Wired power consumption	2-3 Hr heavy use
No-touch operation	Touchpad on right arm, can be voice-controlled	No	Controlled by gestures and voice command
True heads-up display	Yes	N/A	Yes, holograms can also be placed out of field of view

There are always difficulties in introducing new technologies in mainstream, and artificial reality (together AR, MR and VR) is no different. Technical issues will be a constant part of artificial reality devices and software. There are currently many devices and software which still contain glitches, the supporting parameters such as server infrastructure, bandwidth expansion, and processing speed must be improvised to support growing demands. The situation is more complicated with companies that are looking to make profit and compete thus creating hurdles in open access of the technology which can help reduce cost (Brigham, 2017).

One of the major applications of artificial reality is in the field of medical sciences, these technologies are useful in many areas to assist with diagnosis and during surgery. For instance, plastic surgery is an area which demands for complex 3-dimensional view of the human anatomy with the highest accuracy. Therefore, the above difference stated for MR and AR plays a role in identifying the scope for contribution of these technology in plastic surgery practice. It is evident that VR and/or AR together would not suffice the requirements for the medical field. The answer to this lies in mixed reality techniques, which is a combination of many virtual reality and augmented reality features. The first commercially available and popular device for mixed reality is Microsoft's HoloLens <https://www.microsoft.com/en-us/hololens>. This device can provide surgeons with the complex information, the real environment and bidirectional communication facility, all with hands-free option making it easier for use (Tepper et al., 2017).

During the research, in 2016, Microsoft Corporation introduced HoloLens mixed reality device. The advantage of this commercial device is that the headset consists and incorporates a variety of sensors as well acts as an integrated computer. Unlike Google glass, HoloLens represents mixed reality. The HoloLens provides for each user the maximum user interaction, it offers interpupillary synchronization combined along with a real time heads-up display function. It is design in a way that the transfer of visual information from the surrounding environment does not interfere with the vision. The weight of the device is distributed through the head of the user with a customizable headband and is rechargeable for 2 to 3 hours (Tepper et al., 2017).

One area of application of the HoloLens is the medical sector, the surgeon has quick and immediate access to a wide range of valuable applications. The most important feature is the hands-free option Figure 15.

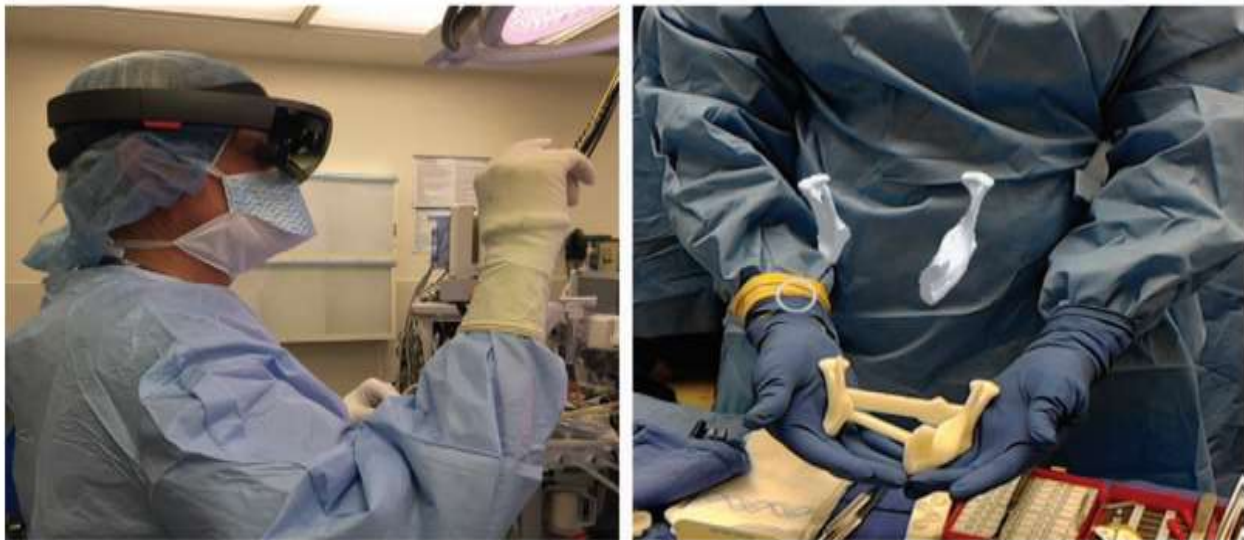


Figure 15: Surgeon Using HoloLens (Left) and (right) Image from HoloLens (Tepper et al., 2017)

When the price of HoloLens is compared with Google Glass and Oculus Rift it is approximately \$3500. But still it makes sense due to the capability of manipulation and visualization of holograms in a 'real' environment that Google Glass or Oculus Rift does not give. HoloLens offer surgeons access without interruption workflow, to real-time, multidimensional information, and surgical efficiency. Surgeons have far greater access to information and create the basis for better decision-making, because they can engage intraoperatively with 3-dimensional data packets(Tepper et al., 2017).

The other most important hardware components for mixed reality applications are the following(Dini & Mura, 2015):

Computer: The computer is used to create the virtual image of the object and at the same time it is also used to map the user position with the object and track the user movement.

Tracking System: To accurately align the virtual image to the real one, a tracking system is required to capture and record the user's position and orientation in space.

The Figure 20 , shows that most commonly used hardware devices, with the head mounted devices are mostly used.

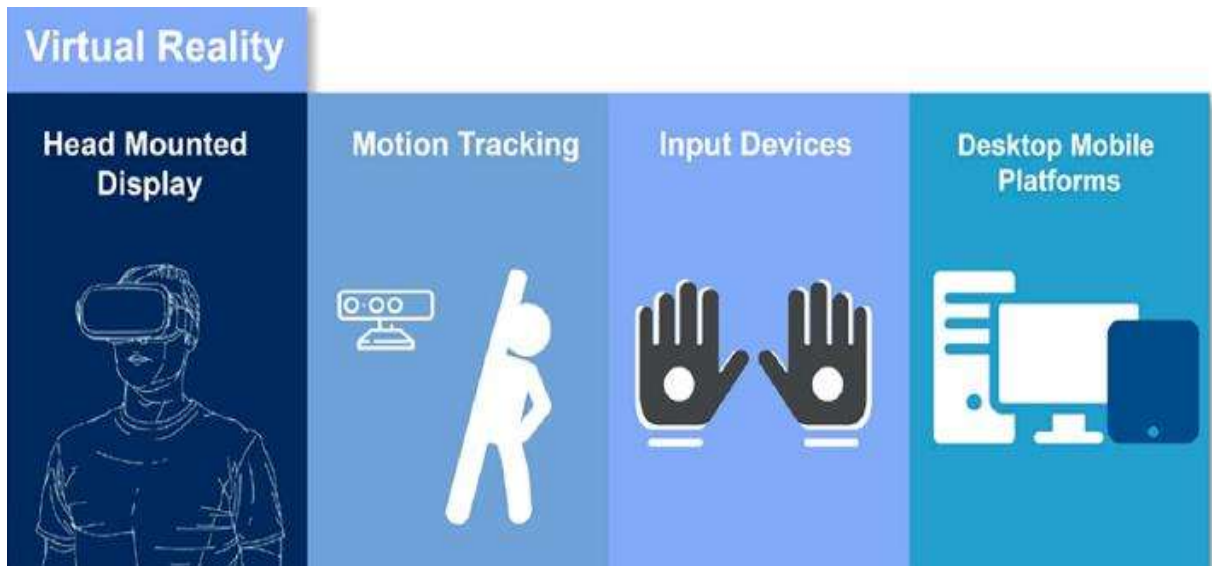


Figure 16: Virtual Reality (VR) Technology Integration (Poyade et al., 2021)

The Figure 16 describes the VR integration. The head mounted devices is used to provide an immersive experience and the motion tracking sensors needs to be in place to track the motion of the user relative to the environment. The input devices can be joystick. The software integration platform can be a computer device(Poyade et al., 2021). The software platform and the tracking technique are discussed in the below sections.

VR is currently regarding as one of the best disruptive technologies and the rise of 3D modelling and animation in the last decade is making VR to be more popular. It is finding it application in number of domains like aerospace, architecture, building, manufacturing, video games, arts and humanities, medical and education.

3.3. Mixed Reality Software Platforms

The software techniques that are used to combine real images and virtual objects are (Dini & Mura, 2015):

1. Optical combination
2. Video Mixing
3. Image projection

In simple terms in the optical combination software technique virtual visuals are projected into the user's field of view while they observe the real scene (Dini & Mura, 2015). For example, the University of Stavanger, asset lab has developed an AR of the fault simulator for learning purpose. Here when the user uses a mobile app, can observe the virtual visuals of the shaft (Figure 17) while they also see the real fault simulator.

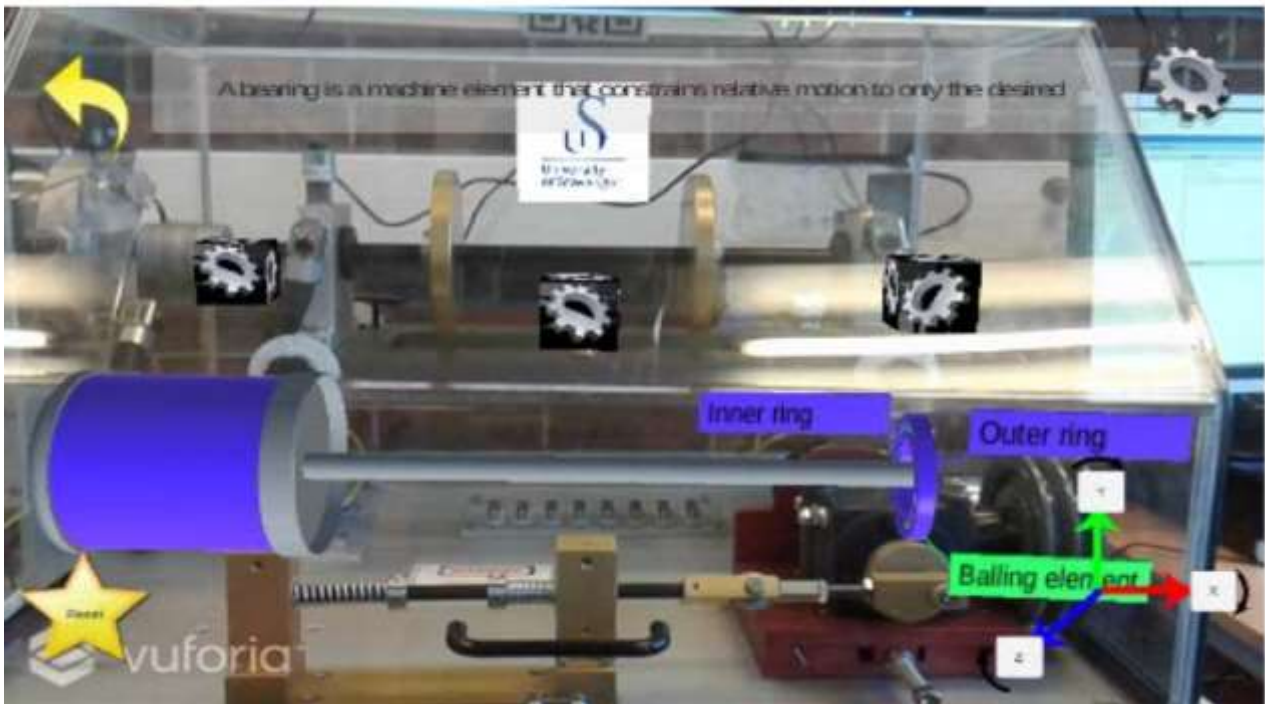


Figure 17: Augmented 3D Drawing of the Machine Fault Simulator, UiS Lab (El-Thalji et al., 2020)

The video mixing technique involves the camera to capture the digital information, which is then manipulated or modelled by a computer. The output is then presented on a monitor, allowing the viewer to see the picture indirectly. This is the most common technique. The Demo MR model is also developed using this technology (Figure 18). The following section analysis will explain how this type of software techniques is developed.

The image projection technique involves images are projected straight onto the surfaces of tangible objects in image projection. The Figure 19 shows an example of how the image are projected for easier working practice. This software technique is the most least used in the industry. The Figure 20 , shows that video mixing lead the way in terms of the most practical method for overlaying virtual components and the image projection is the least used.



Figure 18: Video Mixing Technique (Snap from Demo MR Model, by author)



Figure 19: Image Projection (Lalanne et al., 2009)

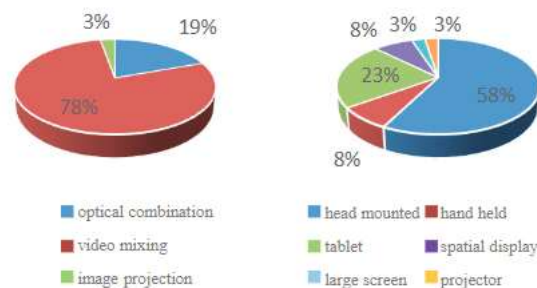


Figure 20: Commonly used Software and Hardware Platforms (Dini & Mura, 2015)

3.4. Mixed Reality Tracking Techniques

Tracking is the important feature which brings the user and the environment in sync. Both the orientation and the position of the user needs to be tracked with respect to the environment in order to achievement effective function of mixed realities. The tracking techniques are broadly classified into vision-based techniques and then sensor-based techniques. The hybrid-based technique combines both the vision and the sensor-based techniques (Palmarini et al., 2018). The vision-based techniques are further classified into (Palmarini et al., 2018).

- Model based tracking.
- Feature based tracking.
- Marker based tracking.

All these three tracking techniques can either be “a priori” or be “had-oc” (Palmarini et al., 2018). In simple terms “a priori” means having previous knowledge about the object to be tracked. Mostly possible in AR applications.

The model-based tracking is one using the computers and developing a 3D model of all the objects in the virtual environment and then the tracking is done using the CAD environment. The feature-based tracking involves the use of images to track and the marker based involves placing markers which can be images or barcodes to track. This type of tracking is the least expensive and therefore the most common (Figure 21), However it has lot of disadvantages because if the marker surface is not clean, then the tracking will not be effective. The sensor-based tracking involves the use of sensors and GPS. MR technology must use the Hybrid type of

tracking. Figure 21 also shows that the 3D modelling is the most commonly used development platform and for this case study we can also using both the 3D modelling and the game engine.

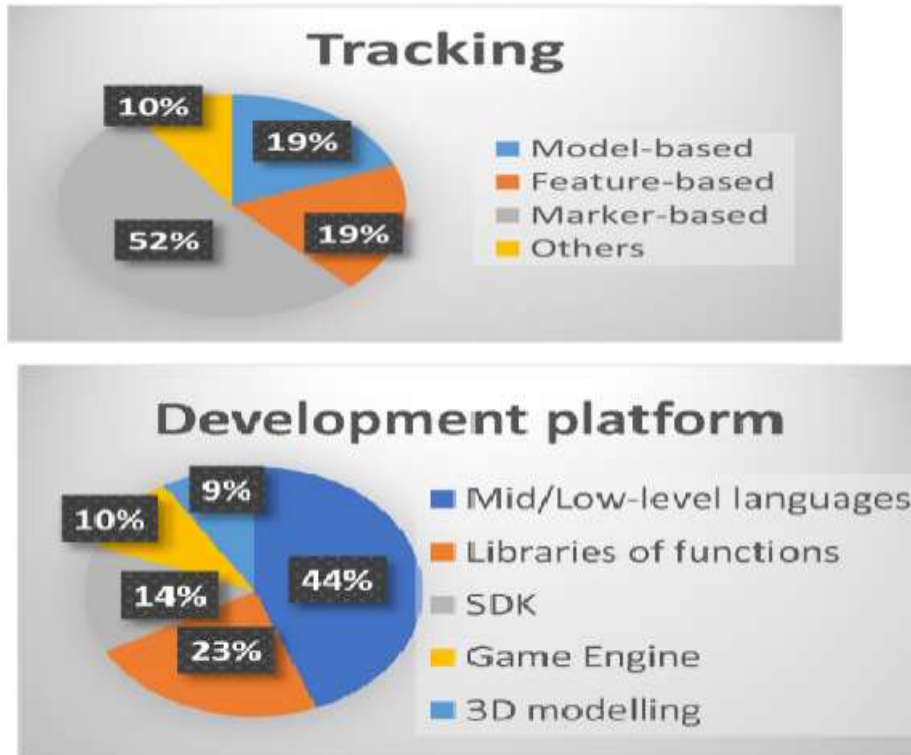


Figure 21: Commonly used Tracking Techniques (Palmarini et al., 2018)

3.5. Evolution of AR and VR

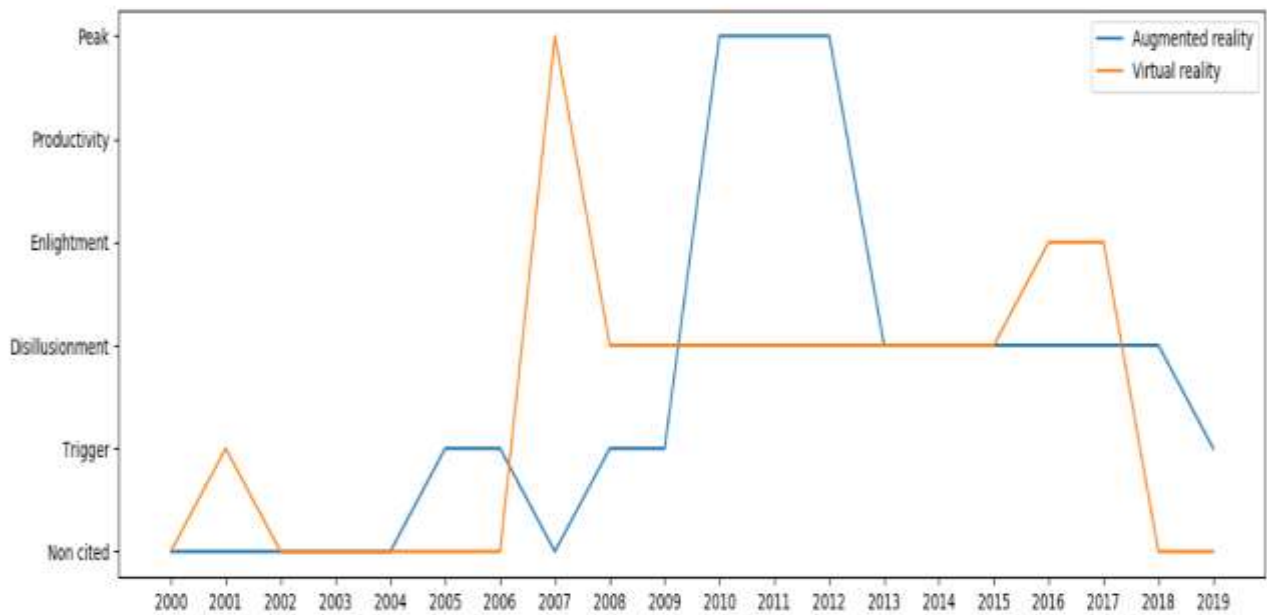


Figure 22: Evolution of AR and VR Technologies (Muñoz-Saavedra et al., 2020)

The Figure 22 shows the gartner's hype of cycle which is known for estimating emerging technologies and time when these will be in production. In above hype cycle for VR and AR, the data is captured for years 2000 to 2019. The x-axis represents the year and y-axis represent Gartner's hype cycle stages as explained above.

Gartner's hype cycle depicts the evolution of interest in particular type of technology classifying them in below five stages during their interest cycle:

- Technology trigger: When technology is starting
- Peak of inflated expectations: Companies release publications with success and failure details
- Trough of disillusionment: most of experiment and implementation fails
- Slope of enlightenment: second or third generation of technology start
- Plateau of productivity: technology is introduced mainstream

As from the figure, the first peak for AR in Gartner's hype cycle is dated back to 2005, this then continues to "Technology trigger" stage and remains active until 2010, after which it reaches "Peak of inflated expectation". Then AR moves to the stage of "Trough of disillusionment" from 2013 to 2018. Then again in 2019, it resurfaces in "Technology trigger" stage, this time with addition of term "Cloud". This is due to inclusion of cloud technologies, which allow for computing in cloud and provide ease of use to end users (Muñoz-Saavedra et al., 2020).

VR technology is observed in different ways in Gartner's hype cycle, for e.g., first it is identified in 2001 in "Technology trigger" stage, then it moves on to "peak of inflated expectation" from 2007 to 2012. After this due to less outreach, it moves to "Trough of disillusionment" stage in 2013. Finally, in 2016 it reaches "Slope of enlightenment" stage (Muñoz-Saavedra et al., 2020)

Both AR and VR are expected to go to the plateau of productivity stage after 2019 and we are seeing at present the application areas are increasing.

3.6. Application areas of AR/VR

The work environments and the areas of applications of AR/VR technologies are represented visually in the below Figure 23 . It can be seen that the use and application of AR and VR is spread across top notch industries and the application ranges from maintenance and repairing and at inspection and testing among various industries.

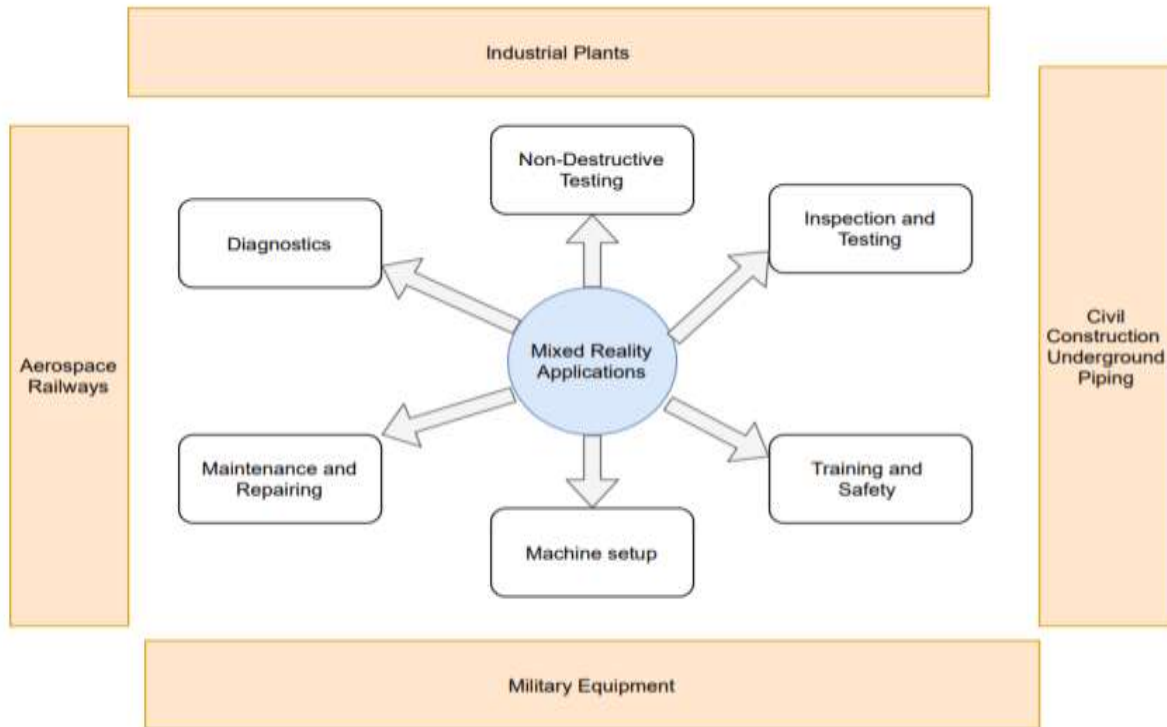


Figure 23:AR/VR Areas of Application and Work Environments

The use of mixed reality application for maintenance and repairing have improved the way the maintenance steps are followed by engineers. One interesting example is from the Korean aircraft industry which uses Intelligent augmented reality (IAR) system to perform an oil check procedure for aircraft (Figure 24). AR was used to provide the detailed steps of operations to be performed. First, a small red box was used to indicate which step is currently being done and when the step is completed the red box moves to the next step to be done. Second, the oil levels were indicated using colored information, meanwhile animation was used to duplicate the method to rotate the dipstick (De Crescenzo et al., 2011).The IAR system helps to minimize errors while performing complex operations.

Second example is the I-mechanic app is an everyday maintenance application. This app uses AR application with smart phones that users can use to perform simple maintenance tasks in their car. This mobile application will provide the instruction required to complete the task (Dini & Mura, 2015). Voice controlled AR devices and speech enabled AR devices are also being explored and the benefit of these are the feedback both in visual and auditory form the user gets from the application. One interesting mention on this type of technology is the SEAR which stands for speech enabled AR framework (Goose et al., 2003).



Figure 24: AR for Performing Oil Checks (De Crescenzo et al., 2011)

The use of mixed reality applications for inspection purpose in underground piping networks is a very useful and effective scenario below Figure 25. The 3D model of such underground piping networks can be superimposed using AR to provide clarity on which area to inspect and understand the piping network (Schall et al., 2009). This can be done using a tablet device.

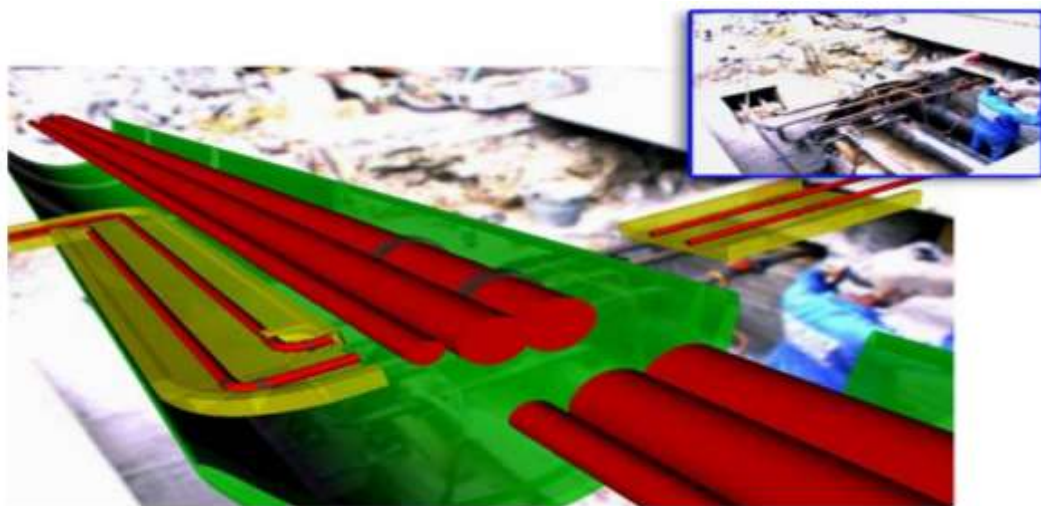


Figure 25: AR in Underground Piping (Schall et al., 2009)

The inspection of wind turbine blades is performed by using drones. The blade repair (Figure 26) is one of the most challenging maintenance operations due to the size of the blades and the height at which it is installed and the working conditions offshore. Thus, VR experience of such a maintenance scenario will provide the firsthand experience and exposure to the workers and will also ensure the safety of operation.



Figure 26: Blade repair offshore Source: <https://www.altitec.co.uk/services>

3.7. Application areas of MR

Mixed reality is a highly interdisciplinary field engaging signal processing, computer vision, computer graphics, user interfaces, human factors, wearable computing, mobile computing, information visualization, and the design of displays and sensors (Lalanne et al., 2009), also suggest the application of MR in following area:

Construction: MR can be used as a medium to cue workers about what work needs to be completed. For example, a supervisor can alert workers for any issue and then workers may use their headsets to view schematic diagrams and diagnose what needs to be addressed.

Manufacturing: Information about the component's performance and energy consumption can be transmitted and update during plant tours and view real time data for specific mechanical components.

Design: MR could allow designers to interact with new products before they are built. For example, MR allowed spacecraft engineers to view and interact with full-scale digital prototypes of a Mars rover to reduce the development time and cost to identify potential design issue.

B2B communication: For geographically dispersed businesses MR could provide simulated face-to-face meetings, as a remote collaboration. Participants can view a life-size, 3-D version of the product being discussed, while translation services can be integrated, eliminating language barriers. Healthcare: surgeons can use MR to practice inserting an extremely small medical implant into a specific patient's body. In future, medical studies will be done by using MR imaging, instead of cadavers, in anatomy classes.

Supply chain management: a supply chain manager can view a pallet through his smartphone's camera or smart glasses.

3.8. Technical challenges of MR

As futuristic this technology sounds it also demands number of technological requirements for its implementation:

1. Display technology (Costanza et al., 2009):
 - 1.1. Head-mounted displays are probably the most common type of displays used in MR. For MR the virtual imagery needs to be mixed with the imagery of the surrounding environment. Due to the complexity of mixing real world with the virtual characters HMDs weight, resolution and field of view becomes the critical feature to delivery under reasonable price.
 - 1.2. Handheld displays are used for MR by using the metaphor of a magic lens, to visualize the enhanced virtual elements. The mix of virtual and real world is displayed using the cameras attached to the device, example interactive road map application. Due to differences in all available handheld device creating a uniform platform becomes a tough call.
 - 1.3. Ambient projector rather than addressing a user's perception through a display, be it head-mounted or hand-held, an alternative is to project computer generated images directly onto the environment using standard video-projectors. Unlike HMDs and hand-held displays, the positions of the projectors are fixed or controlled by the system. This reduces the tracking requirements but, typically, also the user's freedom of movement.
 - 1.4. Hand-held projectors these types of displays require information about the position of objects in the environment relative to the projector and also the orientation of the surfaces onto which the information should be projected.
2. Registration (Costanza et al., 2009) In principle, a tracking system is a device that can determine the position and orientation of a body and interpret it. In order to create a realistic virtual environment, the computer must utilize these systems to acquire this information about the user which can be difficult based on the sensor type, installation, location of the user and mounting position, active or passive tracking, etc.
3. Architecture of MR system (Figure 27): this can comprise the architecture issue, server issue and network issue. The development of an MR system to integrate the aforementioned components requires the use of a suitable software architecture for faster execution of MR algorithms in MR applications (Rokhsaritalemi et al., 2020).

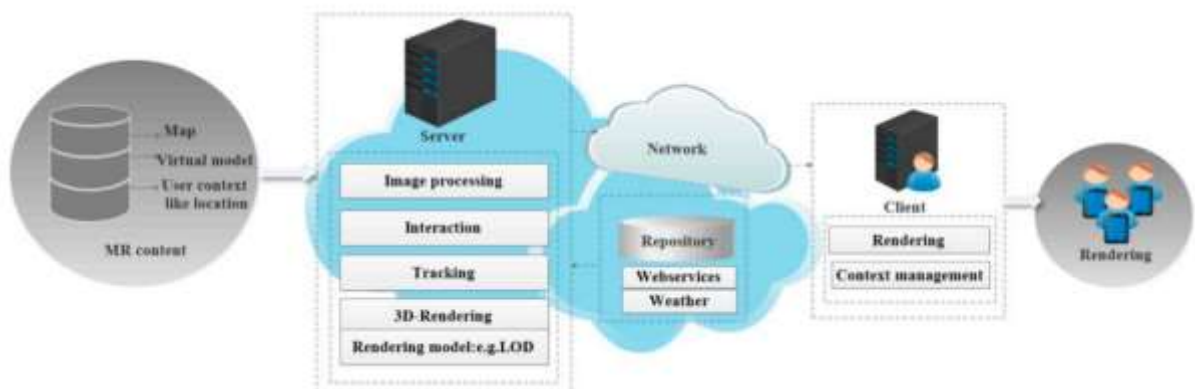


Figure 27: Architecture of Mixed Reality (Rokhsaritalemi et al., 2020)

3.9. Verification and Validation Techniques

The problem entity or the system is the need to implement mixed reality into the training activities which Energy Innovation AS offers. In this case study, the system can be considered as the digital tower and the associated safety training gears. The conceptual model is the kind of the simplified logical idea that was made during the initial brainstorming sessions between me and Energy innovation AS, for example like creating a digital image of the wind turbine tower and of the essential safety gears. The Computerized model is the one which is done by using software's such as Blender and Unreal. This is the output demo MR model(Sargent, 2013).

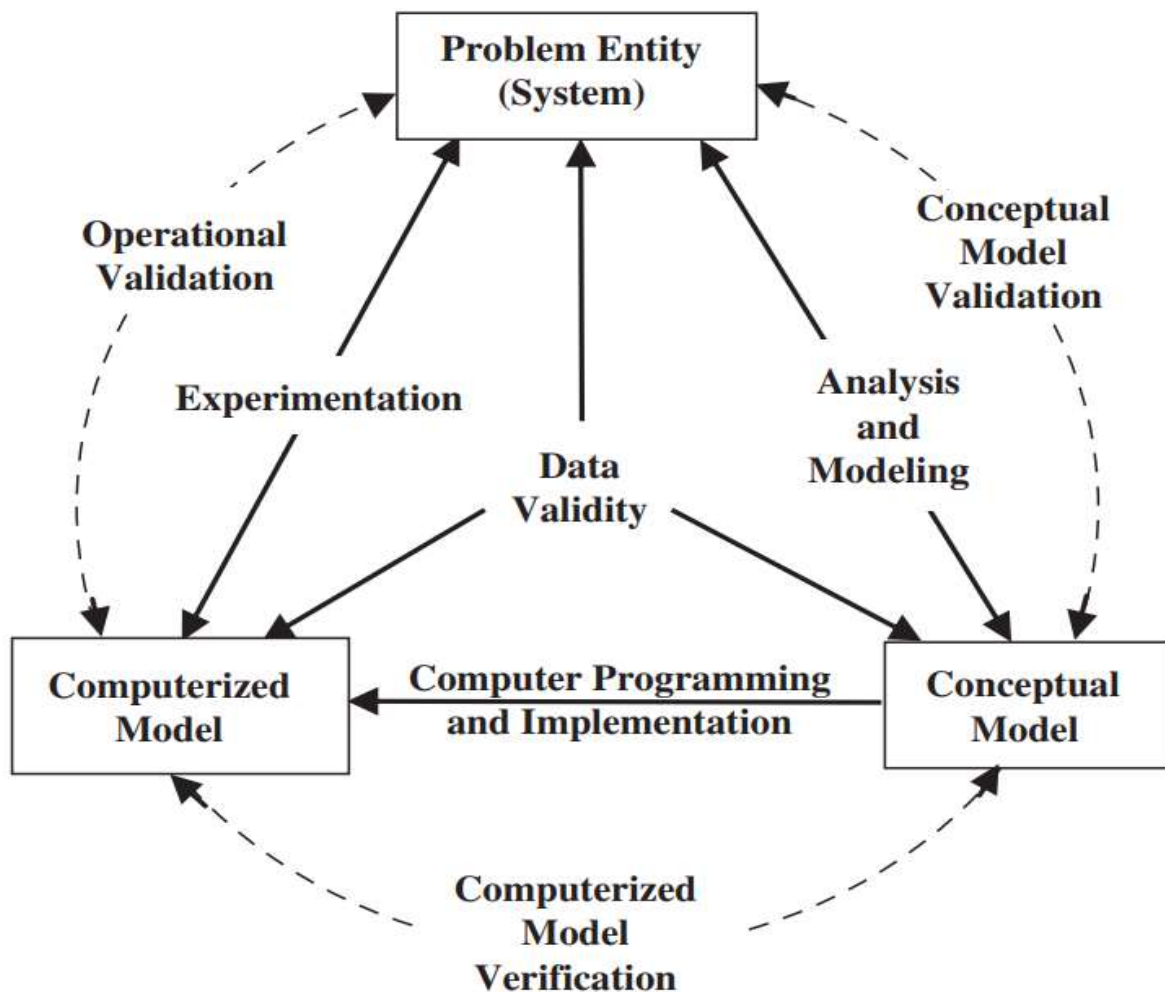


Figure 28: Model Development Process (Sargent, 2013)

The model development process by (Sargent, 2013) provides the procedure to progress from the problem entity to the conceptual model and then to the computerized model and finally back to the problem entity, thereby completing the loop. This clearly indicates that it is an iterative process. The model proposes that analysis and modelling techniques can be used to progress from problem entity to the conceptual model. In the same way computer programming and implementation techniques is required to move from conceptual model to computerized model. Finally, experimentations done by using the developed computer model about the problem entity, will help us to understand the system in a better way.

The model development process (Sargent, 2013) also helps in deciding on the type of verification and validation techniques to be used for different phases. Conceptual model validation is required while doing the analysis and modelling technique. Conceptual model validation is determining if the concepts and theories that are developed to represent the problem entity as a conceptual model are correct (within a reasonable level). In the similar way computerized model verification is required while implementing computer programming and implementation technique. Computerized model verification is double checking and assuring if the implementation of the computer programming methods and techniques are correct. Operational validation is used while doing experimentations. Operational validation is checking if the model output behavior represents the real system behavior, at least to a satisfactory level of acceptance and accuracy. Finally, the data validity is to ensure that the data needed to build the model and to test the model and conduct experiments are all correct and adequate. The whole cycle is an interactive process and its repeated until satisfactory confidence is achieved about the model.

Some commonly used validation techniques that is also essential for this case study are (Sargent, 2013):

Animation: This validation technique checks for the model behavior in a graphical manner over a specific time. This is to check if the model is doing what it is supposed to do.

Face Validity: This is checking with the experts around the particular field or domain. The experience of the people can be able to guide if the model is performing or producing the right results.

Concurrent validity: This is to compare the model results with other results from any other similar model which is known to be valid.

Convergent validity: This is to compare the model results with other research methods and to check if they provide similar measurements of the concepts.

Some commonly used Computerized model verification techniques that is also essential for this case study are (Sargent, 2013):

The major factor to verify is that if the software (Blender and Unreal) for this case study has inbuilt programming scripts or if the programs needs to be written using languages such as C++, Python etc. Incase if they are inbuilt Scripts this will result in less errors as its already been verified by an expert software team and validated. However, when some scripting is done, the main need is to ensure that the software is error free and in certain agent-based modelling. The model can be checked for the generation of random numbers, which is not a problem for this case study.

3.10. GWO Safety Training Concepts

The presentation materials of the 5-day GWO training by Energy Innovation AS will not be attached in this thesis. However, certain important concepts regarding the working with heights module is discussed in this section. This explained theory will be used in the analysis section and for the demo MR modelling.

The most important safety procedure that needs to be followed while climbing the ladder is to use the Y line and secure oneself always with the fall factor of 0 or 1. For example, the left side of the Figure 29, indicates the most efficient and safe way to climb the ladder (fall factor 0). This means the Y line must always be secured above the shoulder height. The right side of the picture shows the least safety way (fall factor 2). However still its recommended, when there is no other option as shown in the picture, for example while working at the top of the nacelle in the wind turbine. The fall factor 1 is when the technician secures himself at the chest level. This is mostly done while working at some platform level inside the wind turbine.

The developed demo MR model is planned to demonstrate the need to secure oneself at safety fall factor 0 or 1.

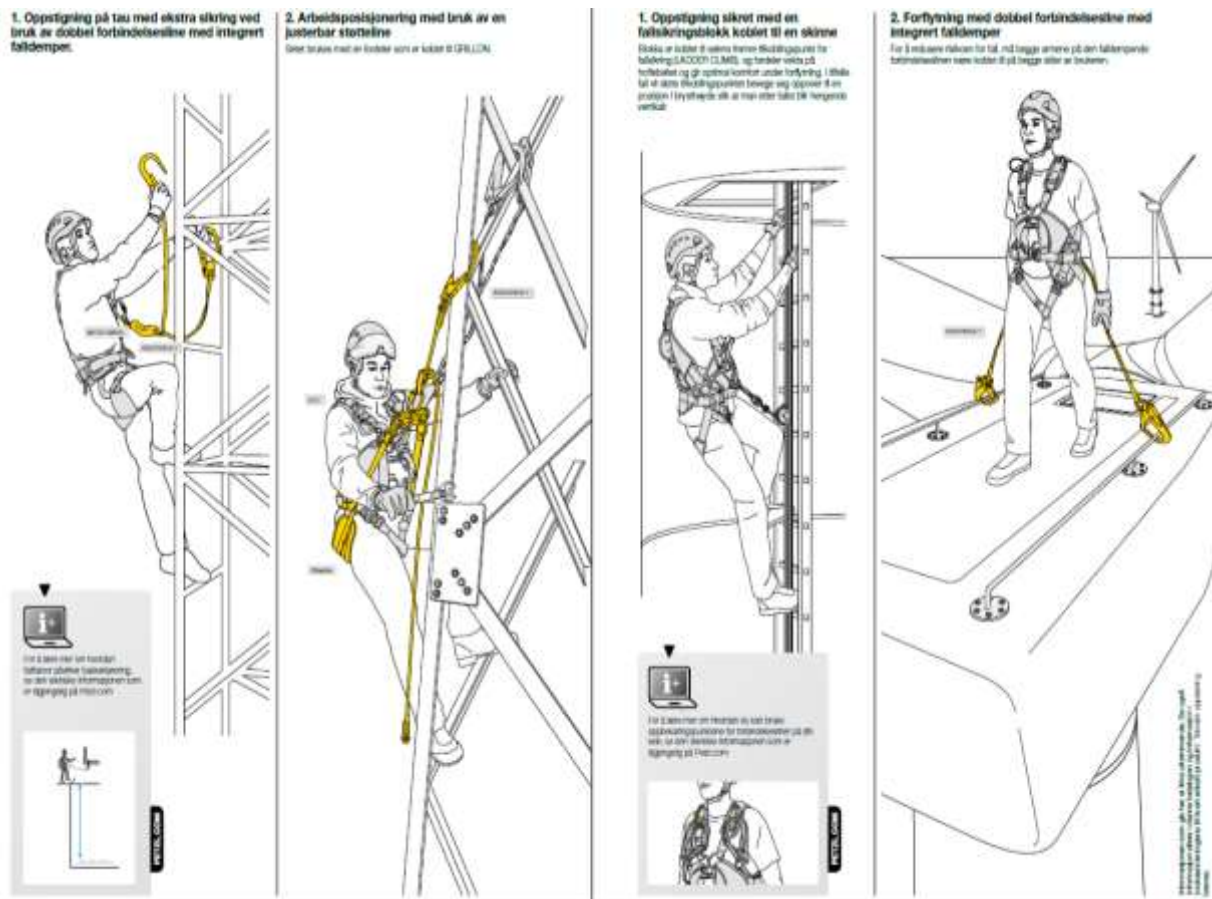


Figure 29: Fall Factors (Bentsen, 2021)

3.11. Safety Training and MR Benefits

The safety training is also to improve the mental abilities of the participants. The use of VR in training provides a beneficial rise on the perception of trainees and reduce the cognitive load and increase the sense of their interest throughout training. The acquisition of knowledge via video lectures and also using simple animation have proved to increase efficiency already. Therefore the use of MR will increase the understanding of the subject (Poyade et al., 2021).



Figure 30: MR in Safety Training (Poyade et al., 2021)

The article (Poyade et al., 2021) tried to understand the psychological benefits of implementing virtual reality in the chemical industry. They tried to check if the workflow is more transferable Figure 30 when using virtual reality in the safety training. With increasing digitization trends and the ongoing and demanding challenges to safety for the chemical industry market. The chemical industry is pushed to use interactive and immersive virtual reality (VR) as a timely technology for improving safety training and be prepared to avoid accidents in hazardous chemical environments.

The COVID-19 pandemic has made it clear the need for such technologies since people can't gathered to train real-life circumstances. Immersive experience of user may be brought to real life circumstances combining digital twin technologies (DT) and virtual reality technologies (VR). It also enables the participation of a larger audience from several workplaces. Safety training solutions using cognitive information options like VR provide us with an efficient alternative to the traditional training. Training can be performed on site in a virtual environment, without generating production disruptions or exposing trainees to hazards (Poyade et al., 2021).

3.12. Software's Used

Blender <https://www.blender.org/> is a free and open source 3D animation creation software developed by the company Blender Foundation. Blender software is considered as a one stop package for all 3D related development features such as modelling, animation, rigging, simulation, rendering, composition and motion tracking, video editing and game development. The software is available for use by the public. As it is an open source it allows for small changes to the codebase by any user thereby helping to improvise the software to include new features, bug fixes and user enhancement.

This project has used the Blender software to explain the concepts. Blender software can be used to make animation characters as seen in movies using the modelling feature. The texturing tools in the software allows for adding color to the surface of the created models. To add life to the created model, the software allows for making them move using rigging and animation tools. Blender also features tools to facilitate game creation function.

To describe some of the available functionalities, we provide brief description of features available on the software.

1. **Design and Model:** Blender has a wide range of modelling tools that allow creating, transforming, sculpting and editing models an easy task. The modelling tool has features such as keyboard shortcuts, Python script for specialised requirement, and Grid and bridge fill options to make modelling efficient. There are options for including modifiers which makes adding effects to the model a possibility for novice people.

2. **Animation and Rigging:** Blender also provides a platform to allow users to create their own animation using their toolset. They offer “character animation pose editor”, NLA for independent movements, Forward/inverse kinematics for fast poses, sound synchronization. Rigging options have allowed for enveloping, skeleton and automatic skinning to the created models, mirroring option, easy weight painting etc.

3. **Simulations:** Simulations enhance the design work, effects such as making building collapse, making rain appear, adding scenes like fire, smoke, or destructions happening is a visually fun and appealing feature for any user. Blender provides all such features in its free source application. This enables user to apply the options and tools in a wide range of area to help educate, simulate case studies or scenarios that are not cost effective to recreate naturally.

Unreal Engine <https://www.unrealengine.com/en-US/unreal>

Unreal Engine was initially created in 1998, it is also an open and advanced 3D creation software. The software has features such as rendering, collision detection, AI, visibility, networking, scripting and file management (Sanders 2016). The software is also used by general users to create small films, automotive and engineering modelling, construction modelling etc. This is also an open source application where users can use available features to create and develop their own games and videos. This platform is also a bridging zone for creating animation creation, simulation and virtual production. The software is popular for its use in games such as Gears of War, Final Fantasy VII remake etc for the graphic capabilities.

Unreal Engine has a complex interface but also allows for development using visual scripting system for designing models. This software is more user friendly for experienced users and provides support for development of desktop games with high performance. The software supports different platforms such as Windows PC, Playstation, Xbox, Nintendo, MacOS, Linux etc.

4. Data Collection

Chapter Outline:

The chapter starts with a brief explanation about the case company (Energy Innovation AS) and the modules of the 5day GWO training and the description of the training tower are briefly described. The data collection methods used in the thesis are tabulated and are discussed in detail in the subsequent sections. The quality of the data collected, and the reliability of the data is checked and tabulated. Finally, the traceability check between the data collection techniques and the research objectives is tabulated to check if the progress is in the right direction.

4.1. Case Company

Energy innovation AS is located at Langholmen in Egersund (South West Coast of Norway). It is a center which offer safety training according to global wind organisation (GWO) standard for the wind industry. The training includes both onshore wind safety training and offshore wind safety training. Energy Innovation AS is also involved around innovation, research and development in both onshore and offshore wind industry and other renewable and sustainable technologies (<https://www.energyinnovation.no/hjem>).

Energy Innovation AS is a part of the business network of cluster of companies at Egersund energy hub and it is well positioned to offer complete operations and maintenance (O&M) services to the wind industry in the future. The Egersund energy hub has a workshop facility of 8000 square meters which can facilitate O&M training facilities. Energy Innovation is in a close collaboration with the Norwegian offshore wind cluster (NOWC) organizing various seminars periodically regarding digitalization and innovation around the wind industry. Energy innovation AS is also the first company in Norway to provide the GWO blade repair training and from Autumn 2021 it also plans to provide wind technician education in Norway in association with Dalane vocational college.

Energy Innovation AS is actively involved in blade inspection with an inhouse specialized drone pilot. The scope of the project involves inspecting around 294 vestas turbines across Norway. The Robinson-a Horizon 2020 project is one of the innovative projects Energy innovation AS has initiated and it aims to create energy self-dependency and circular economy on the island Eigerøy at Egersund. The development plan involves creating an integrated energy system to help decarbonize (industrialized) islands (<https://www.energyinnovation.no/innovasjon>).

The 5 day GWO training involves four modules namely the basic first aid, manual handling, fire safety awareness and working with heights. Energy innovation AS also offers advanced courses such as sea survival, advanced rescue and enhanced first aid.

A 30-meter training tower launched on May 2018 enables wind tower service technicians to get hands on training meanwhile also simulating real conditions in a wind turbine. Undergoing a working at height module or an advanced rescue training in the tower at a height of 20 m will simulate the real working condition and will also emphasize the risk associated and the importance of safety.

The training tower is equipped with sufficient anchor points to ensure safety while working with heights and the total number of participants at any time in the tower is limited to maximum of 5. The tower is also equipped with the wind speed measuring device and a lighting protection device. The control cabinet at the tower basement is equipped with a training simulator called tower base panel (TBP). The controller helps to create various situations like smoke emissions and light conditions (power failure) for effective training. The tower is assessed by a door at the base and as a safety protocol the lighting switch must be on as one enters the tower and the ladder will be illuminated. The tower is maintained bimonthly and every year an independent inspection is done for the ladder systems, lift and climbing systems(Bentsen, 2021).

The digital image of the training tower will be created using the Blender Software, which will then be used in the Unreal software to create a demo MR model.

4.2. Data Collection Methods

The types of data collected for this thesis are reported in the Table 12 Meanwhile the Table 8 gives a brief description of the data source used in the thesis. Table 8 also includes the data collection and the data analysis techniques required to satisfy the research needs and the objectives of the thesis.

The data that is required to model this case study is divided into qualitative data and quantitative data, and both are sub divided into primary and secondary data sources. The research choice for this thesis is mixed methods and the mixed method strategy that was used in this thesis is embedded design where both the qualitative data and quantitative data are fused together with the idea that the qualitative data enhances the quantitative results. For example, in this case the observational data (qualitative data) from personal participation in the GWO training will enhance the selection of crucial scenarios (quantitative results) of the training than to just take it from the training materials and the presentations that Energy Innovation AS uses.

Table 12: Data Collection Methods

	Primary Data Source	Secondary Data Source
Qualitative data	Interviews with Energy Innovation AS managers.	Observational data from 5-day GWO training.
Quantitative data	GWO training materials and other documents from Energy Innovation AS. Worksheet sheet: Hazards and Measure from Energy Innovation AS.	The training tower 2D drawing from Energy Innovation AS. Literature Review. 3D Inputs for demo MR model from Blender Software.

Note: The data sources names mentioned in Table 12 are improved just language wise, however they convey the same idea and meaning and is in alignment with the data sources mentioned in Table 8.

4.3. Qualitative Primary Data Collection

Energy innovation AS was very eager to explore the possibilities of implementing AR/VR into their training programs and that is one main reason they wanted to collaborate with university of Stavanger for this master thesis.

The primary qualitative data collection started with interviewing the managers of Energy Innovation AS to understand the company perspective on the topic of possibility of implementing mixed reality application for the safety trainings in the wind energy sector.

The following questions were asked to three managers within Energy Innovation AS namely Frank Emil Moen, Magnus Østebrød and Kjetil Bentsen. The Project Manager of Espeland Energie AS, Odin Moen was also interviewed for his opinion. Then one external manager Kjetil

Torgeirsen from SAFER was interviewed. Energy innovation AS works closely with SAFER to create AR application for advanced rescue operation offshore.

1. Do you think that implementing mixed realities will be one of the innovative solutions to improve the effectiveness of the training programs?
2. Do you know the crucial training scenarios for which an AR/VR application will be beneficial?
3. Do you think it is beneficial to do cost benefit analysis in case of implementing AR/VR into the training programs?
4. Do you wish to create a demo model which you can use while making the final decision to implement such mixed realities?
5. Do you believe that a framework or flowchart which will indicate the crucial training scenarios and will suggest the most effective hardware and software platform for implementing mixed realities will be useful for the company?
6. Do you agree if it's a good idea to do a critical review of such mixed reality application based on the potential unintended consequences of having such a technology? The optimal tradeoff considering both the risk and the ambiguity. The level of constraints such technology will have on operations. What's happens if something goes wrong. What is the backup?
7. The literature study shows that there is not any specific academic literature based on implementing MR for safety and technical training in the wind sector, do you agree?
8. Which is more effective either to use AR/VR for training beginners or to aid experts for better efficiency and decision making?
9. Do you think that it's a good idea to publish an article based on this thesis?
10. Do you think it's ideal to have a flowchart which will indicate whether it is effective to use VR or AR based on the scenario?

The Interview replies are attached in the appendix. For quick visualizations the replies are presented as a pie chart in the data analysis and results (chapter 5).

4.4. Qualitative Secondary Data Collection

I attended a 5-day GWO training (Figure 36) to collect the data which helped to identify the crucial scenarios of the safety trainings. The training is predominately divided into 4 modules such as

- Working with heights
- Manual handling
- Fire safety and awareness
- Basic First AID

The observational data collection was focused only for the working with heights module since it was highly critical, and Energy Innovation AS felt that a Demo MR model for this module will be very crucial for them. However, criticality classification of the modules based on the accident data from literature review is given in chapter 5 (Section 5.2).

The working with height module deals with providing the participants the safe way of using the various fall protection equipment's such as the harnesses, fall arresters (Y-line), support belt (stocking ropes), self-locking slider on flexible guide (vertical safety ropes), scaffolding hooks, fall blocks (which are used to descend in a controlled manner), self-locking slider on rigid guide (attached to the wind turbine ladder railings), fastening – anchoring (these are the anchor points

to secure the Y-line to prevent falling. Figure 31 illustrates some of the safety gears (Bentsen, 2021).



Figure 31: Safety Gears (Me at GWO training)

The module will also provide the needed knowledge of how to secure safely oneself against falls to a lower level and quick evacuation techniques in case of fire (Figure 32).

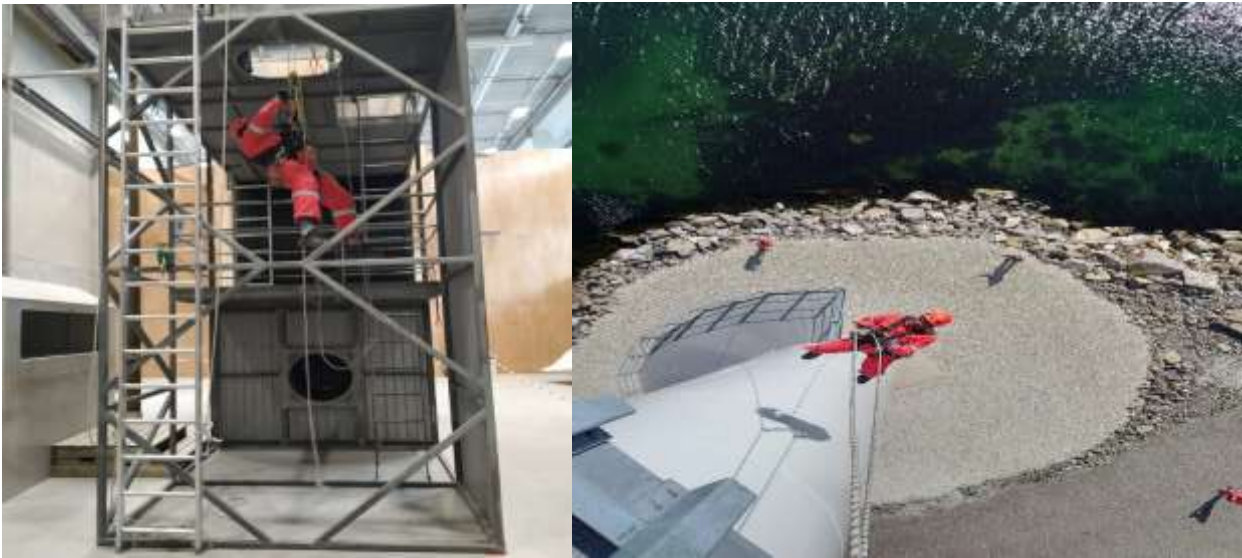


Figure 32: Fall Protection (Left) and Quick Evacuation (Right)

The course emphasizes that a risk assessment needs to be carried out for all working at height scenarios, be it 5 meters or 100 meters, and the person working at heights must be aware of the accident and health hazards that may be associated with the work. Further, the importance of working in teams and checking each other for following the protocols in a strict way was emphasized. Usage of headlamps was suggested. One key rule is that the body must never be exposed to force more than 6kN (approx. 60kg) during the fall (Figure 33). However, the anchoring device must withstand around 15kN (Bentsen, 2021). Therefore, the awareness of the above facts associated with working with heights and mainly of the evacuation procedure must be clarified before any work starts, and then more importantly, the self-assessment of the risk associated is a compulsory task; every technician must assess the risk involved before carrying any tasks and must raise an alarm to any unsafe practices.

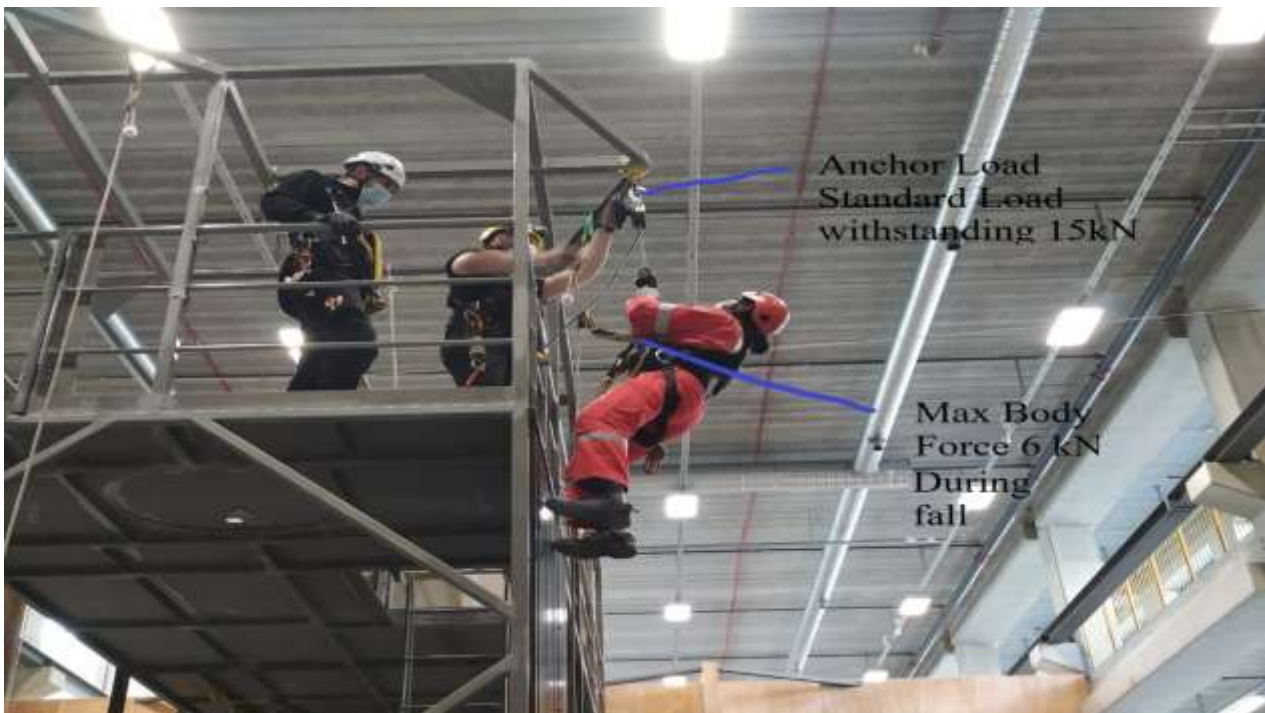


Figure 33: Free Fall Loads

The module also ensured that every participants are aware of the various safety hooks located in the wind turbine (Figure 34).The safe manner to climb the ladder and the safety precaution of closing the latch of ladder after reaching a certain height or level in the wind turbine (to avoid falling down, Figure 34).The awareness about the location where the safety, first aid kit is usually placed in the wind tower and then about the evacuation technique in case of fire was also discussed. The demo MR model will be based on these scenarios.



Figure 34: Safety Hook (Left), Ladder Safety Precaution (Right)

The rescue techniques while working at height was very interesting and useful to learn (Figure 35). There were two rescue techniques, one is to save a person while going from a lower level to a high level and second is to save a person who is free hanging at heights. Hanging trauma which is the stress experienced by the person who is hanging for a long period of time needs to be considered in the rescue operations. A person hanging in a harness can becomes helpless, unconscious and in the worst consequence he can die from the injuries. The patient may enter an unconscious state even before 10 minutes have elapsed(Bentsen, 2021).

One interesting observation that was made in the presentation of the training was that at lower altitudes, there is a tendency to take safety more lightly.15-20% of fatal accidents of working at heights are fall from lower heights of 3-7 meters (Bentsen, 2021). This is where the negligence of not using the safety ropes kicks in, but in the end turns out to be most dangerous. The standard recommends that there must be railings or other protective measures whenever the height is greater than 2 m.

One relevant MR scenario this thesis aims to develop is using the VR application to aid in climbing the turbine ladder safely and performing evacuation jump in case of fire emergencies while undergoing the safety training or performing any work sequence inside the WT. Meanwhile in the same time having an AR application to aid in locating the safety hook and to locate the first aid kits and emergency evacuation gears inside the WT. Complacency to such simple tasks often leads to injuries and deaths. Therefore, having a MR model will enforce this safety idea again and again, so it gets fixed in the minds of the workers.



Figure 35: Rescue Techniques



Figure 36: GWO Training Tower (Left), Selfie Inside Tower (Right)

4.5. Quantitative Data Collection

The quantitative data which are collected for the purpose of this thesis are given in Table 13. The 2D drawings, worksheet sheet: hazards and measure are attached in the appendix. The training materials that Energy Innovation AS uses for its training purpose will not be attached. However, I have the observational data (personal notes) based on my own training experience.

Table 13: Quantitative Data Collection

Data Needed	Purpose	Software Used	Data Source
The training tower 2D drawing from Energy Innovation AS. (Quantitative data: Secondary)	To create 3D models.	Blender	<ul style="list-style-type: none"> • Energy Innovation AS. • The training tower manual.
GWO training materials and other documents from Energy Innovation AS. (Quantitative data: Primary)	To classify critical module To develop steps for animation and MR model	Unreal Engine	<ul style="list-style-type: none"> • The 3D output from Blender. • The training tower manual. • The GWO training presentations.
Worksheet sheet: Hazards and Measure from Energy Innovation AS. (Quantitative data: Primary)	Helps to develop the worksheet to identify the critical training modules/scenarios.	Spreadsheet	<ul style="list-style-type: none"> • Energy Innovation AS • Worksheet: Hazards and measures

4.6. Data Collection Reliability Check

The reliability check which indicates the extent to which this case study data collection techniques can be reproduced if repeated by another researcher are tabulated in the Table 14.

Table 14: Reliability Data Collection

Data collection techniques	Reliability	Reason
Interviews with Energy Innovation AS managers. (Qualitative data: Primary)	Medium to High	<p>The interview was conducted with 5 different managers and their responses was documented without any personal bias.</p> <p>Therefore, if the same questions are repeated by another researcher and if the managers responses are captured without any personal bias. The Reliability will be high.</p>

		However, the responses from the managers might vary. That's the reason why the reliability is classified as medium to high.
Observational data from 5-day GWO training. (Qualitative data: Secondary)	Medium	The type of training given is standard for all participants. However, the reason for medium reliability is the difference in personal ideas and perception of different researchers.
GWO training materials and other documents from Energy Innovation AS. (Quantitative data: Primary)	Medium to High	The training documents is same for all the participants. However, the difference in personal ideas and perception of different researchers is the reason why the reliability is classified as medium to high.
Worksheet sheet: Hazards and Measure from Energy Innovation AS. (Quantitative data: Primary)	Medium to High	The reason for medium reliability is that the likelihood and the impact rating of consequences used for the risk matrix are based on my personal perception and expert's opinion. Meanwhile the worksheet sheet is a standard document giving it a high reliability.
The training tower 2D drawing from Energy Innovation AS. (Quantitative data: Secondary)	High	It's a technical drawing used on a technical software. The results could be replicated as many times as possible.
3D Inputs for demo MR model from Blender Software. (Quantitative data: Secondary)	Medium to High	It is again a software modelling and the method is standard. However, the visual representation of the MR model can change based on the individual experience and preference is the reason why the reliability is classified as medium to high.
Literature Review. (Quantitative data: Secondary)	Medium	The level of understanding of literature varies among different researchers.

4.7. Traceability Check Data Collection Techniques and Research Objectives

The research objective is recalled for easier reference to develop the Table 15 which checks if the data collection techniques followed helps us to achieve the research objectives.

To recall the objectives of the thesis are:

1. To develop a worksheet to identify the critical training modules/scenarios and further classify them to check if implementation of mixed realities is needed or not?
2. To develop a workflow which will help to implement mixed reality technology into training activities of the wind sector.
3. To develop a flowchart which will help to recognize the technical specifications like the suitable hardware platform, suitable software platform and relevant tracking technique.
4. To develop a framework which will capture the method to implement mixed reality technology.

5. To design and create a demo MR model based on the workflow developed in order to validate the workflow and understand the associated practical challenges like complexity of such mixed reality technologies and user familiarity.

Table 15: Traceability Check Data Collection Technique

Data Collection Technique (Table 12)	Relation to thesis objectives
Interviews with Energy Innovation AS managers.	Helps to identify the needs and requirements.
Literature Review	Helps to identify if some similar frameworks are available in other engineering industry. Helps to develop the technical specifications and work processes (workflow). Helps to develop conceptual flowchart to indicate the relevant type of technology and associated technical specifications.
Observational data from 5-day GWO training.	Helps to identify the critical training module for which the worksheet is constructed.
GWO training materials and other documents from Energy Innovation AS.	Helps to develop the worksheet which aids to classify the critical training module and identify if mixed reality is needed to be implemented or not.
The training tower 2D drawing from Energy Innovation AS.	Helps to develop the 3D model using the Blender Software. Helps to develop the steps for demo MR model.
3D Inputs for demo MR model from Blender Software	Helps to develop the demo MR model.
Worksheet sheet: Hazards and Measure from Energy Innovation AS.	Helps to develop the worksheet to identify the critical training modules/scenarios.

Collectively all these data collection techniques together help to develop the workflow and framework which will help to implement mixed reality technology into training activities of the wind sector.

5. Data Analysis and Results

Chapter Outline:

The chapter starts with the systems analysis where the industrial needs and requirements were studied with the help of interview technique. The use case analysis is explained which helps to identify the critical training module in the 5day GWO training program and one similar framework in construction industry is described in detail. The conceptualize phase helps to classify the selected critical module and perform a risk assessment of the training steps. Finally, the scenario modelling is described in detail. The computerize phase explains in detail how to create the 3D model, the safety animation, and the demo MR desktop game. The fifth stage starts with the development of flowchart which will indicate how to identify the relevant type of technology (AR/VRMR) and to identify suitable technical specifications associated with the selected technology. Second the worksheet is developed. Next a workflow is described which will help to implement mixed reality into safety training of wind sector and finally the framework is constructed. The validation of the outputs concludes this section.

The data analysis chapter follows the methodology steps that are defined in Table 7 and it follows the data analysis techniques mentioned in the Table 8 of Chapter 2.

5.1. Systems Analysis

The system analysis mainly deals with extracting the industrial needs and requirements. To achieve this, three managers from Energy Innovation AS were interviewed. One manager from Espeland Energie AS which is located with Eigersund energy hub was interviewed. One external manager from a company called SAFER was also interviewed. This helped to broaden my understanding of the industry view. The interview questions are described in detail at Chapter 4. The interview replies by email are attached in the appendix. For quick visualizations the replies are presented as bar charts in this section.

An interesting observation from interview with Frank Emil Moen, the managing director of energy innovation AS was that (F. E. Moen, personal communication, 18 April 2021) he was very optimistic about introducing mixed realities to improve the training efficiency and was willing to involve companies like Bouvet which specialize in developing such mixed realities after the workflow is being developed and once we had identified the crucial scenarios and the demo MR model is ready. This is a positive motivation to develop the framework and, he also reports that companies like Vestas already have such mixed reality application and they use them in their internal trainings, but they do not share the knowledge.

An interesting observation from interview with Kjetil Torgeirsen, manager external training programs was that (K. Torgeirsen, personal communication, 19 April 2021) he believes that scenarios where the participants need to implement certain behavioral patterns and when there is a need for the participants to act faster (like evacuation) are all crucial scenarios. This comment helps in identifying the crucial scenarios for demo MR model. He also believes that the framework will not add any benefit for the industry. He suggests any working model as a good tool for companies, where he speaks about SAFER collaboration with Bouvet and Energy Innovation. He believes the framework/flowchart is more suitable as academic literature. He strongly believes that technology is to supplement training at a training center not as a substitution. Most importantly, he also shared an illustration of workflow which SAFER uses to provide its clients to visualize such implementation of technology (like steps of implementation).

Chain of survival



Figure 37: SAFER Workflow Process (K. Torgeirsen, personal communication, 19 April 2021)

Figure 37 suggested that it is very useful to develop a workflow which will suggest the steps to implement mixed reality technologies in safety training of wind sector.

An interesting observation from interview with Odin Moen, project manager of Espeland Energie was that (O. Moen, personal communication, 24 May 2021) he believes the biggest challenge that the service sector of the wind industry currently faces is that the technicians cannot get a realistic experience of maintenance at wind turbine until they are introduced physically into the turbine. This challenge can be overcome to an extent by implementing innovative solutions like MR. He believes that one of the crucial scenarios to implement MR will be health and safety related, practicing evacuation and first aid through VR/AR scenarios. With this application it is easier for technical personnel to be equipped to deal with emergency scenarios. He also states that implementing a system for VR support from a blade repair expert to a blade repair technician to create a dynamic support system for on-field operations. He also believes that the framework and flowchart will add value to the company for further research. He supports in publishing an article based on the case study.

An interesting observation from interview with Magnus Østebjørn, technical manager, Energy Innovation AS was that (M. Østebjørn, personal communication, 24 May 2021) he believes that VR is getting more accessible in the market and prices of VR gears are getting better, so he believes that more educational places and industries will try to implement VR in their training activities in the future. For Energy Innovation AS he feels that VR will help to make the training more interesting before doing real training in the field. Regarding augmented reality (AR) he feels that this can be used for remote training activities like having a technician in the field, and a specialist somewhere in the world following up on a specific task. For example, in case of Inspection, he feels that AR glasses in future might run real-time AI detection programs to help the inspector finding flaws, and might even combine different methods of non-destructive testing, where a specialist will be remotely looking at the performing, and reading the signals of the inspection from an office far away. Blade inspection is often done with rope access personal, and this could also be monitored by client, or a specialist with AR glasses in a place like Egersund Energy Hub.

An interesting observation from interview with Kjetil Bentsen, training manager, Energy Innovation AS was that (K. Bentsen, personal communication, 24 May 2021) he was my trainer for the 5day GWO Training program and he believes that having demo MR models will help to reiterate the training steps into the minds of the participants. He gave example of rescue scenarios where the participants can practice different ways to rescue a person in a game environment and understand the challenges associated and the time taken. Therefore, when it happens in real time scenario, the participant is better prepared.

The Figure 38 describes the managers response to implementing mixed realities as an innovative solution to improve the effectiveness of the training programs. We can observe that all the managers are in favor of MR as an innovative solution to tackle the challenges that training industry faces.

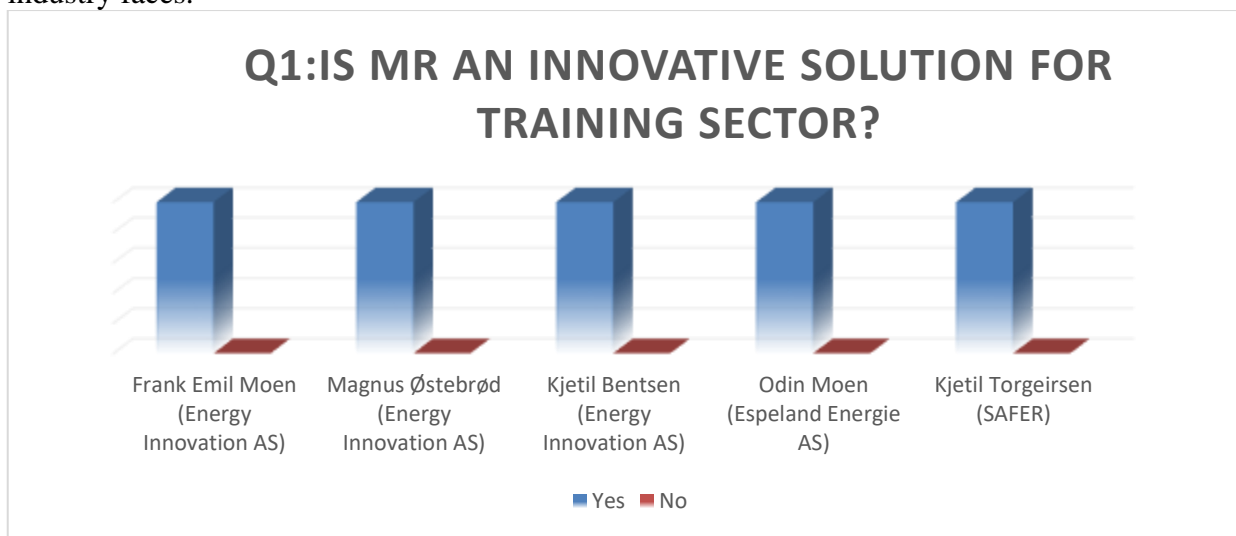


Figure 38: Question 1 (Interview with Managers)

The training scenarios which are crucial to implement MR application will be identified. This is one of the important requirements of the thesis. It is the reason I also attend the GWO training personally. Therefore, all the managers agreed that there is a need to identify the crucial training scenarios for which an AR/VR application will be beneficial.

Regarding the topic of doing a cost benefit analysis for this thesis, there was a mixed opinion among the managers (Figure 39). Since we are already identifying the most crucial scenario for which MR will

- Equip the workers to be aware of the risks involved.
- To iterate the safety precautions to be taken while working at heights and in crucial situation.

This means that the need to implement MR in this situation is very crucial and advantageous to improve safety aspects, therefore the safety is more important than cost. Moreover, we are only developing a demo MR model for only one crucial scenario, so it's very difficult to do a cost benefit analysis for that particular situation. Meanwhile in the future, when Energy innovation AS realizes the potential for implementing MR for the entire training modules (all crucial scenario's), then surely a cost benefit analysis will be carried out. Therefore, the importance of carrying out a cost benefit analysis will be emphasized in the workflow and framework developed. However, the cost benefit analysis is not in the scope of this thesis.

All the managers agreed on having the demo MR model (Figure 39) which will be a useful tool to serve as an example for future extensive works.

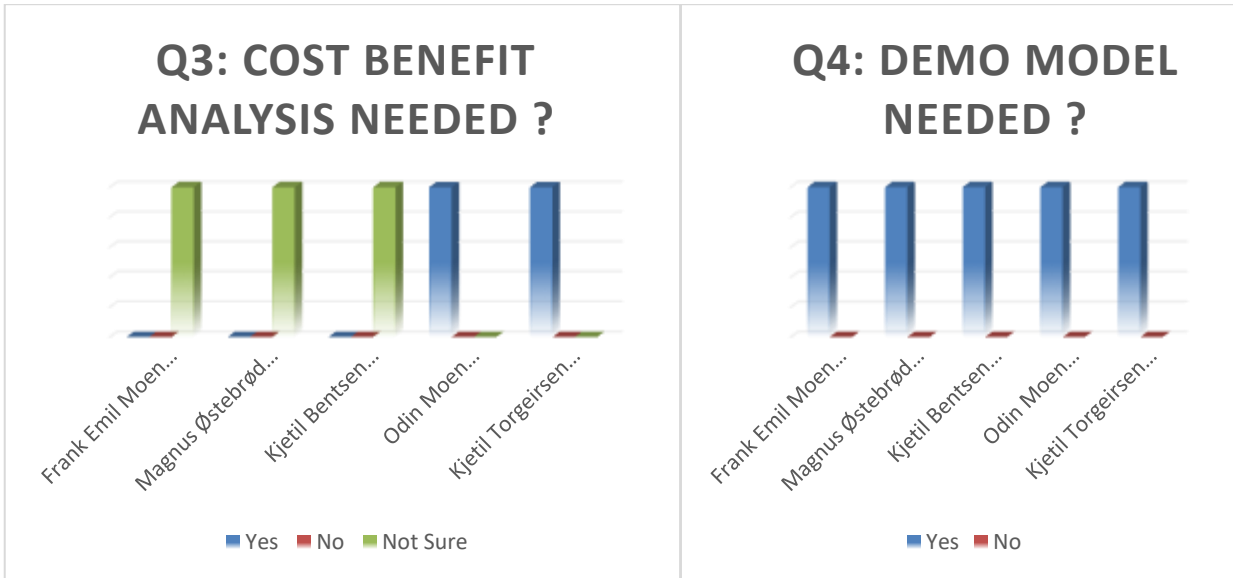


Figure 39: Question 3&4 (Interview with Managers)

The managers opinion for having a framework or flowchart which will suggest the most effective hardware and software platform for implementing mixed realities was divided (Figure 40) with some managers feel that the framework is more suitable for a literature point of view. However, other managers support the need for the workflow which will give a foundation for implementing MR in other areas in the future.

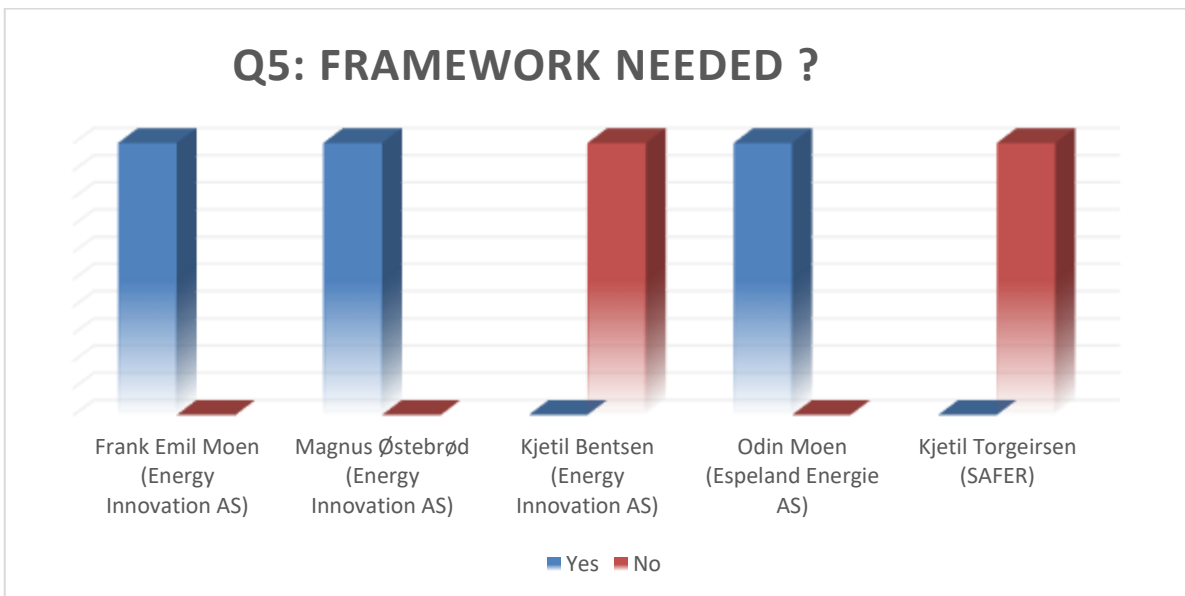


Figure 40: Question 5 (Interview with Managers)

Different managers had different views on the need to have a critical review about having mixed reality application. However, the majority supported the intention to discuss the tradeoffs and to discuss the basic questions like what happens if something goes wrong. what is the backup?

The managers were not aware about specific literature reviews on the topic. However, they all were supportive and open to publish an article based on the thesis. They also felt that MR training

will be suitable for both beginners and experts. The flowchart concept which will indicate whether it is effective to use VR or AR based on the scenario was well appreciated.

5.2. Use Case Analysis

The use case analysis deals with the creation of the case context. This step is further divided into two important steps

1. Select the critical training module based on accident data from literature review.
2. Identify one similar framework in other engineering industry through literature review.

The 5-day GWO training which is explained in detail in Chapter 4 is predominately divided into 4 modules such as

- Working with heights
- Manual handling
- Fire safety and awareness
- Basic first AID

Energy Innovation AS felt that a demo MR model for the working with heights module will be very crucial for them. However, criticality classification of the modules based on the accident data from a relevant literature called wind turbine accident data (Asian et al., 2017) was done. This is presented in Table 16.

Table 16: GWO Training Module Classification

Module Name	Accident Cause Table 1:WT Human Cause Accident Data (Asian et al., 2017)	Accident count Table 1:WT Human Cause Accident Data (Asian et al., 2017)	Criticality Rating Based on Table 1:WT Human Cause Accident Data (Asian et al., 2017)	Personal Perception of Criticality	Mixed reality implementation crucial
Working with Heights	Human (Negligence) and Human (Fall)	4+1	High	High	Yes
Manual Handling	Human (Wrong Action)	4	High	Low	No
Fire safety and Awareness	Human (Interference in control systems)	2	Medium	Medium	No
First AID	Human (Heart attack)	1	Medium	High	No

The Table 16 has six columns. The first column indicates the training module name and the second column indicates the accident cause from the Table 1:WT Human Cause Accident Data

(Asian et al., 2017) which matches with the type of accidents possible to occur within the corresponding training module. For example.

In the module working with heights, the possible type of accidents to occur are due to slip, fall and unsafe human actions. These accidents matches with the accident cause Human (Negligence) and Human (Fall) from the Table 1:WT Human Cause Accident Data (Asian et al., 2017).

Similarly, in the module manual handling, the possible type of accidents to occur are due improper body positions and actions. These accidents matches with the accident cause Human (Wrong Action) from the Table 1:WT Human Cause Accident Data (Asian et al., 2017).

Similarly, in the module fire safety and awareness, the possible type of accidents to occur are due electrical short circuits and unavailability of fire safety equipment's or lack of knowledge to use them effectively. These accidents matches with the accident cause Human (Interference in control systems) from the Table 1:WT Human Cause Accident Data (Asian et al., 2017).

Similarly, in the module basic first aid, the possible type of accidents to occur are due sudden heart attack or hanging trauma and lack of immediate medical treatment. These accidents matches with the accident cause Human (Heart attack) from the Table 1:WT Human Cause Accident Data (Asian et al., 2017).

The third column in Table 16 indicates the corresponding accident count based on data from Table 1:WT Human Cause Accident Data (Asian et al., 2017). The fourth column represents the criticality rating based on the data from Table 1:WT Human Cause Accident Data (Asian et al., 2017). However before deciding to select which module is the most crucial to implement mixed reality for this case study. My personal perception of criticality rating of the modules based on my experience from the 5-day GWO training I took is documented in the column five. Energy Innovation AS agreed to document my personal perception of criticality since my view as a participant of the course, will give some indication to what other participants feel about the modules. The sixth column indicates the module which is selected for mixed reality application.

The Figure 41 indicates the wind turbine accidents between the years 1980 and 2013. These data are also used for the research paper (Asian et al., 2017) mentioned above. Therefore, it's a valid data. The data reports that the human negligence category leads in the death, injury and the transport accident number. Meanwhile the mechanical category which includes short circuit etc. is the main cause for fire accidents. This indicates that lack of following basic safety precautions or human error is the main cause of the accidents. Thus, using an MR application to reiterate the safety procedures again and again into the human mind will potentially avoid such failures.

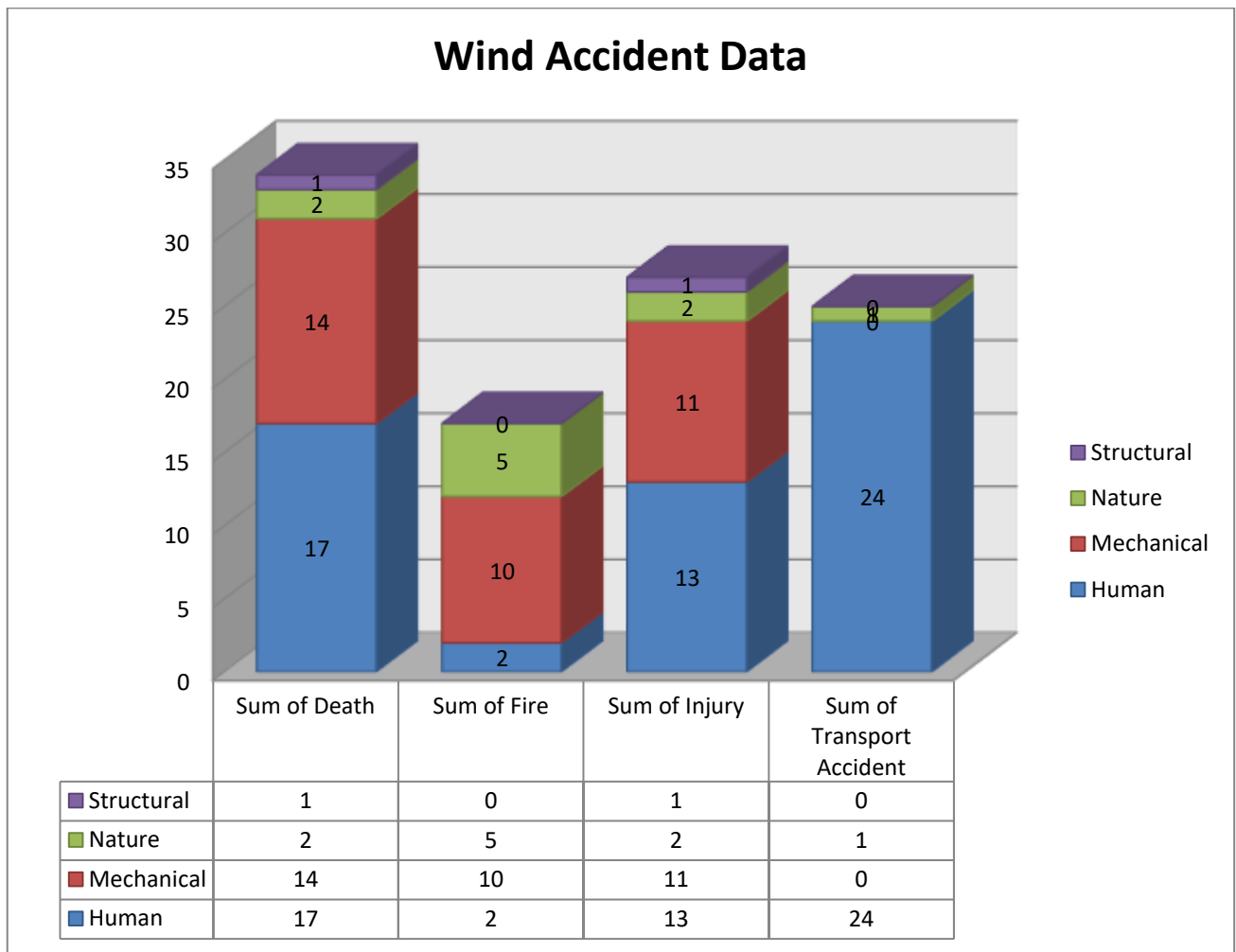


Figure 41: WT Accident Data (Wind Turbine Accidents Data, 2021)

Based on the Table 16 and Figure 41, the working with heights module is selected as the most critical module since it has high criticality as any human error could lead to serious injuries and deaths. The worksheet and demo MR model are created for this module. However, first AID is also crucial, but Energy Innovation is already working with SAFER regarding this module.

The second part of the use case analysis involves in selecting one similar framework in other engineering industry through literature review. Based on the extensive SLR done and mentioned in the section 1.9 one best framework was selected.

Decision making accident scenario (DMAS) is a framework used in the construction industry which uses an android VR application which enables the users to improve their risk identifications and to decide on suitable mitigation techniques based on different accident scenarios(Gupta & Varghese, 2020).

The VR model when opened in the tablet, lets the user to see himself as an avatar and he is then presented with an accident scenario. The user needs to identify the identify the risks associated with the scenario and then need to select the correct precaution that he needs to take to mitigate the risk. After making the final decision regarding the accident scenario, the user can test virtually if his precautions are correct. The avatar might end up in an accident if the precautions selected by the users are wrong. This will help to increase the awareness of the users and the impact of selecting a wrong precaution in real life scenario(Gupta & Varghese, 2020).

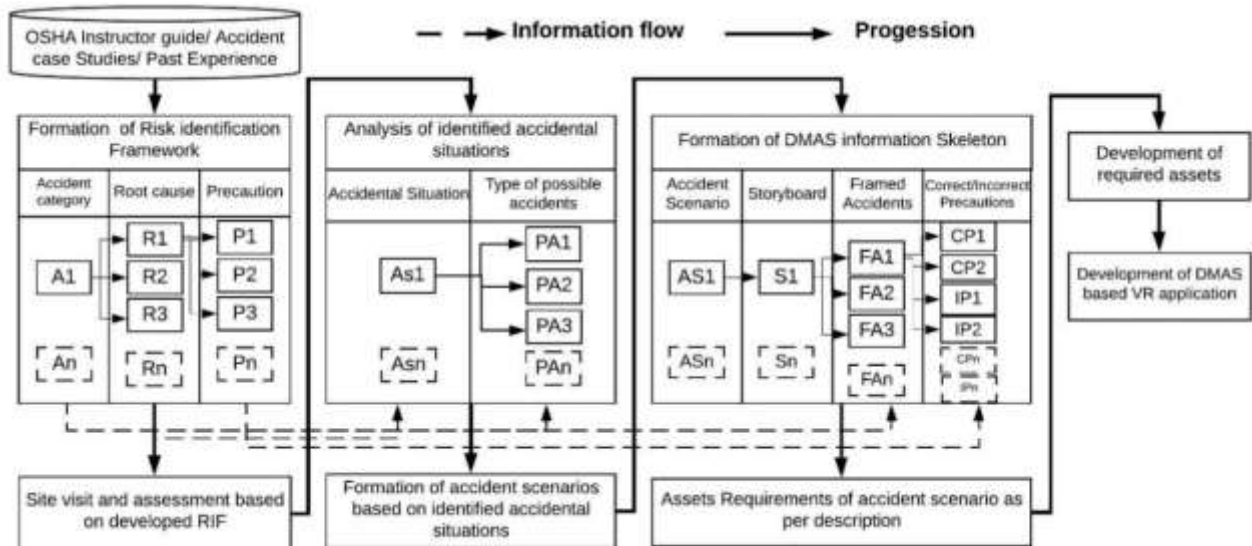


Figure 42: DMAS Framework (Gupta & Varghese, 2020)

The methodology to develop the framework is described in the Figure 42. In the first box (left) it involves three steps

- An=Identification of the various common types of accidents that will happen in the construction site.
- Rn=Make a root cause analysis of the accidents.
- Pn=Developing suitable precautions and mitigation strategies.

The second (middle) box involves in visiting the site and deciding on the site-specific accident situations, it involves two steps

- Asn=Identification of accidental situations which can simulate an accident as a result of negligence.
- PAn= Possible accidents selected out from the accidental situations.

The third (right) box is the actual DMAS skeleton. It involves four steps and identification of two variables.

- ASn=Accident scenario is the VR replica of the accidental situations Asn from step2.
- Sn = Create a storyboard based on the VR scenario that is going to be modelled.
- FAn= Framed accident. This is the first variable that is identified. This is a scenario that can be modelled in VR. This will be the accident scenario that the user can play in the game.
- Cpn/IPn = Correct precautions and Incorrect precautions for the framed accident, these are the selections made by the users when they play the VR game. This is the second variable that is identified.

Finally, the 3D model for the DMAS framework is developed as mentioned in Figure 43.

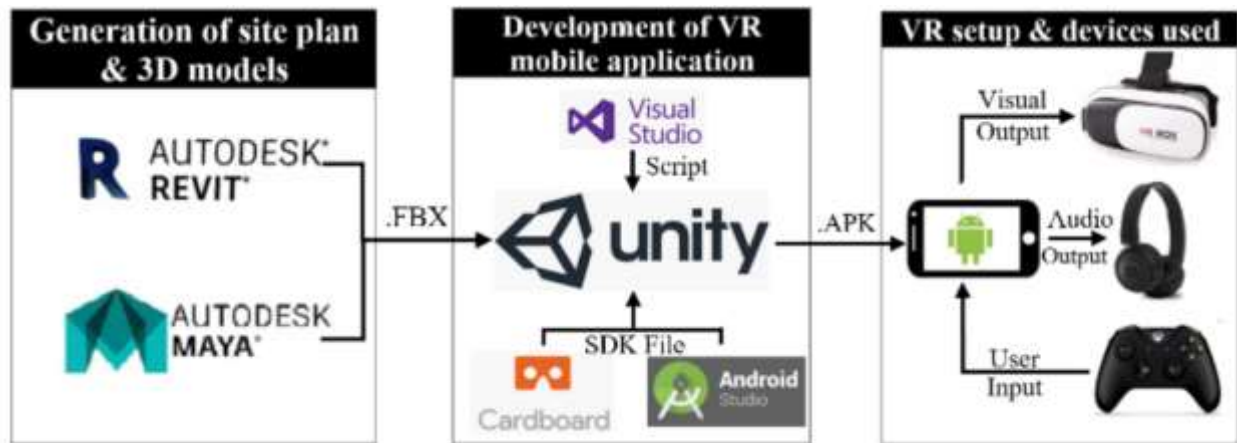


Figure 43: 3D Development DMAS Framework (Gupta & Varghese, 2020)

The construction site details are modelled in 3D using different modelling software's like Revit and Maya and then transported as .FBX file into software's like Unity which helps to animate and create VR game environments. Certain VR actions needs to be scripted, in order words programmed using visual studio and then Android Studio (SDK file) was used to building apps on android device. Finally, the app is made compatible to VR hardware devices.

The use case analysis helped to define the case context which are

1. The working with heights is the most critical module selected from the 5-day GWO training to develop a worksheet and demo MR model.
2. The DMAS framework emphasized the need to further classify the chosen critical module.
3. The DMAS framework emphasized the importance of risk identifications and to decide on suitable mitigation techniques
4. The DMAS framework emphasized the need to develop the steps of the scenario for MR modelling
5. The DMAS framework emphasized the importance of deciding the potential technical specifications and to identify the steps of 3D modeling, MR modelling and the game output capture.

5.3. Conceptualize

The conceptualization part is further divided into two important steps

1. Classify the selected critical module (Working with Heights) into training tasks and identity the risk associated with each training tasks.
2. Build the scenario for MR Modelling: This step is called the MR concept study step: Scenario modelling.

The first step in conceptualization stage involves in classifying the selected critical module which is working in heights in this case. However, a general flowchart is presented in Figure 44 which when followed will guide to classify other modules when needed. The classification is based on Energy Innovation AS training materials (Bentsen, 2021) however the training materials will not be attached in the appendix. My personal notes and pictures I took during the 5day GWO training will be helpful to classify.

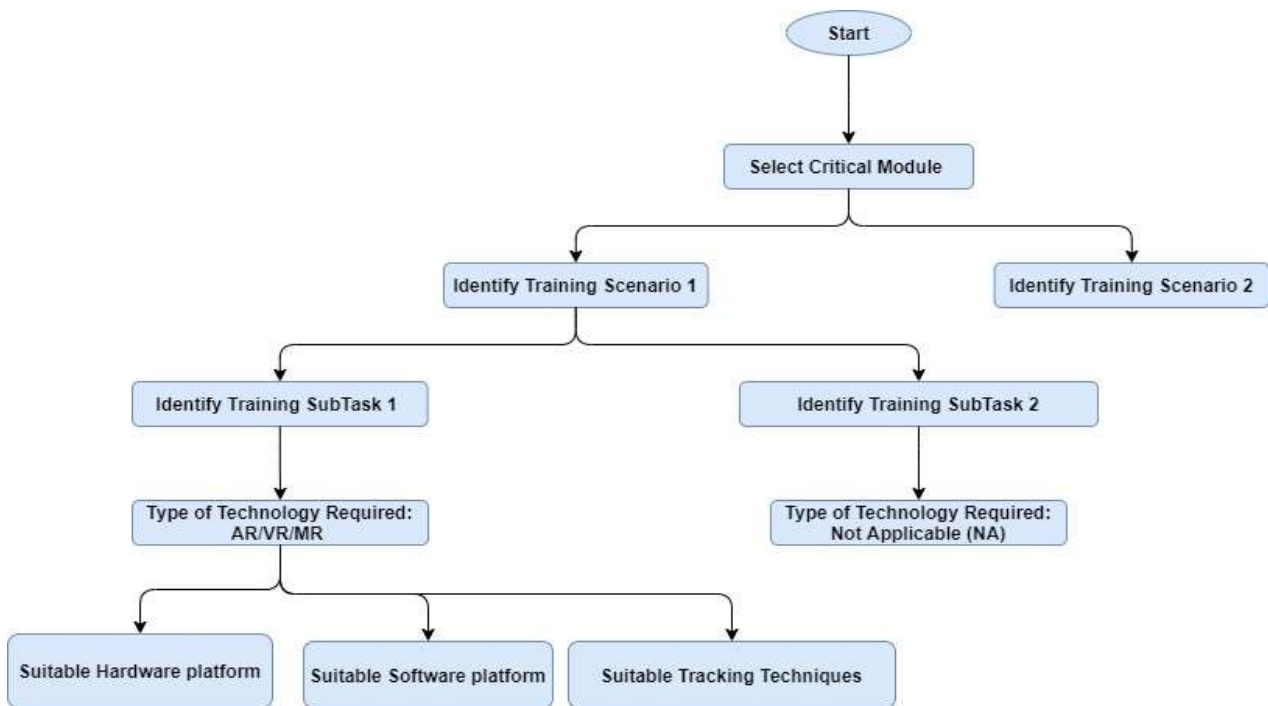


Figure 44: Flowchart Critical Module Classification

The working with heights module is a 2-day training program and can be predominately classified into 4 different safety training scenarios like

- Effective use of the safety gears
- Safe manner to climb (assess) the turbine
- Controlled descent to lower level
- Basic rescue operation

All these scenarios are further divided into different training tasks which are mentioned in Table 17. These tasks are the ones which the participants need to do and train on them during the 2-day training.

The first scenario effective use of safety gears scenario involves with how to use the safety gears properly and how to wear the harnesses in a safe manner and how to use the different safety gears effectively.

The second scenario safe manner to climb (assess) the turbine scenario mainly deals with the safety steps that the participants need to do once they enter the turbine, it mainly focus on how to climb the ladder safely, how to use the self-locking slider properly with the ladder railings while climbing and to ensure safety tips like remembering to close the door hatch at every level. Then at each level remembering to connect the Y liner to the yellow anchor point.

The third scenario-controlled descent to lower level involves training with the milan (equipment) and how to effectively use it and how-to descent to lower level inside the turbine safely. The scenario also focusses on the evacuation jump that must be done in case of fire emergencies and the steps that needs to be followed to ensure safety before the evacuation jump.

Table 17: Critical Module Classification

Module Name	Safety Training Scenario	Training Tasks
Working with Heights	Effective use of the safety gears. Refer Figure 31	Wear the harnesses properly
		Effective use of fall arresters (Y-line)
		Effective use of support belt
		Proper placing of the self-locking slider on ladder railings
	Safe manner to climb (assess) the turbine. Refer Figure 34	Open and close the hatch door safely
		To connect the Y line to the anchor point (Yellow) with fall factor 0 or 1
		Locate the Anchor Point (Yellow)
	Controlled descent to lower level. Refer Figure 32	Effective use of the Milan to descent safely to lower height
		To connect the self-locking slider to perform the evacuation Jump safely
		To identify the evacuation gear in case of emergency
	Basic rescue operation. Refer Figure 35	To rescue a person from lower level to reach him upwards
		To rescue a person from higher level to reach him downwards
		To recognize if rescued person has suffered a hanging trauma

The fourth scenario basic rescue operation scenario deals with the steps that are needed to be followed while rescuing a person inside the turbine in a safe manner without hurting the other person or putting oneself at risk. The space constraint is one of the biggest limitations for performing rescue operations inside the wind turbine.

After the classification into different training tasks in Table 17 , it is very important to define the training complexity (low/medium/high) using a risk-based approach inspired from the book risk analysis by Terje Aven as mentioned in the Figure 45 for each of the training tasks.

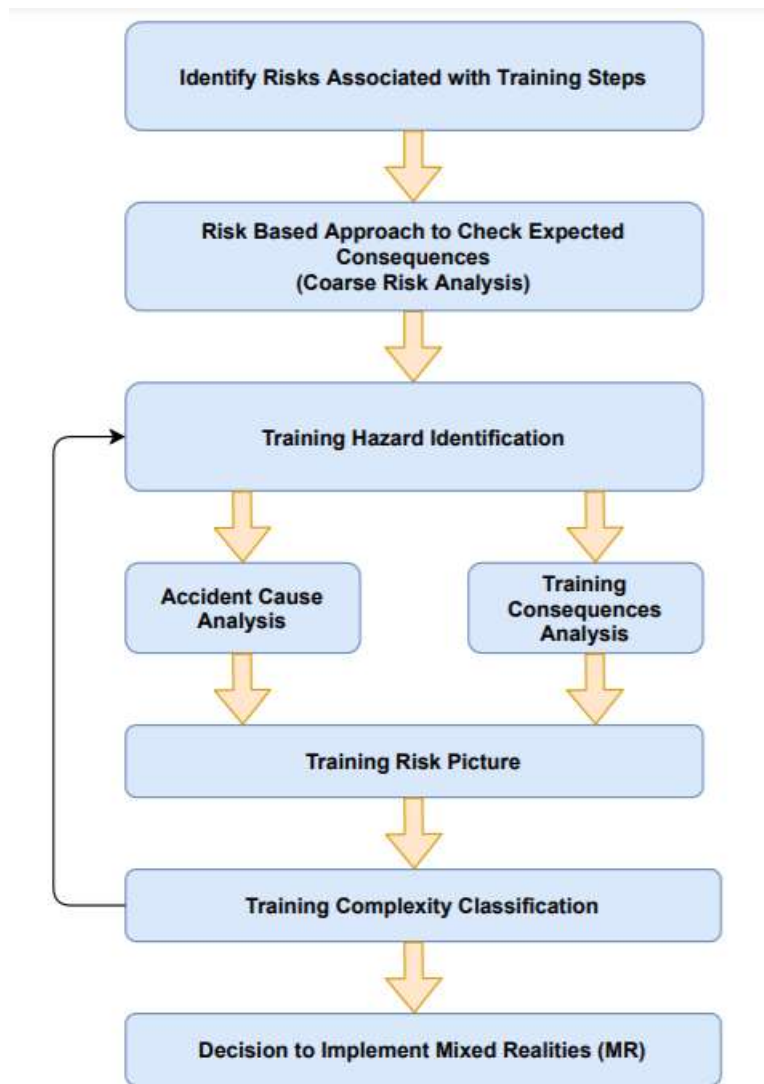


Figure 45: Risk Analysis Steps (Aven, 2015)

The next step in conceptualization stage involves in identifying the risk associated with each training steps. The classification as low/medium/high is done based on the consequence associated with each of the training steps. The consequences are decided after talking with industrial experts in the training field and with my personal experience from the 5-day GWO training.

The risk analysis is done mainly to get a risk picture associated with the event and to classify the event based on the criticality. Risk analysis is very helpful to make decisions. Risk definition must always include a combination of consequences and uncertainty and the presence of the background knowledge about the specific area, this knowledge is got from the industrial training experts and personal perceptions (Aven, 2015). In the case of safety training, each training steps will have an associated consequence (negative) and there is also an uncertainty if that consequence will occur or not, but it is better to stay prepared. For example, in the case of evacuation jump, there is always a consequence that if the safety steps before the jump are not followed properly, the jump might turn catastrophic, however there exists an uncertainty if such emergencies will occur or not.

A coarse risk analysis is done to classify the training steps, this is a primary risk analysis method. Detailed risk analysis methods can be followed to identify the risk picture in the future if required. The coarse risk analysis steps are to identify the hazards associated with each of the training steps and the associated cause and consequences are identified. The training hazards are identified from the worksheet provided by Energy Innovation AS and it is also attached in the appendix. The accident causes and the training consequences are identified by speaking with training managers from Energy Innovation AS and from my personal experience from the 5-day GWO training. The purpose I attend the training was to capture such details. Therefore, the likelihood and the impact rating which are used in the risk matrix shown in Figure 46 are purely based on expert opinion and my personal perceptions.

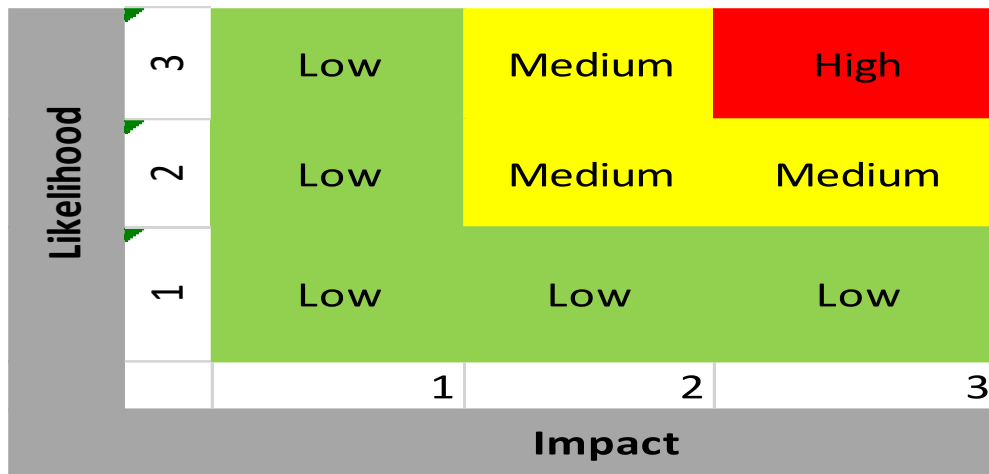


Figure 46: Risk Matrix (Aven, 2015)

The final step of the coarse risk analysis is to develop the training risk picture as in Table 18. This risk picture will help us to define the training complexity and to aid in making a decision to check if there is a need to implement mixed reality for that particular training task. The training risk picture also indicates the possible measure to avoid or reduce the consequences.

Now after developing this training risk picture (Table 18), we can update the critical module classification Table 17 to include the training complexity and the decision if mixed reality implementation is required for the training tasks or not. The updated version of the critical module classification Table 17 is called decision critical module classification and is shown in Table 19

The decision to implement mixed reality for a particular task in Table 19 depends on

- If the risk is identified as high, then go for implementation of mixed reality.
- If the risk is identified as medium, then go for implementation of mixed reality provided it is related to working with heights.
- If the risk is identified as low, then go for implementation of mixed reality only if happens in an emergency situation.

Again, these guidelines are only for this thesis, however similar such guidelines can be developed for other purposes in the future. However, the procedure remains the same. The guidelines are from personal perception and discussion with managers of Energy Innovation AS.

Table 18: Training Risk Picture

Training Tasks	Hazards (From Energy Innovative AS Worksheet) attached in Appendix	Accident Causes Analysis	Likelihood: Expert Opinion and Personal perception. 1= Least Likely, 3= More likely	Training Consequences Analysis	Impact: Expert Opinion and Personal perception. 1= Least Impact, 3= More Impact	Training Risk Figure 46	Possible measure to avoid or reduce the consequences
Wear the harnesses properly	Sprain associated with improper wearing of harnesses	Improper training, Negligence	1	Injury	1	Low	Second person check
Effective use of fall arresters (Y-line)	Fall, slip, stumble, sprain, misstep	Improper training, Negligence	2	Injury, Sprain	2	Medium	Repeated Training or using Innovative methods like VR/AR
Effective use of support belt	Fall, slip, stumble, sprain, misstep	Improper training, Negligence	2	Slip and Stumble	2	Medium	Repeated Training or using Innovative methods like VR/AR
Proper placing of the self-locking slider on ladder railings	Fall, slip, stumble, sprain, misstep	Improper training, Negligence	2	Injury, Death	3	Medium	Repeated Training or using Innovative methods like VR/AR
Open and close the hatch door safely	Fall from high altitude workplaces	Not following safety procedures	2	Injury, Death	3	Medium	Provide safety instruction check list
To connect the Y line to the anchor point (Yellow) with fall factor 0 or 1	Fall from high altitude workplaces	Negligence	3	Injury	2	Medium	Provide safety instruction check list
Locate the Anchor Point (Yellow)	Infrastructure/traffic ways	Lack of exposure to the infrastructure	1	Misstep, Psychological Stress	1	Low	Create awareness about Infrastructure

Effective use of the Milan to descent safely to lower height	Fall from high altitude workplaces	Improper training, Negligence	3	Injury, Death	3	High	Repeated Training or using Innovative methods like VR/AR
To connect the self-locking slider to perform the evacuation Jump safely	Fall from high altitude workplaces	Improper following of safety steps, lack of repeated training and practice	3	Injury, Death	3	High	Repeated Training or using Innovative methods like VR/AR
To identify the evacuation gear in case of emergency	Infrastructure/traffic ways	Lack of exposure to the infrastructure	1	Misstep, Psychological Stress	1	Low	Create awareness about Infrastructure
To rescue a person from lower level to reach him upwards	Confined spaces & hand/arm movements	Improper following of safety steps, lack of repeated training and practice	3	Self-Injury and Death of to be rescued person	3	High	Repeated Training or using Innovative methods like VR/AR
To rescue a person from higher level to reach him downwards	Confined spaces & hand/arm movements	Improper following of safety steps, lack of repeated training and practice	3	Self-Injury and Death of to be rescued person	3	High	Repeated Training or using Innovative methods like VR/AR
To recognize if rescued person has suffered a hanging trauma	Confined spaces & hand/arm movements	Lack of exposure to accident scenario	2	Improper First Aid	2	Medium	Advanced First aid Training

Table 19: Decision Critical Module Classification

Module Name	Safety Training Scenario	Training Tasks	Training Complexity Risk Based Approach from Table 18	Mixed reality Implementation Required
Working with Heights	Effective use of the safety gears. Refer Figure 31	Wear the harnesses properly	Low	No
		Effective use of fall arresters (Y-line)	Medium	Yes
		Effective use of support belt	Medium	Yes
		Proper placing of the self-locking slider on ladder railings	Medium	Yes
	Safe manner to climb (assess) the turbine. Refer Figure 34	Open and close the hatch door safely	Medium	Yes
		To connect the Y line to the anchor point (Yellow) with fall factor 0 or 1	Medium	Yes
		Locate the Anchor Point (Yellow)	Low	No
	Controlled descent to lower level. Refer Figure 32	Effective use of the Milan to descent safely to lower height	High	Yes
		To connect the self-locking slider to perform the evacuation Jump safely	High	Yes
		To identify the evacuation gear in case of emergency	Low	Yes
	Basic rescue operation. Refer Figure 35	To rescue a person from lower level to reach him upwards	High	Yes
		To rescue a person from higher level to reach him downwards	High	Yes
		To recognize if rescued person has suffered a hanging trauma	Medium	No

The second step in conceptualization stage involves in developing the scenario for MR Modelling: This step is called the MR concept study step, scenario modelling. This is very similar to the storyboard writing of the DMAS Framework Figure 42.

The scenario modelling concept involves 7 steps (Figure 47). All the planned steps will be executed in the section 5.4. However, the step 4 which is selecting the training steps for MR modelling will be described in this section.

The training steps which are selected for MR modelling is based on three factors

- Training steps which Energy Innovation AS preferred to have as demo model.
- Training steps which is classified as medium / high risk classification in Table 19
- Training steps which are easier to model with the possible time frame and with my level of expertise and knowledge.

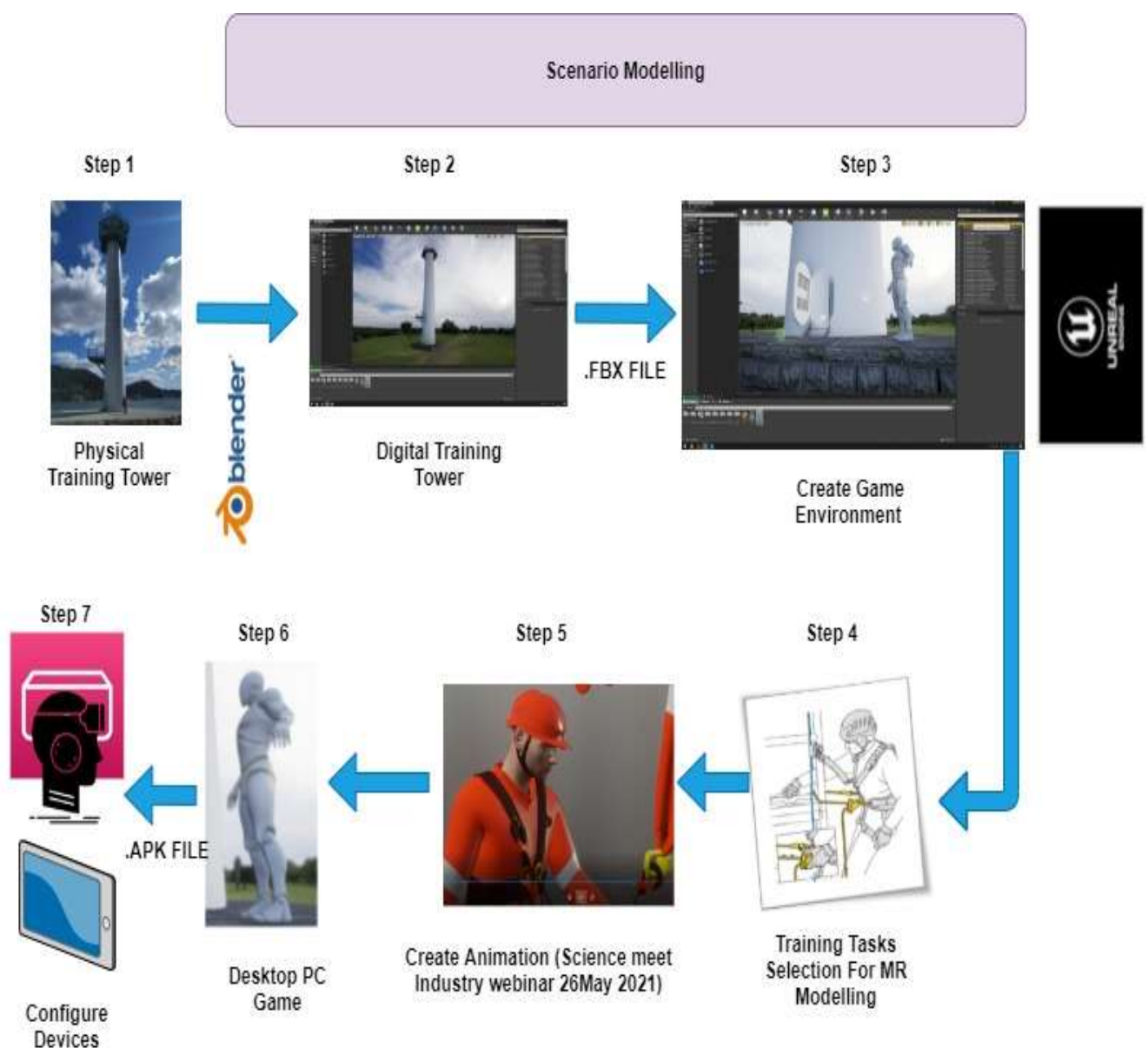


Figure 47: Scenario Modelling Chart

The training tasks (mentioned in Table 19) which are selected for the creation of the animation are as below. The animation was created for science meet industry webinar which was organized by Norwegian offshore wind cluster <https://offshore-wind.no/event/webinar-science-meets-industry-floating-offshore-wind-in-norway/> for which I was selected as a speaker to present my master thesis case study. There was around 400 participants and I presented it in the studio in Stavanger, Norway (26th May 2021).

1. Wear the harnesses properly
2. Effective use of fall arresters (Y-line)
3. Proper placing of the self-locking slider on ladder railings
4. Open and close the hatch door safely
5. To connect the Y line to the anchor point (Yellow) with fall factor 0 or 1
6. To connect the self-locking slider to perform the evacuation jump safely
7. To identify the evacuation gear in case of emergency

The animation scenes are planned as below, it will cover all the above-mentioned training task. The animation will be done in blender software.

Scene 1: The technician dressed appropriately (wearing the safety gears as in Figure 48) standing outside the turbine.

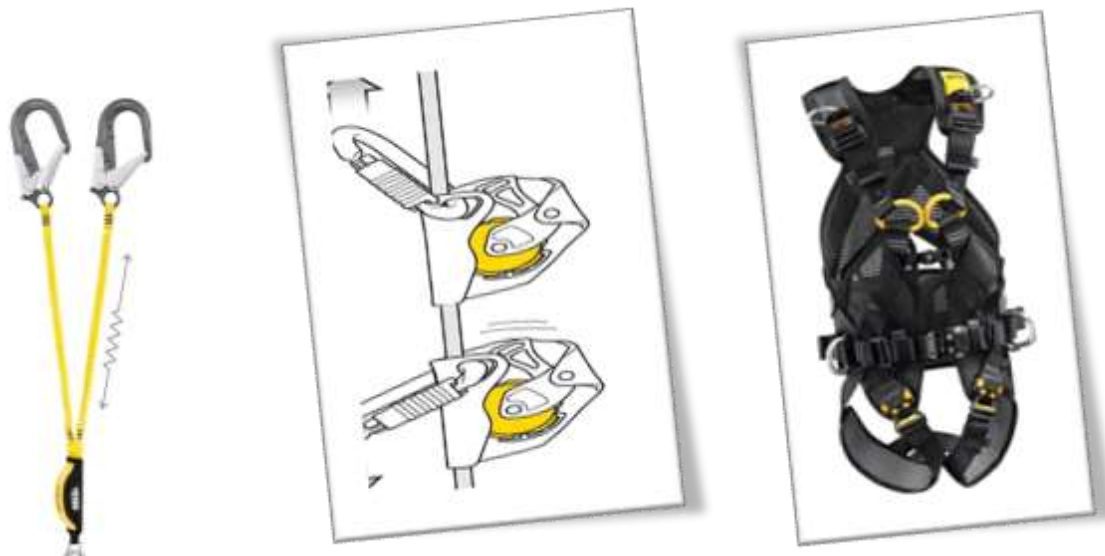


Figure 48: Safety Gears Planned for Animation

Scene 2: The technician opens the door and enters the wind turbine

Scene 3: The technician secures the self-locking slider on ladder railings and starts climbing the ladder as described in the Figure 49.



Figure 49: Safety Climbing Protocol

Scene 4: The technician reaches the first level and opens and closes the hatch (refer Figure 34)

Scene 5: The technician identifies the first aid kit

Scene 6: The technician climbs further and reaches the second level and secures Y line to the anchor point (Yellow Figure 50) with fall factor of 1 (explanation of fall factor 1, refer theory chapter)



Figure 50: Anchoring Device (NS-EN 795)

Scene 7: The technician locates and picks up the evacuation gear as shown in Figure 51 and Figure 52 and then disconnect the Y line (following safety protocol).

Scene 8: The technician reaches the top level of the wind turbine to perform an evacuation jump.
Scene 9: The technician remembers to connect his self-locking slider and other safety gears as in Figure 52 for safety purpose
Scene 10: The technician jumps from the outer part of the tower using devices as shown Figure 51.



Figure 51: Milan For Controlled Descent



Figure 52: Carabiner Hooks & Fall Dampener

The pictures are collected as a part of scenario modelling as they will help to create 3D image in animation and MR model. The character creation and the scene creation for the animation can also be used for the demo desktop PC game.

The training tasks (mentioned in Table 19) which are selected for the creation of the demo MR model (Desktop PC game) are as below. The demo desktop PC game is created to show the possibility of creating a MR game scenario, which Energy Innovation AS can use it to send to the participants to train in their home before reaching out for the actual physical training.

The Demo MR Model (game) will have only a few game scenes, the main reason is the level of my expertise and knowledge around this area and the time frame I had to learn and complete this master thesis and the fact creating a game requires a team of expertise working and also fixing the bug with each version as and when the users provides feedback about the game. However, the main purpose of the demo MR model is for providing the case company the simple model which will give them confidence to continue with such innovative ideas. In future Energy innovation AS plans to collaborate with companies with Bouvet or create their own task force, to develop such MR models for all the other modules like fire safety, first aid and manual handling.

The demo MR model game scenes are planned as below, it will cover all the above-mentioned training task. The game will be developed using Unreal software.

Scene 1: The technician enters the wind turbine through the door and can look around in 360 degree to get an immersive feel of being inside the wind turbine.

Scene 2: The technician can climb the ladder

Scene 3: The technician enters the lift and goes to the upper level

Scene 4: The technician identifies the evacuation gear

Scene 5: The technician goes to the top level and jumps

5.4. Computerize

The computerize part follows the scenario modeling chart in Figure 47 and consist of the below tasks.

- Create the 3D model of the training tower (Blender Software)
- Develop safety animation (Blender Software-for science meet industry conference)
- Create game environment / desktop PC demo MR game (Unreal Software)
- Extract the game as .APK file to support it in android mobile device and configure with headgear

The 2D model of the training tower which was received as input from Energy Innovation AS was converted into 3D model in Blender software.

The first step is the planning stage, such as to think about the concept of modelling, collecting references, discussing with the team. This step is discussed already in detail in the data collection chapter.

The second step when it comes to building 3D Modeling, it all begins with adding a shape like cube or spear in Blender Software, from that shape, we sculpt whatever shape we require. This is shown in Figure 53.

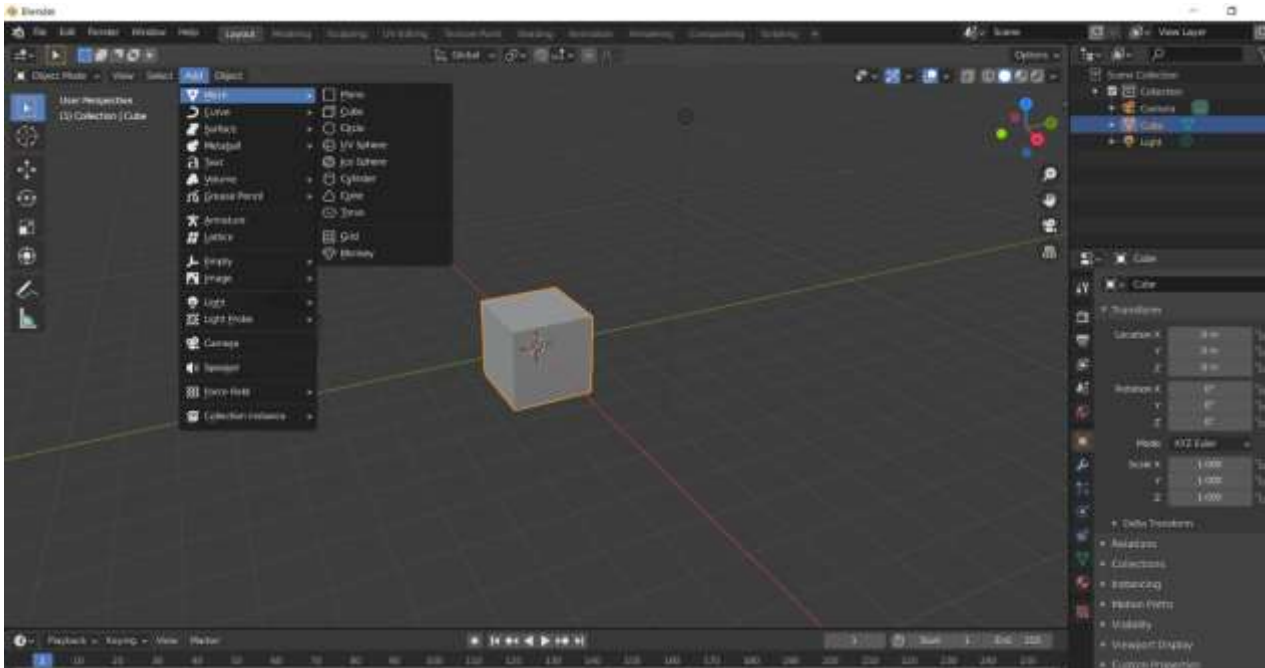


Figure 53: Add Basic Shapes Blender

The third step is building the individual props in Blender like the outer portion of the tower, the lift and ladder inside the tower. All these can be done by using three basic features of 3D modelling in Blender known as

- Vertex - It can be changed to sculpt the icosphere has shown in Figure 55.
- Face - It can be changed to sculpt the cylinder has shown in Figure 56.
- Edge - It can be changed to sculpt the cone has shown in Figure 57.

These are individual elements which will allow to edit the object such as the icosphere shown in Figure 54.

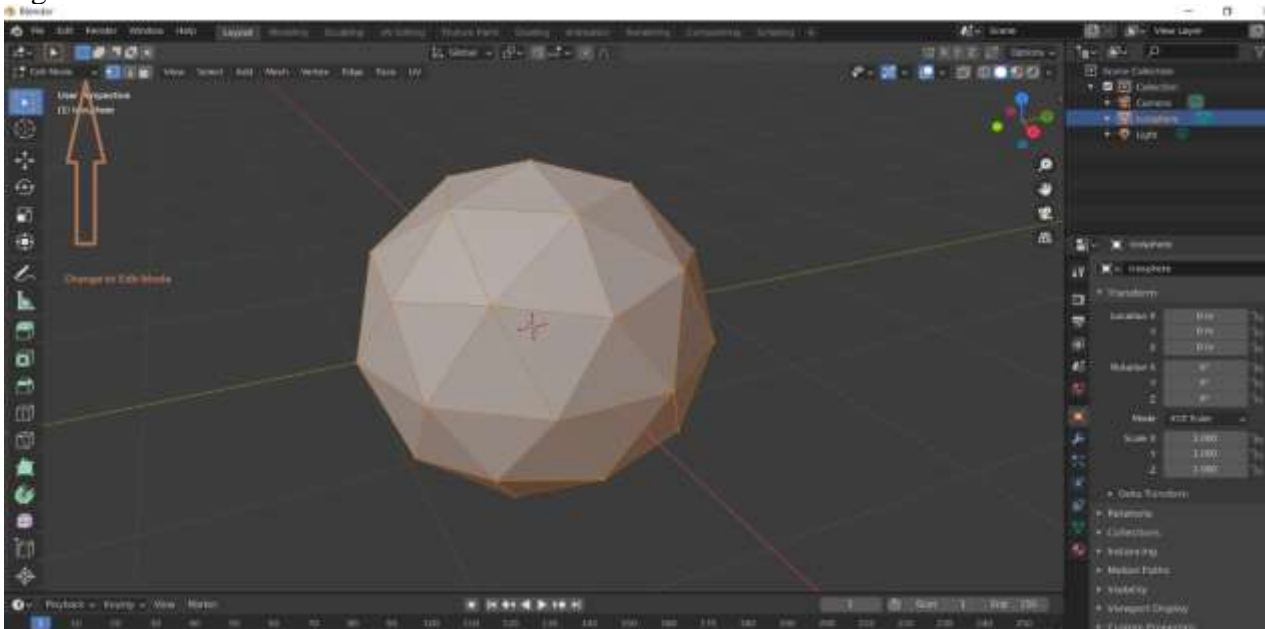


Figure 54: Edit Shapes

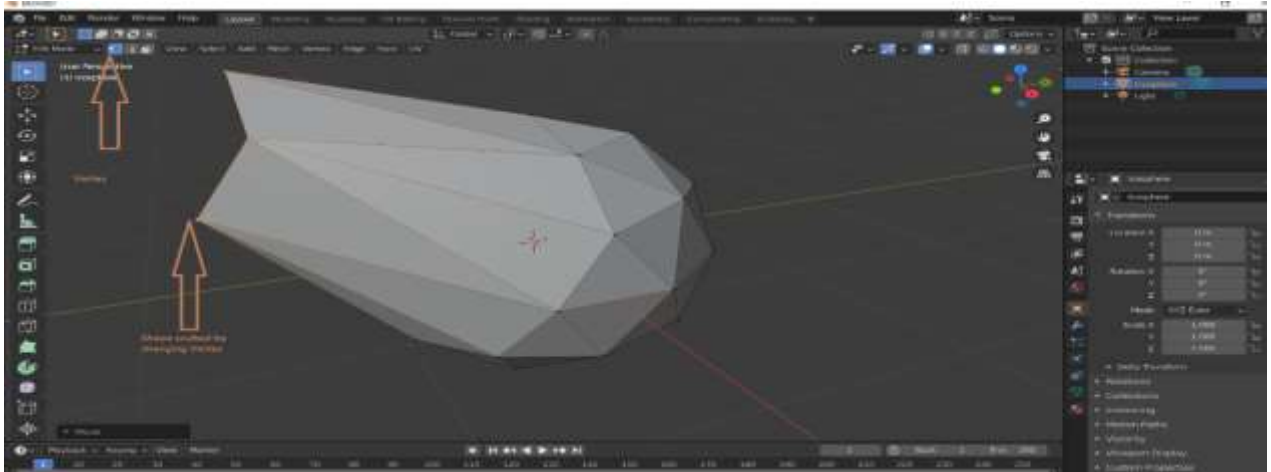


Figure 55: Edit Vertex

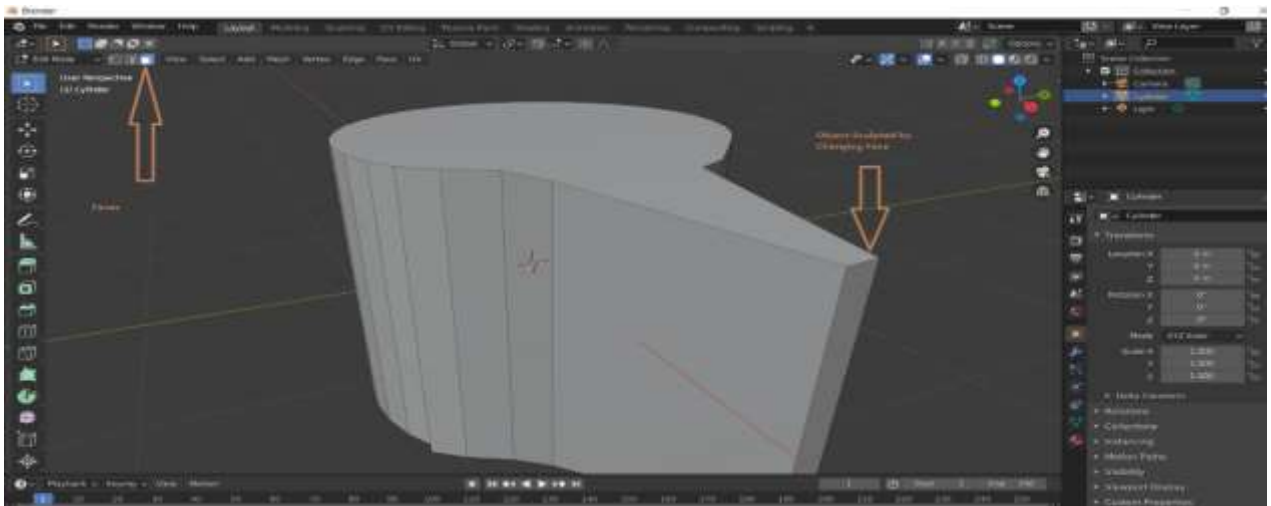


Figure 56: Edit Face

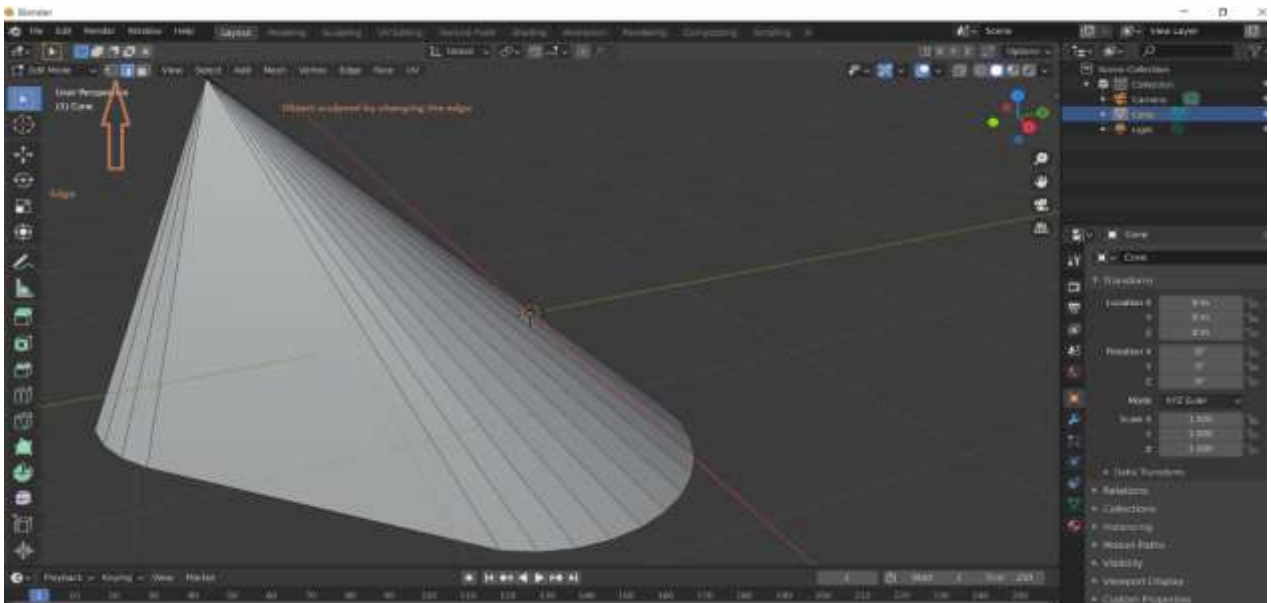


Figure 57: Edit Edge

The individual props such as the outer portion of the tower, the ladder, the door and the platforms inside the tower are created using Blender Software by using the techniques described above and shown in Figure 58.

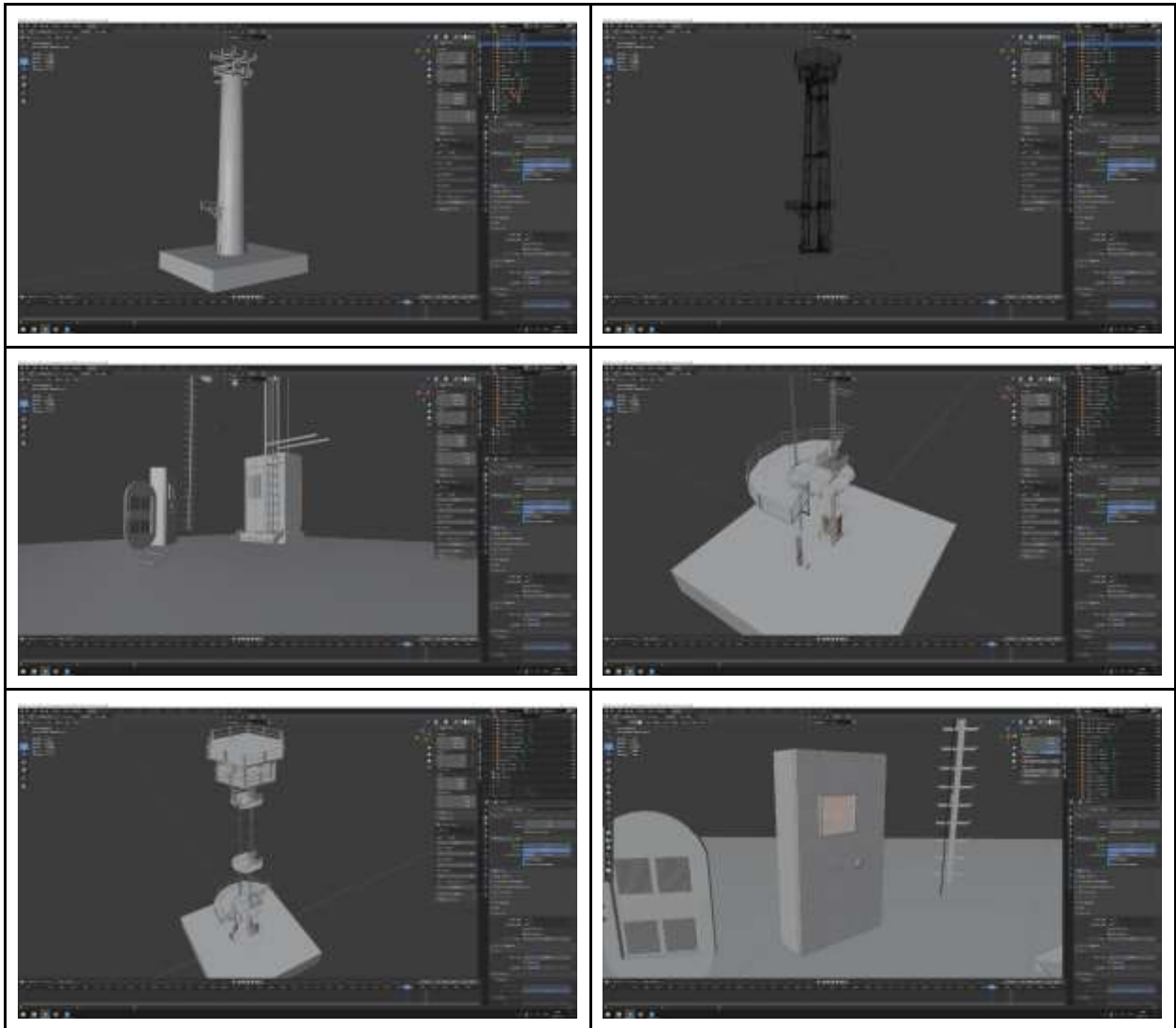


Figure 58: Individual Props Modelling

The final step is creating the materials, texturing, and UV mapping in Blender software. To change the material properties of the objects we sculpted, we use different nodes and link each other in Blender Software. These nodes in simple terms represent different properties of the object we create like the texture, the color, the reflection, the transparency, etc.

Figure 59 represents working with a simple sphere and making it translucent. Left side of Figure 59 shows the default principal material node with multiple options in it and the way it is linked. Figure 60 shows the different type of nodes including the texture nodes used for this 3D modelling and the way it is linked. Texturing in simple words is coloring the objects we created as shown in Figure 61.

UV (denotes two axes of 2D texture) mapping is when projecting a 2D image to a 3D model surface. For, example in Figure 62 we take a 2D image of the platform floor (anti slip layer) and project it into the 3D model. This feature is used to make the realistic 3D model. However, for the demo 3D model, this is not very essential step.

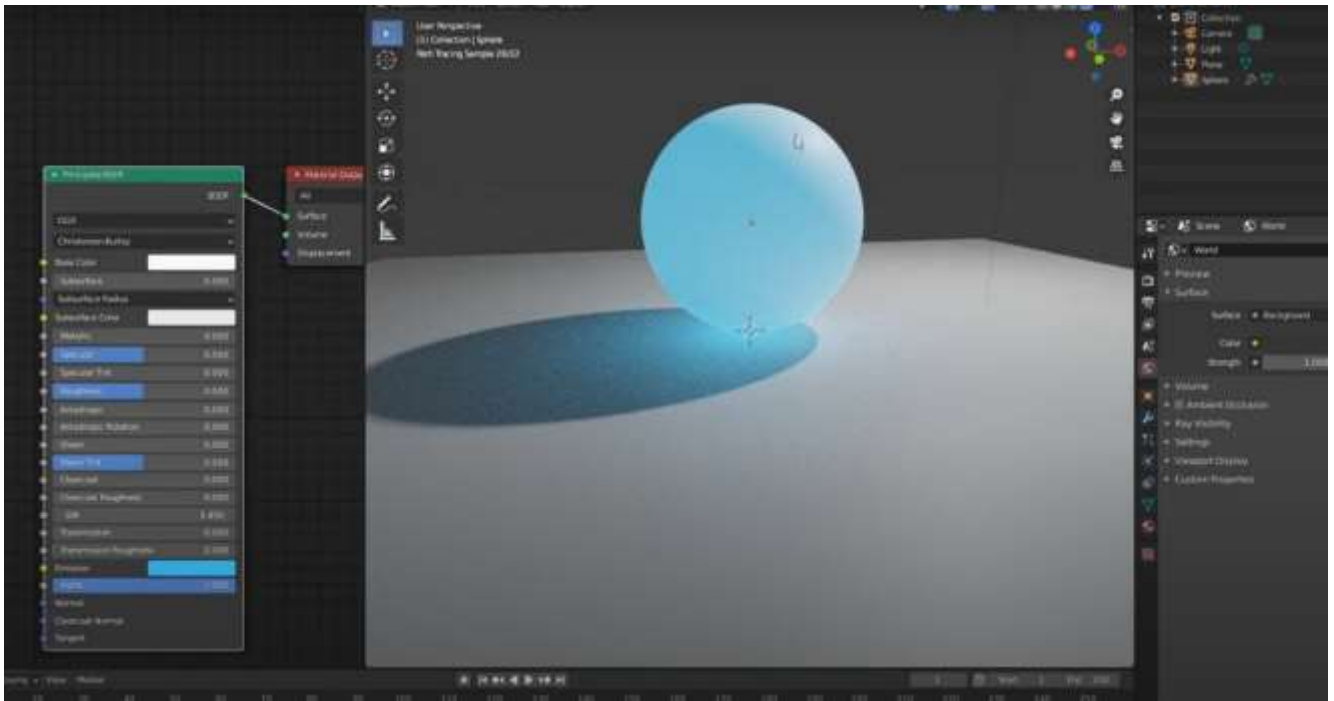


Figure 59: Material Nodes

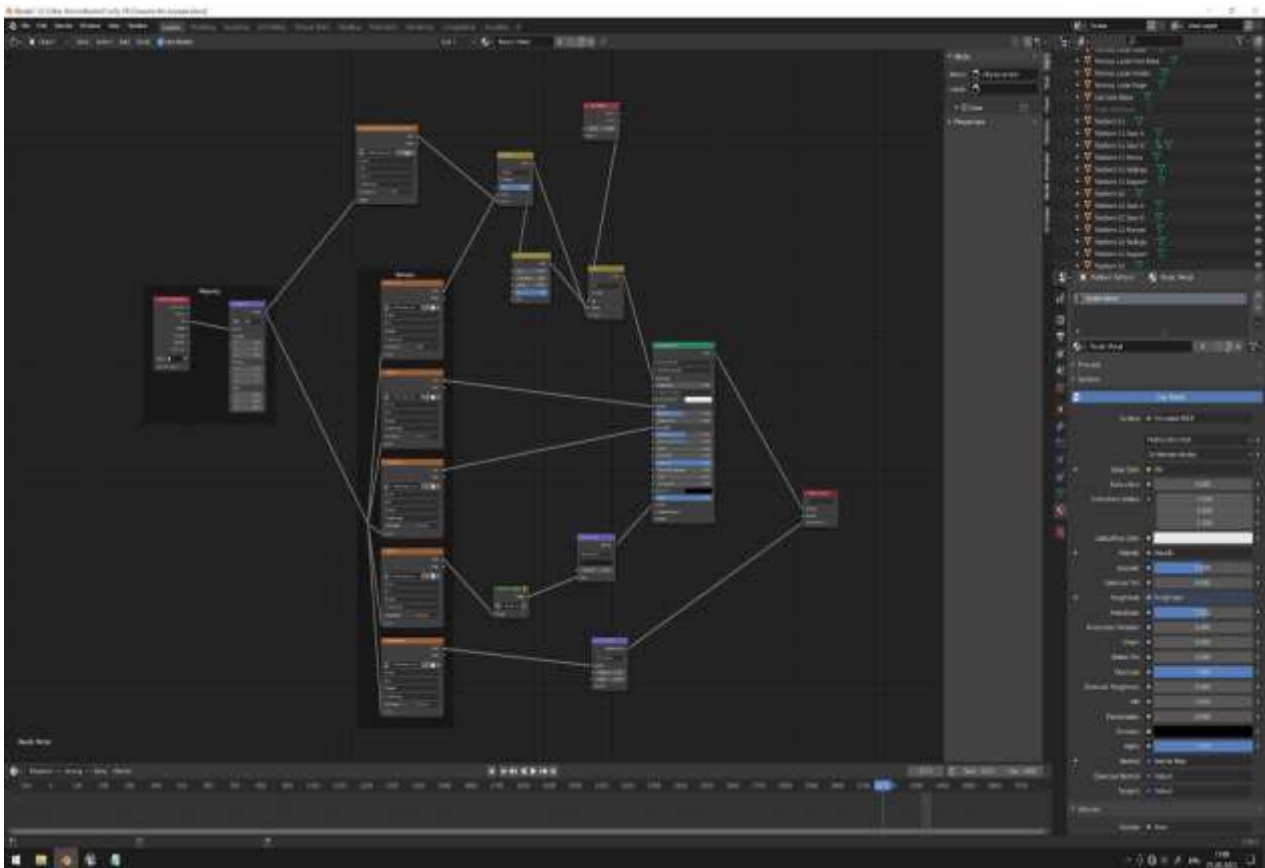


Figure 60: Material Nodes for 3D Model

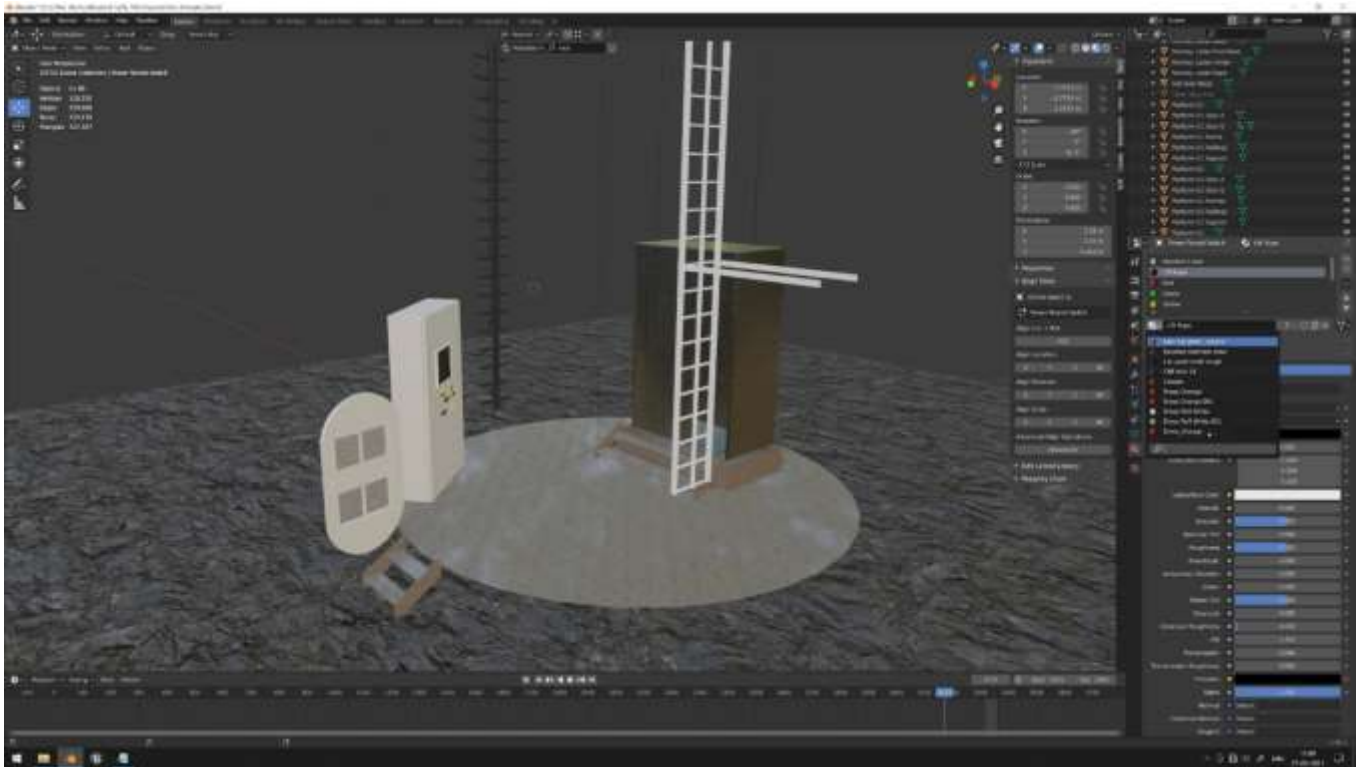


Figure 61: Texturing

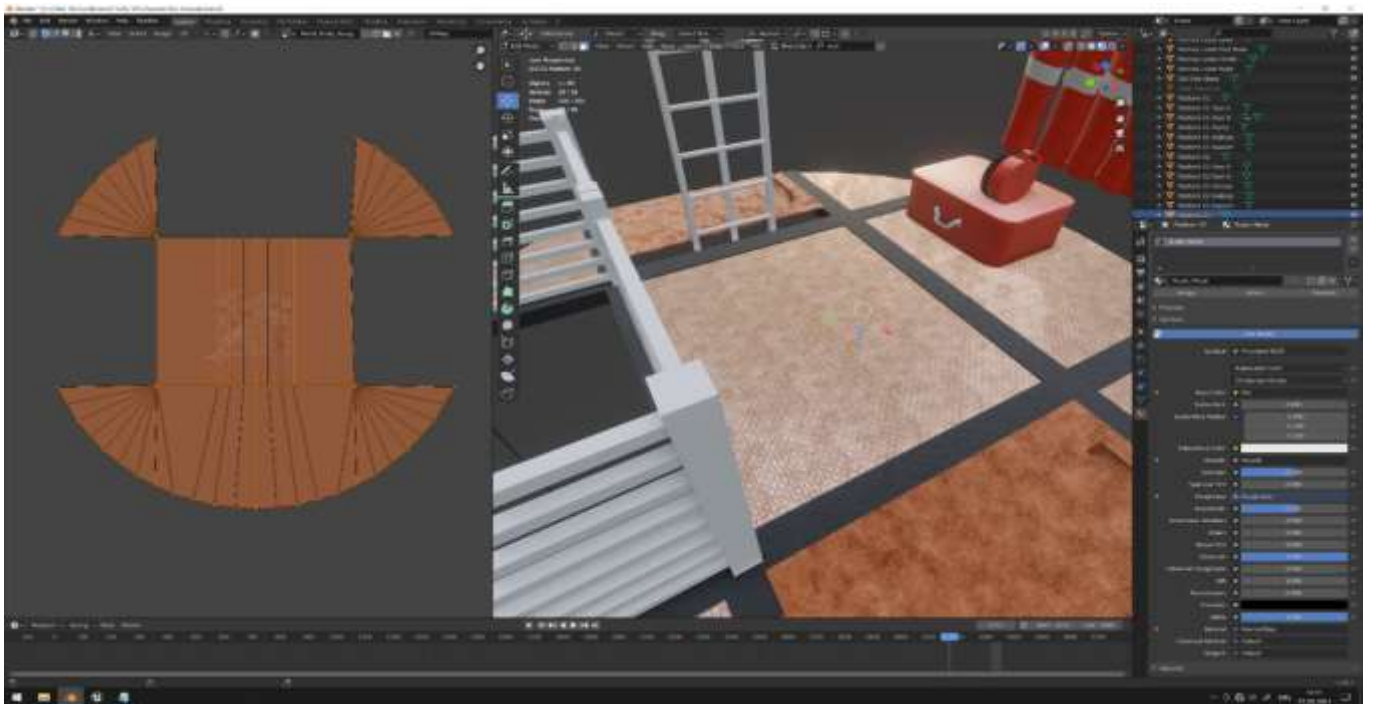


Figure 62: UV Mapping

To develop the safety animation which was presented for science meet industry webinar Stavanger, Norway (26th May 2021) and organized by Norwegian offshore wind cluster, the character which resembles a wind turbine technician was created using the Blender Software. The character development starts with collecting some scale drawing representing human in the internet and a sphere shape is sculpted into a human in Blender software. The left side Figure 63 represents the scale drawing and the right side shows the character development. The Figure 64 shows the character with safety props developed using same modelling techniques as described in the previous section (3D Modelling).

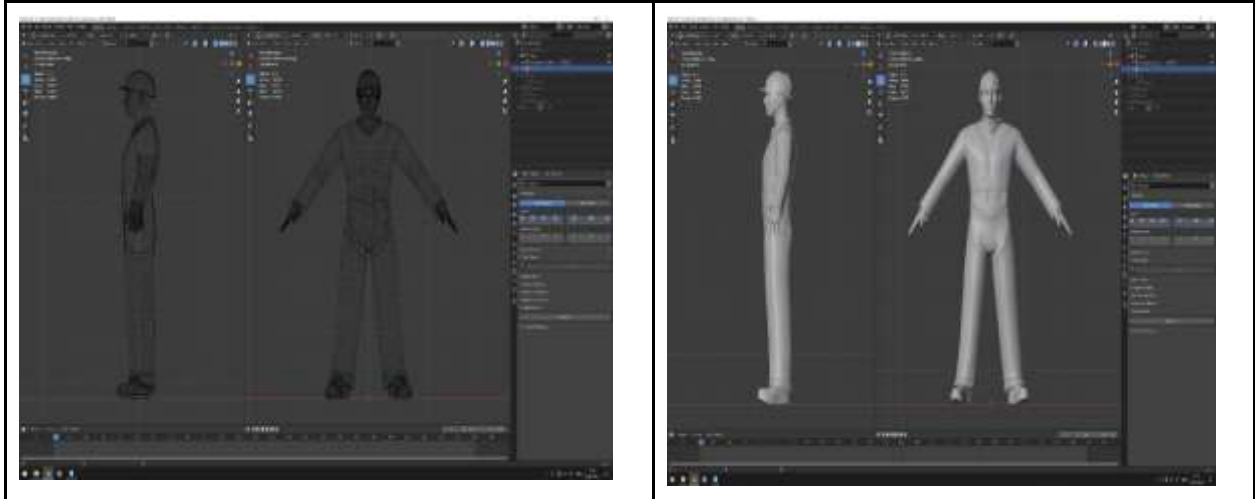


Figure 63:Character Modelling

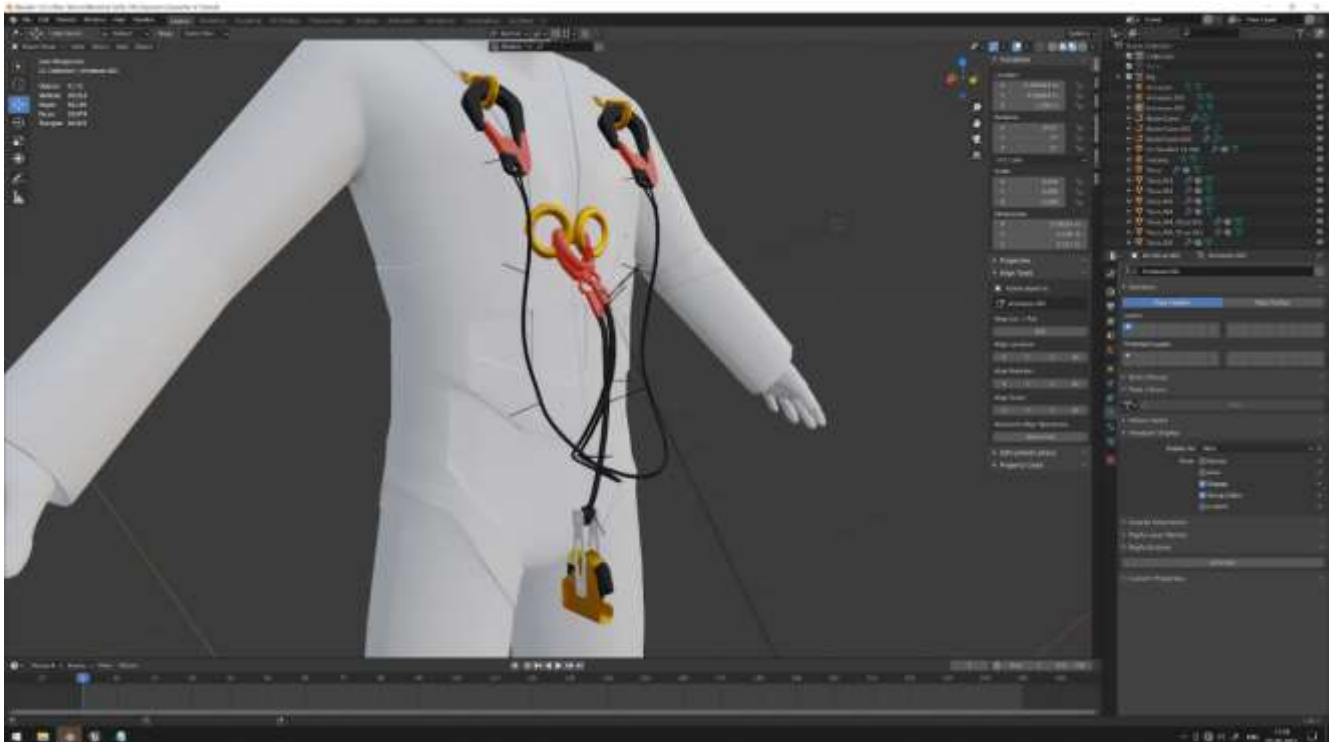


Figure 64:Character Safety Props Modelling

The face modelling must be done separately as it requires a lot of attention to details. It requires creating multiple materials nodes, texture node and UV mapping. Figure 65 shows the face modelling from a face sketch. Figure 66 shows the importance of UV mapping for face modelling, since without effective UV mapping, the finer details of the face like eyes, nose etc. are difficult to arrive. Figure 67 shows the character after texturing and giving the required color, material feel to the human character.

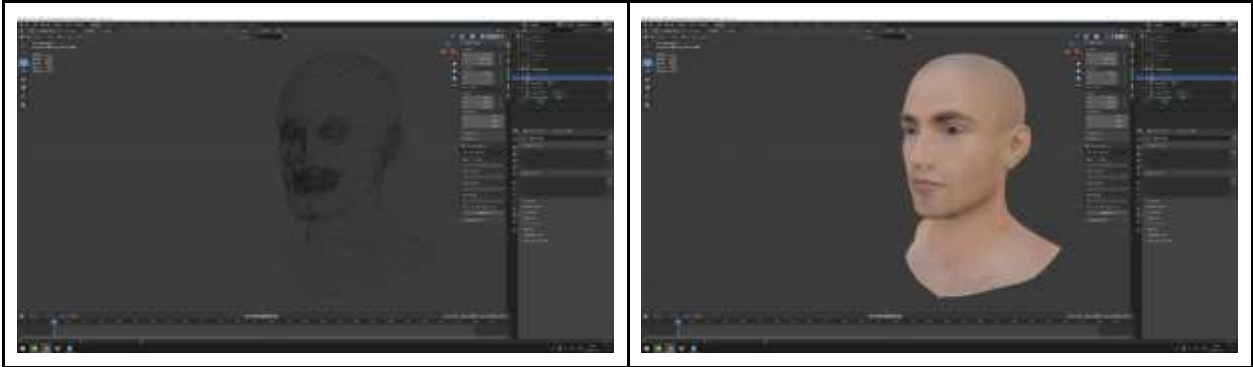


Figure 65:Character Face Modelling

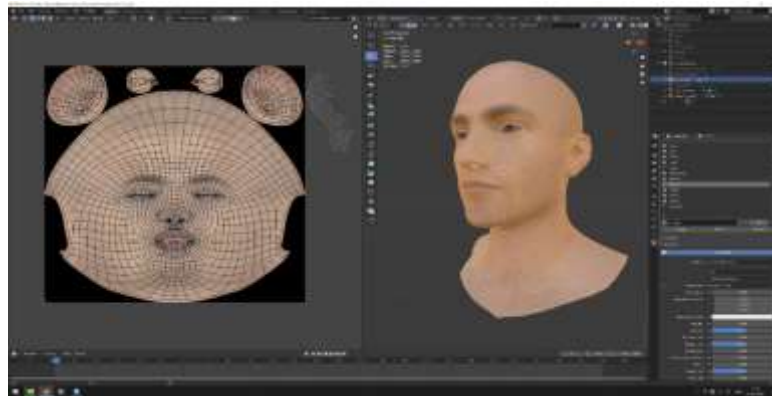


Figure 66:Character Face UV Mapping



Figure 67:Final Character after Texturing

The most important step that needed to be done in order to animate the character or to implement character movement in the game environment is called rigging. The process of setting up the bones for the character we have developed is called rigging. The Figure 68 shows the bones we have developed to enable the leg movement, hand movement, face movement and body movement. We can create animation of the character with those bones.

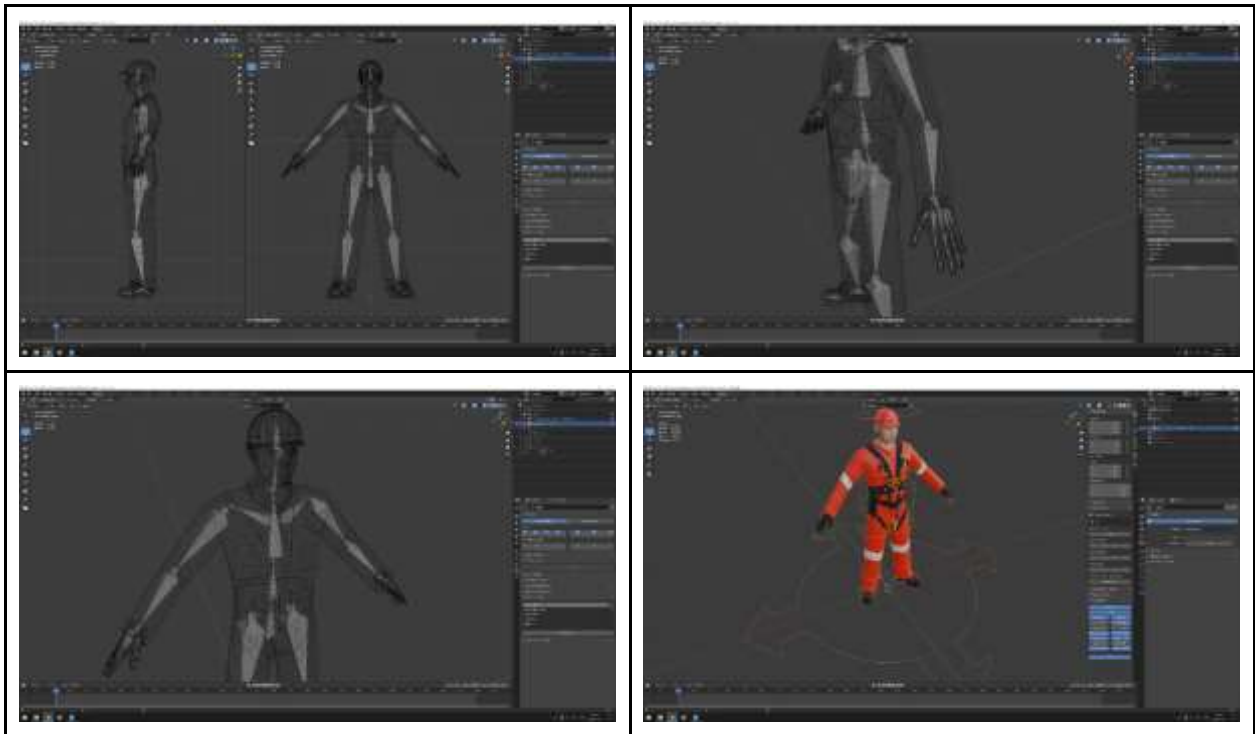


Figure 68: Rigging Character

The rigged character in Blender could be animated with certain type of controlling options as shown in Figure 69 like

- Moving – To move forward, backward and to the sides.
- Rotating- To turn around 360 degree.

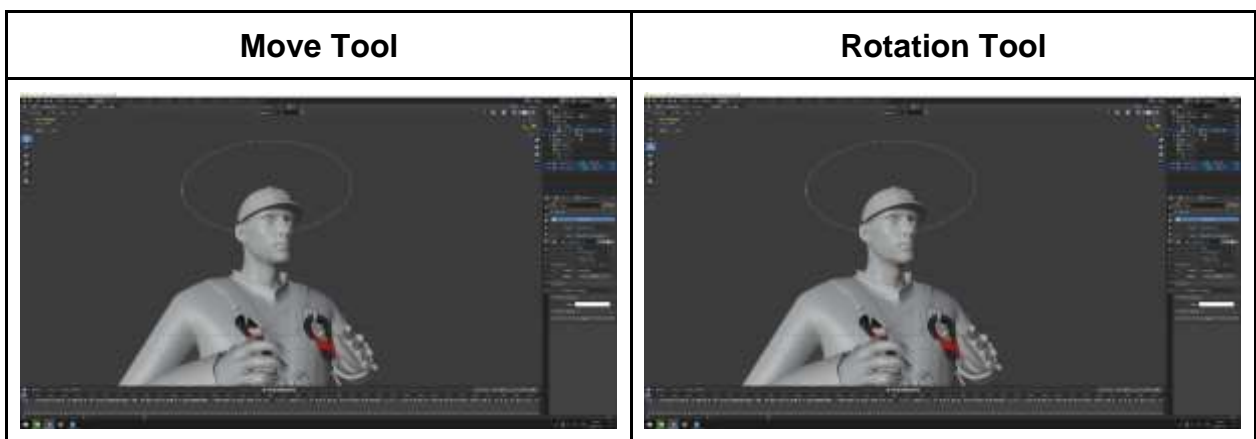


Figure 69: Controlling Movements

Before creating any animation in Blender, the body movements must be recorded real time as shown in left side of the Figure 70. The person climbs the ladder to demonstrate the safe way of climbing and the time required and style of climbing. This will help to match the timing that is required for every movement. In the same way face expressions are also recorded in real time first and then animated.

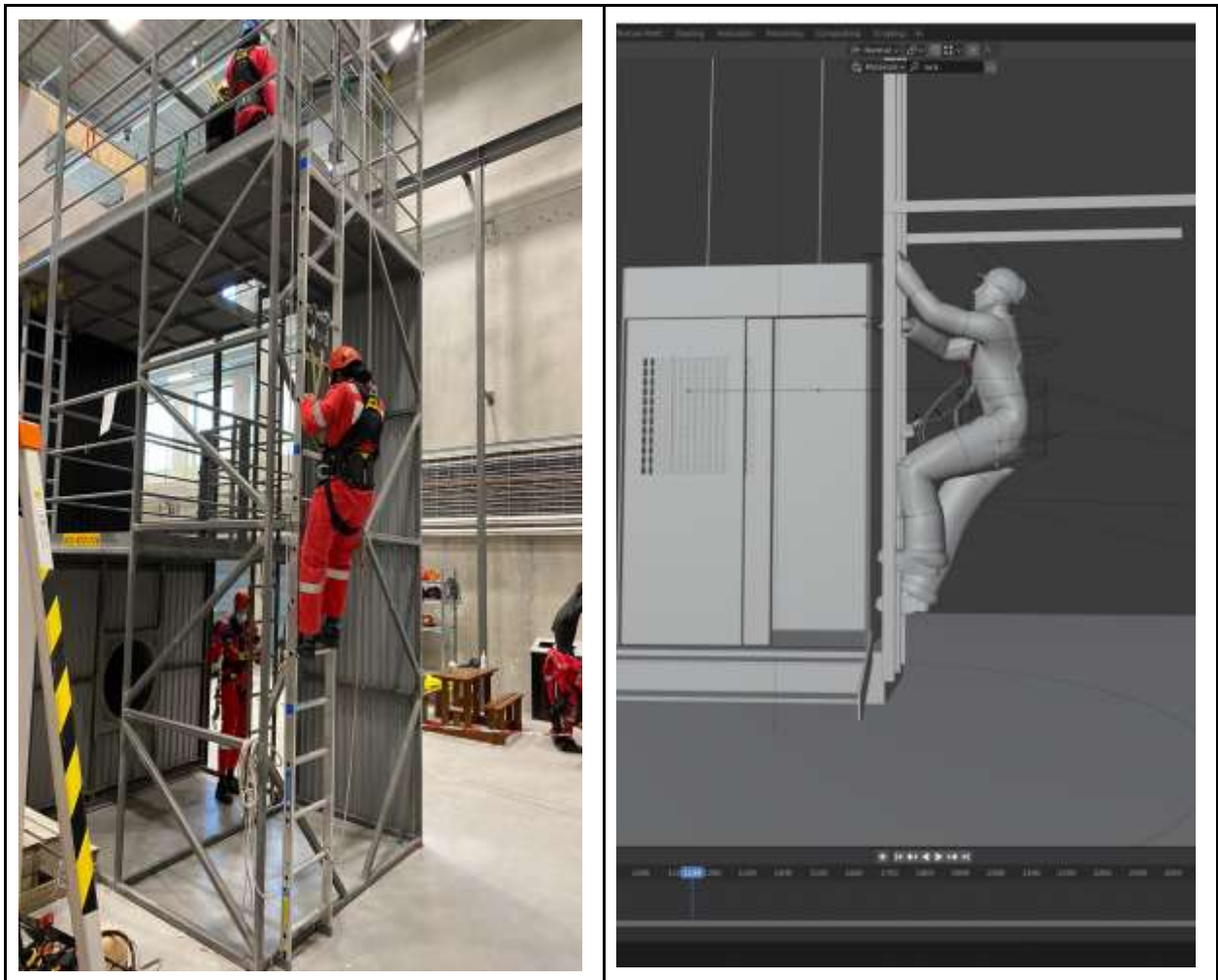


Figure 70: Animation Reference

The final step is to add lighting (Figure 71), the external environment (Figure 73) and camera angles (Figure 74) to the animation or the game environment. Lighting helps to improve the visibility of the scene as shown in the Figure 72. The numbers of lights added to the scene was highlighted in orange in Figure 71. The animation scene created has 21 shots meaning 21 different camera angles as highlighted in orange in Figure 74.



Figure 71: Lighting Locations

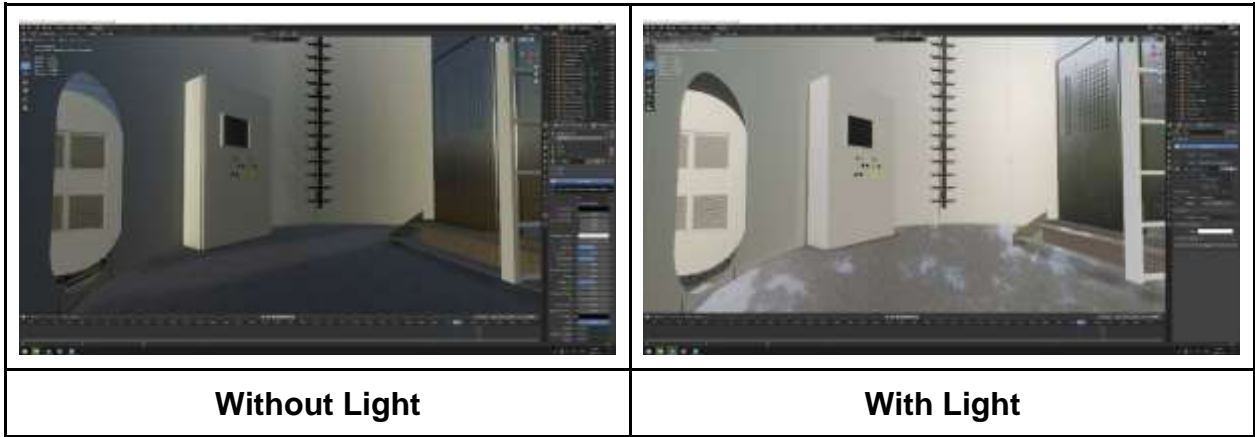


Figure 72:Lighting Effects

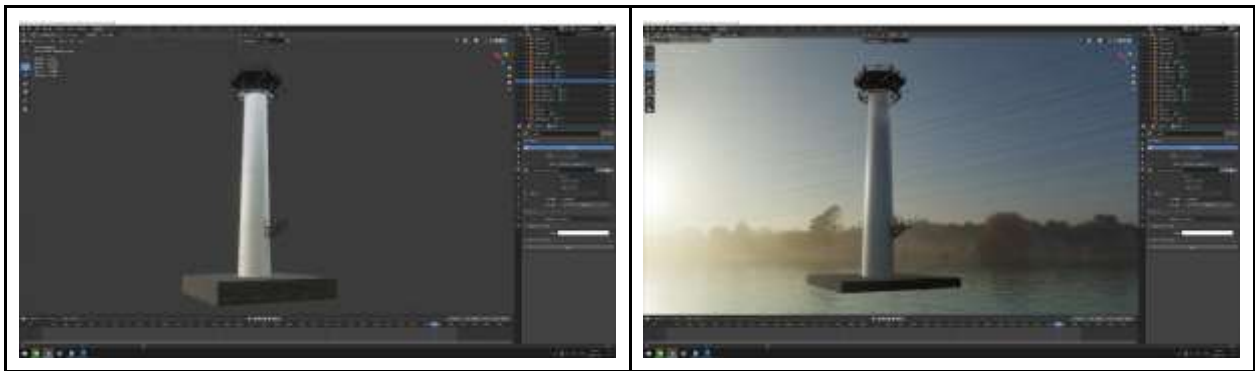


Figure 73:External Environment

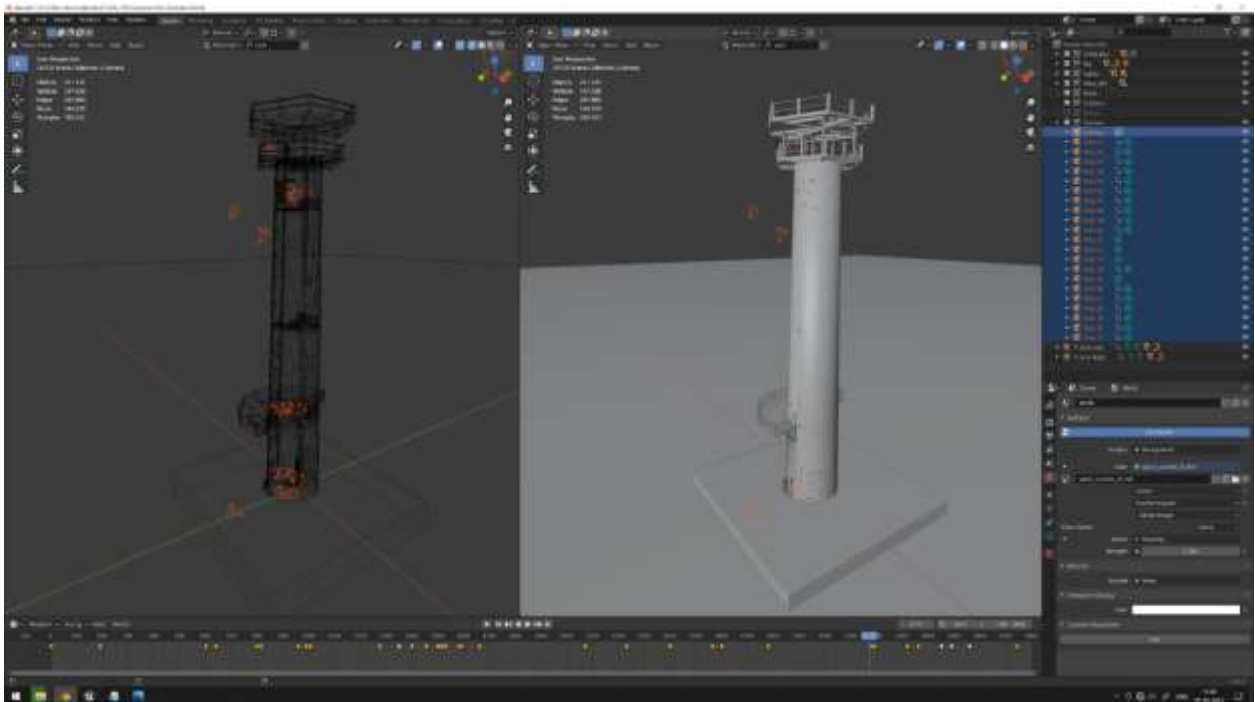


Figure 74:Camera Locations

Rendering is the final step in the animation and gives the required final appearance of the single image or an image sequence or in case of a video file. Each of the 21-camera shots needs to be rendered separately and then the final animation output needs to be trimmed using a video editing software. There are 24 frames per second in the animation video produced and upload in YouTube at <https://youtu.be/o5zzT9b630k>

Please accept the cookies request if asked by YouTube. This is a public video, I have not locked it, anyone can view it.

To create the game environment and to develop a desktop PC demo MR game we use the Unreal Software. The output from the Blender software (.FBX) after rigging the character and defining the controlling movements as shown in Figure 69 is imported into the Unreal Engine Software and then we can define the lighting conditions, external environment and camera locations as shown in the Figure 75.



Figure 75:Unreal Engine

The next step in game development is the most interesting step which involves writing:

- Custom C++ Scripts: To create the sequence of the game.
- Building nodes: To create animation in game or for material properties.
- Controls and commands: To create the character movements.
- Connecting Nodes (Groups): To achieve a sequence of motion, for example the node group to open the main door by pressing key 'F' is shown in Figure 76.

Here each node container is interlinked with specific actions, commands, and animations. In the same manner every action, command buttons, animations and activities are built and connected with hundreds of node groups.

The last stage is preview the game development every step in order to check the sequence as shown in Figure 77. Every progress and process have to be checked. No game, software or an app come's without an error or bug. A single symbol, letter, or a node error may cause the whole work to be crashed. Time and enough patience are key to find and solve it (Figure 78).

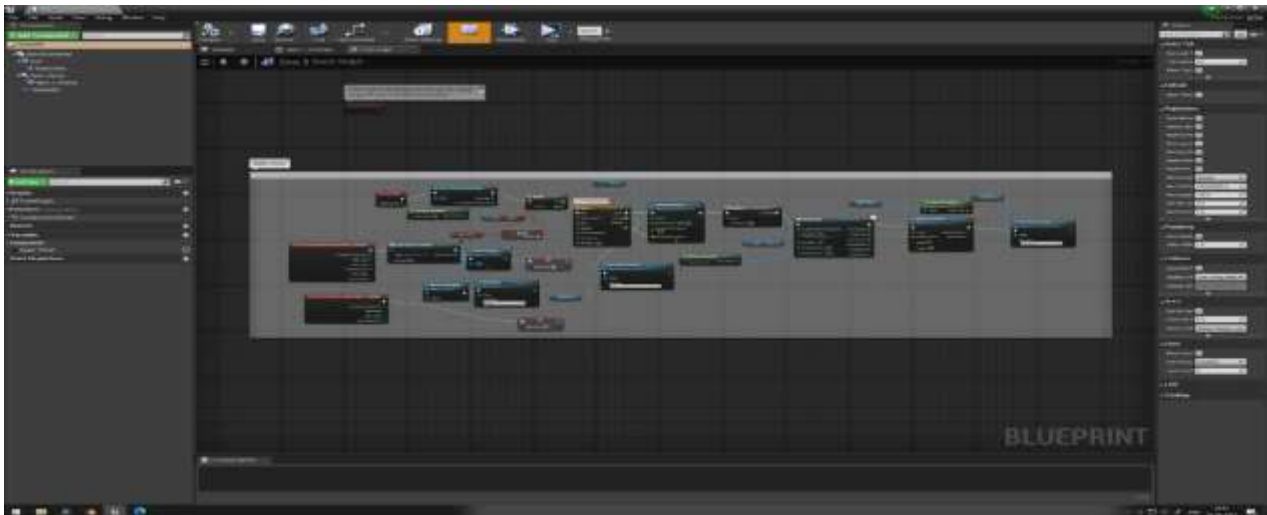


Figure 76:Unreal Node Groups



Figure 77:Preview Game Development



Figure 78:Game Bug Correction

The final desktop game is played and upload in YouTube at <https://youtu.be/6bEqzCGC93Q>
Please accept the cookies request if asked by YouTube. This is a public video, I have not locked it, anyone can view it.

To extract the game as .APK file to support it in android mobile device and configure with headgear is the final step in the computerize process. This process is mainly about creating the User Interface (UI). There can be different UI for the desktop PC game and if the same game is played in mobile device (may be more buttons). Android SDK is a third-party plug-in developer tool which was used to process the Unreal output for being android mobile compatible application in .apk format. The second task can be adding sound to bring a realistic feel, but this step is not in the scope of the thesis. The process to configure the headgear can be done even while creating the controls and commands nodes (Figure 76). In this case we have decided to use the oculus head gear and so the Oculus support developer tool kit provided in oculus website was used.

This process of having the android mobile application has a lot of challenges by its own to solve. For example, this developed demo app cannot be downloaded in the Google play store since this process requires the developed application to undergo various virus checks and quality checks determined by google. Finally, the service needs to be pay. Thus, it is not in scope of the thesis. The demo application that will be developed is planned to be used in the android mobile devices by people who trust this demo application. Also due to Covid-19 restrictions, multiple people cannot experience the oculus head gear.

5.5. Construct Flowchart, Worksheet, Workflow and Framework

The first step in construct stage involves in developing a conceptual flowchart as shown in

Figure 79 which will aid to classify training tasks into VR or AR or MR and aid to choose the required technical specifications like suitable, hardware, software, and tracking technique. This is a general flowchart which can be used to classify any training module and will also aid to select the type of technology which is applicable for a particular training task. It is ideal and useful to model some training tasks as augmented reality (AR) and some as virtual reality (VR) and for a few tasks a mixed reality (MR) technology will be helpful.

The flowchart starts with the actual physical image (wind tower) being converted into a 3D model using commercial software's like Blender and exported as a .FBX format into software's like Unreal where a game environment of the 3D model is created. The next step is to classify the training scenarios and further identify the training tasks each participant will be taking in real life scenario. These training tasks are the ones to be checked if the implementation of the mixed realities will help to develop its quality.

It is very important to define the training complexity (low/medium/high) using a risk-based approach for each of the training tasks. The classification as low/medium/high is done based on the consequence associated with each of the training steps. The consequences are decided after talking with industrial experts in the training field and with my personal experience from the 5-day GWO training. Further after classifying the training complexity, if the training step does not require any implementation of mixed realities it is classified as physical training and if the training step is classified as one which is essential to implement mixed reality, it will be further checked for which type of technology will be applicable.

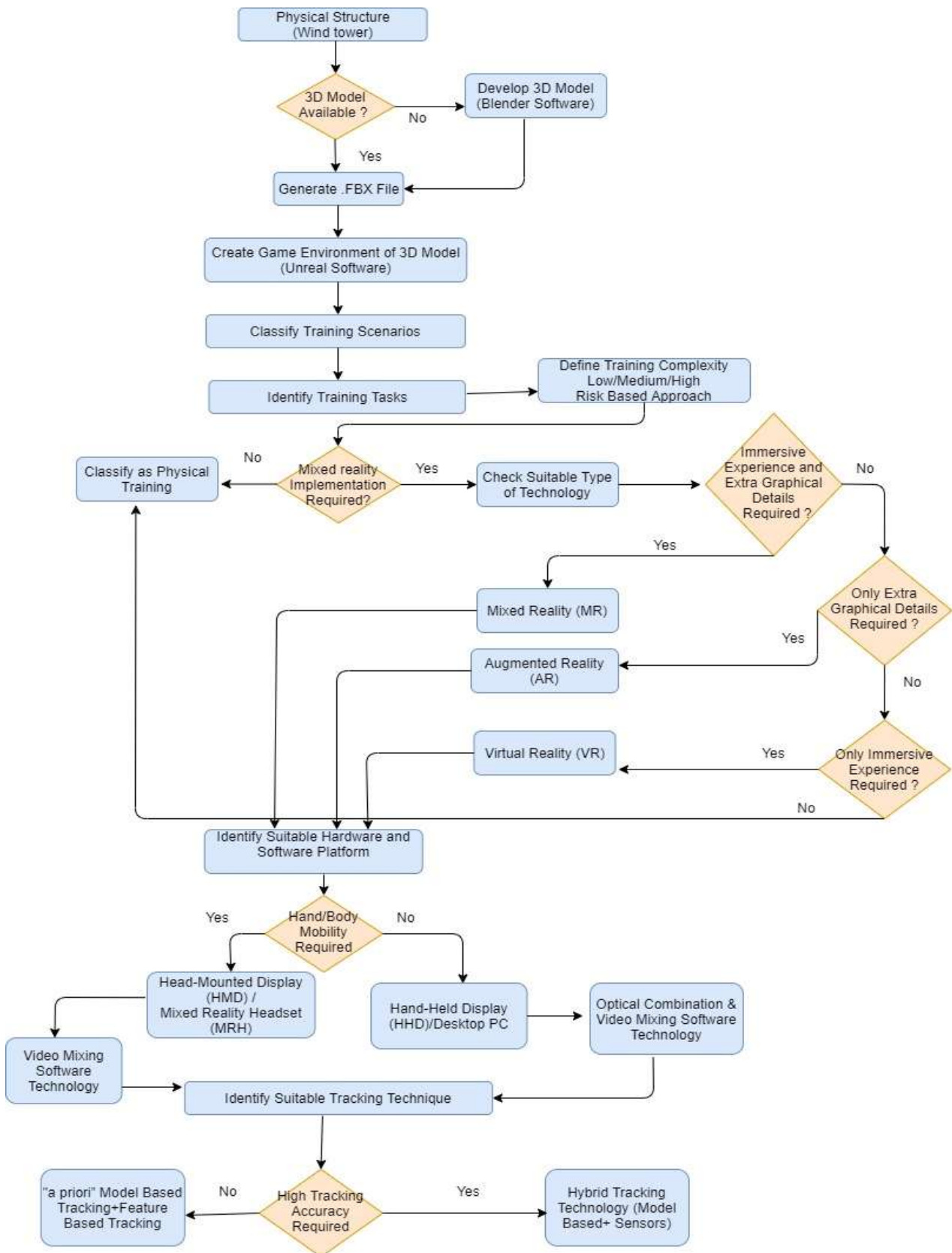


Figure 79: MRTS Flowchart

In case where the training step requires both an immersive experience which will help to improve the visualization of working conditions and also requires to be augmented with extra information or graphics in the persons view then mixed reality (MR) technology will be chosen. However, if only a simulated immersive experience that can be like working in a wind turbine is required then virtual reality (VR) technology will be chosen. Similarly, if only extra information or graphics in the persons view to help technicians to locate the tasks to perform in a maintenance sequence is required then augmented reality (AR) technology will be chosen.

The final part of the flowchart helps to choose the associated technical specification with the chosen technology. If the persons needs to move around and perform tasks using both his hands (hand/body mobility).For example, tasks like climbing the ladder, rescue a person, then head mounted display (HMD) or the mixed reality headset (MRH) is the most ideal one(Dini & Mura, 2015) and (Palmarini et al., 2018). However, if the tasks do not require much hand mobility or physical moving around like maybe performing a repair tasks in fixed position or to learn a task. For example, how to connect the self-locking slider to ladder railings or to identity certain tasks or procedures associated with safety then a handheld display (HHD) like tablet or cell phone or a desktop PC is sufficient (Dini & Mura, 2015) and (Palmarini et al., 2018).

Further, based on the choice of hardware platform the associated software platform also changes. When the head mounted display (HMD) is selected, the video mixing software technology is very ideal as it involves capturing digital information of the physical object by camera and develop 3D model using a computer, similar to the one which is planned for this thesis. However, for the handheld display (HHD) both video mixing software technology and the optical combination software technology can be used. Optical combination software technology is when virtual images are projected into the visual field of the user when he looks into real objects(Dini & Mura, 2015). Optical combination is very ideal for augmented reality (AR) situations.

Finally, after identifying the suitable hardware and the software platform, it is very important to find the suitable tracking solutions. The various types of tracking solution which are available are discussed in detail in chapter 3. It is first ideal to understand the difference between tracking and recognition. Tracking involves having a record of all the previous position and orientation of the object associated. However, recognition just involves in the present position and orientation, it does not care about previous position (Palmarini et al., 2018). When a high accuracy of tracking is not required like in the case of identifying the evacuation gear inside the wind turbine, this can be done with AR and a feature (by images) based tracking can be used. Model based tracking which involves CAD based tracking techniques can also be used for wide range of VR application and AR Applications. However when a high accuracy of tracking is required like in case of using mixed reality (MR) technology then hybrid tracking technology is used which is the combination of model base tracking and sensor (using GPS) based tracking(Palmarini et al., 2018).

The flowchart Figure 79 is named as Mixed Reality Technical Specification (MRTS) flowchart.

The second step in construct stage involves in developing the worksheet which can be used by Energy Innovation AS to identify the relevant type of technology (AR/VR/MR) and the suitable hardware platform, software platform and the relevant tracking technique for each of the training steps for which implementation of mixed reality is found needed from the (Table 19: Decision Critical Module Classification). The Table 19 is improved further by following the steps and the theory explained in the MRTS Flowchart (Figure 79) and develop a MRTS Worksheet as shown in the Table 20.

Table 20: MRTS Worksheet

Module Name	Scenario Safety Training	Training Tasks	Training Complexity	Mixed reality Implementation Required	Mixed reality Implementation Required	Suitable Hardware Platform	Suitable Software Platform	Suitable Tracking Technique
Working with Heights	Effective use of the safety gears		Risk Based Approach		Suitable Type of Technology: Refer MRTS Flowchart	(Dini & Mura, 2015)/Palmarini et al., 2018)	(Dini & Mura, 2015)	(Palmarini et al., 2018)
		Wear the harnesses properly	Low	No	Not Applicable (NA)	Not Applicable (NA)	Not Applicable (NA)	Not Applicable (NA)
		Effective use of fall arresters (Y-line)	Medium	Yes	Virtual Reality (VR)	Head-Mounted Display (HMD)	Video Mixing Techonlogy	"a priori" Feature Based Tracking
		Effective use of support belt	Medium	Yes	Virtual Reality (VR)	Head-Mounted Display (HMD)	Video Mixing Techonlogy	"a priori" Feature Based Tracking
		Proper placing of the self-locking slider on ladder railings	Medium	Yes	Augumented Relality (AR)	Hand-Held Display (HHD)/Desktop PC	Optical Combination	"a priori" Model Based Tracking
	Safe manner to climb turbine	Open and close the hatch door safely	Medium	Yes	Augumented Relality (AR)	Hand-Held Display (HHD)/Desktop PC	Optical Combination	"a priori" Model Based Tracking
		To connect the Y line to the anchor point (Yellow) with fall factor 0 or 1	Medium	Yes	Augumented Relality (AR)	Hand-Held Display (HHD)/Desktop PC	Video Mixing Techonlogy	"a priori" Model Based Tracking
		Locate the Anchor Point (Yellow)	Low	No	Not Applicable (NA)	Not Applicable (NA)	Not Applicable (NA)	Not Applicable (NA)
	Controlled descent to lower level	Effective use of the Milan to descent safely to lower height	High	Yes	Virtual Reality (VR)	Head-Mounted Display (HMD)	Video Mixing Techonlogy	"a priori" Model Based Tracking
		To connect the self-locking slider to perform the evacuation Jump safely	High	Yes	Mixed Relaity (MR)	Mixed Reality Headset(MRH)	Video Mixing Techonlogy	Hybrid Tracking Technology (Model Based+ Sensors)
		To identify the evacuation gear in case of emergency	Low	Yes	Augumented Relality (AR)	Hand-Held Display (HHD)/Desktop PC	Optical Combination	"a priori" Feature Based Tracking
	Basic rescue operation	To rescue a person from lower level to reach him upwards	High	Yes	Mixed Relaity (MR)	Mixed Reality Headset(MRH)	Video Mixing Techonlogy	Hybrid Tracking Technology (Model Based+ Sensors)
		To rescue a person from higher level to reach him downwards	High	Yes	Mixed Relaity (MR)	Mixed Reality Headset(MRH)	Video Mixing Techonlogy	Hybrid Tracking Technology (Model Based+ Sensors)
		To recognizie if rescued person has suffered a hanging trauma	Medium	No	Not Applicable (NA)	Not Applicable (NA)	Not Applicable (NA)	Not Applicable (NA)

This MRTS Worksheet is a very useful spreadsheet for Energy Innovation AS, as they can look the classification of a critical module along with the technical specifications in a single table.

The third step in construct stage involves in developing the workflow which can help to implement mixed reality into training activities of the wind sector. This Workflow is named as Mixed Reality Analysis (MRA) Workflow. The workflow is spread across five different stages and each stage is already mentioned in detail in section 5. The workflow chart (Figure 80) is a quick and self-explanatory visual representation that is presented to the managers of Energy Innovation AS.

The hexagon inside each stage represents the main tasks to be performed. The techniques to perform the tasks are also indicated by text boxes inside each of the stages.

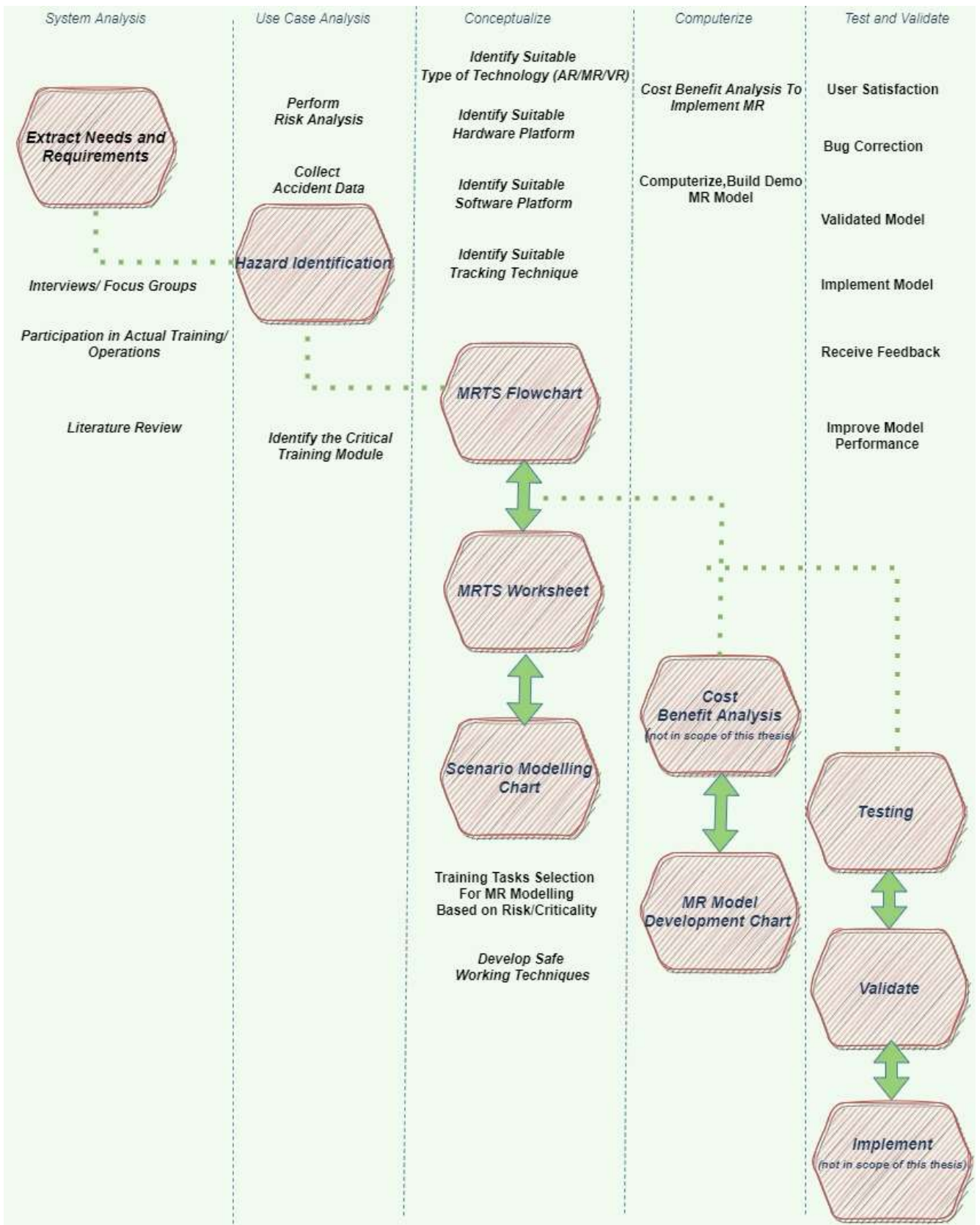


Figure 80: MRA Workflow

The steps that are needed to be followed to develop the MR model chart is indicated in the Figure 81. The main subtasks inside each step is also mentioned and the file format to transfer from each step is indicated.

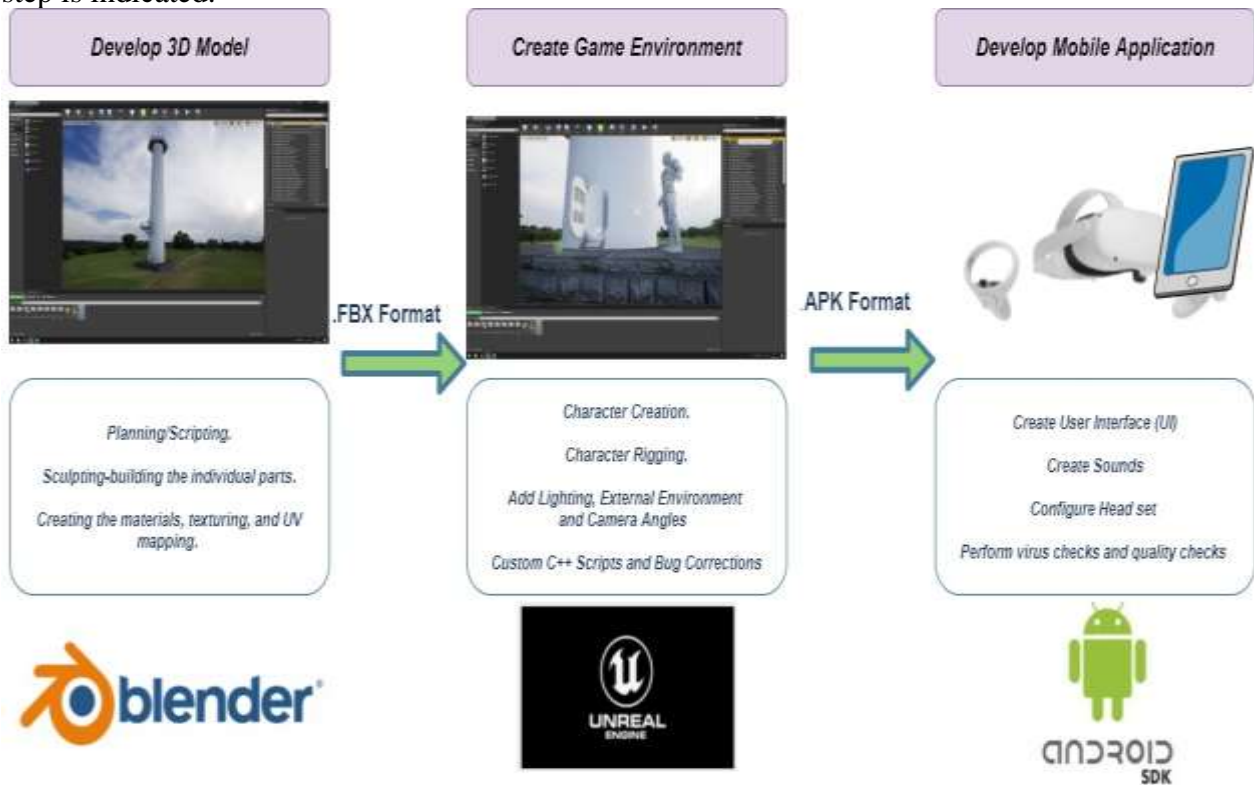


Figure 81:MR Model Development Chart

The limitations for the demo MR model developed for this thesis are the C++ scripts are not individualized for many actions in the game. Therefore, there is lot of movement mismatch in the game and bug corrections was time consuming and certain bugs was not rectified fully. The development of mobile application is not in the scope of the thesis as it involves third party virus and quality checks to be performed and it requires payment of money. There will not be any sounds in the game. However, I tried to create a user interface for the mobile application (unofficial personal use version) and to connect the oculus headgear to understand the challenges associated. I will mention some challenges in the discussion part.

The fourth step in construct stage involves in developing the Mixed Reality Analysis (MRA) framework as shown in Figure 82 which can help to implement mixed reality into training activities and also this framework can be little refined and can be used to implemented mixed reality for inspections, repair and maintenance in future. The framework starts with the need identification, for example, in the case of this thesis research, the need was to check if it's possible to implement mixed realities into the 5-day GWO training program. The needs are further tuned into relevant requirements after discussion and brainstorming with the team.

The next step is to conduct a risk analysis to identify the most critical module and the hazards associated (Table 18). The type of risk analysis performed depends on the industry and the level of detailed required, for example to find out the most critical module in training sector, a basic coarse risk analysis (Figure 45) was more than sufficient. Once the critical module is identified, the next step is to classify the critical module further into simple training steps (Table 19). This is essential because for each different training tasks, different type of technology may be relevant. For example, VR is very essential for the training steps where the user wants to have an

immersive experience, that is in case of performing the evacuation fire jump from the top of tower. This is an excellent scenario to implement VR because the user can play the game again and again and overcome the fear of heights. Other tasks could be very relevant with AR, for example to understand the safety steps before climbing the ladder. Or may be to look (graphics view) at the different type of safety gears inside the emergency evacuation kit. These examples are explained in detailed while playing the demo MR model created and also uploaded in YouTube at <https://youtu.be/6bEqzCGC93Q>

Please accept the cookies request if asked by YouTube. This is a public video, I have not locked it, anyone can view it.

After identifying the relevant type of technology for each of the training steps using the Figure 79:MRTS Flowchart, the next step is to find out the relevant hardware platforms such as the headgear, tablets, etc. associated with that technology. A detailed explanation about how to identify the right hardware platform for each type of technology is explained in detailed along with the MRTS flow chart (Figure 79). Similarly, the right software platform and the tracking technique are identified. The Table 20: MRTS Worksheet can be prepared now to present all the technical specifications in one sheet.

Scenario modelling (Figure 47: Scenario Modelling Chart)is the next step, it is the process of building a conceptual storyboard of what is required to be modeled using the computer. The safe and effective manner to perform the tasks are also identified in this step, so that the demo MR model will illustrate these safe practices. Cost benefit analysis is done to check if the implementation makes financial sense. Next the MR model is developed, for example by following the techniques mentioned in Figure 81. These two steps (cost benefit analysis and build MR model) are interlinked as the cost benefit analysis can be reworked if new challenges are identified while developing the demo MR model.

The developed MR model is first tested for bugs and virus and confirmed that it matches the quality requirement to be published online. Further it is validated by discussing with experts around the field and by comparing it with similar models if available. Finally, the mixed reality model is implemented and after being put to use, the feedbacks from the user must be collected to review if the MR model is achieving the objectives for which it was designed. It is essential to capture any new user requirements and again the needs are to be updated and the cycle can be repeated to further improve the model effectiveness.

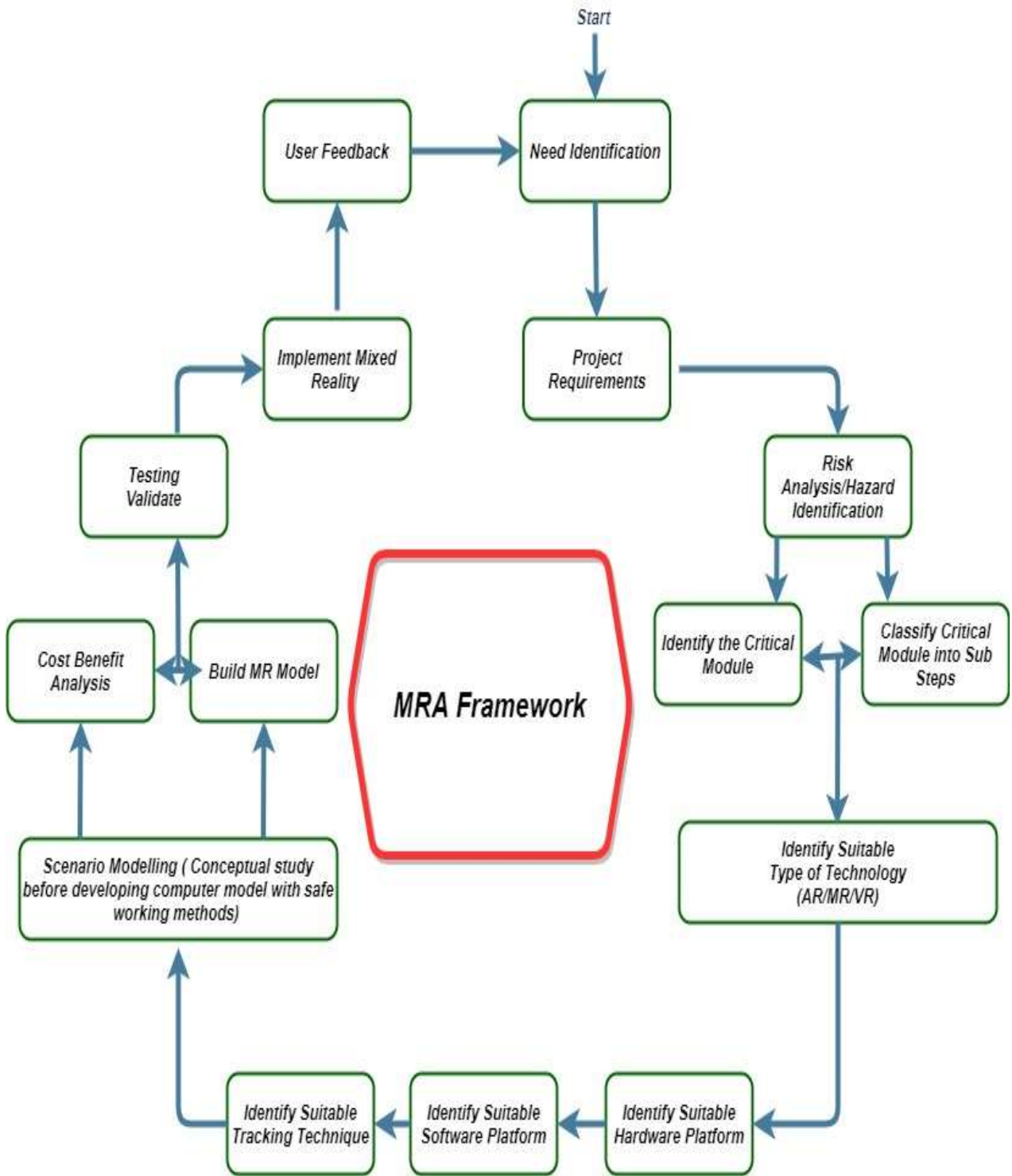


Figure 82: MRA Framework

5.6. Verify, Validate and Visualize

This section deals with verification and then validating the research outputs. The Table 10 in Chapter 2 indicated the planned approach to validated the research outputs and the Table 8 in Chapter 2 indicated some techniques that were planned to perform the verification and validation. The visualizations of the MRA workflow process is the demo MR model produced.

Verification is the process of checking if the developed worksheet or any process is right and model verification is to ensure that the developed computer model and its implementation are correct (Sargent, 2013). The verification measures taken for this case study is mentioned in Table 21.

Table 21: Research Outputs Verification Measures

Thesis Outputs	Verification Measures
MRTS Flowchart	The MRTS Flowchart is verified for its decision flow by using it to build the MRTS Worksheet. The MRTS Flowchart was checked and verified by the academic supervisor during thesis review meeting.
MRTS Worksheet	The MRTS Worksheet was double checked and verified for its contents and presentation by me. The MRTS Worksheet was checked once for its contents by project technical manager at Energy innovation AS.
MRA Workflow	The MRA Workflow was verified for its effectiveness as the same workflow was used to build the Demo MR Model. The MRA Workflow was checked and verified by the academic supervisor during thesis review meeting.
MRA Framework	The MRA Framework was double checked and verified for its contents and presentation by me. The MRA Framework was checked and verified by the academic supervisor during thesis review meeting.
The Demo MR model	The demo MR model is verified by for its effectiveness by correcting the software bugs and errors shown in Figure 78. The demo MR model PC game was sent to a few participants to play it and they verified it was bug free. The demo MR model was uploaded in Youtube and it was verified for its accuracy to represent the planned procedures by some comments received.

Validation is the process of getting the approval of the developed product and model validation is to establish by proof that the model has an acceptable range of consistency and accuracy (Sargent, 2013). The validation measures taken for this case study is mentioned in Table 22. Three different validity measures are planned to be taken for the research outputs, namely the face validity, concurrent validity and the convergent validity. The definitions about the validity measures are mentioned in the theory chapter.

Table 22: Research Outputs Face Validation Measures

Thesis Outputs	Face Validity
MRTS Flowchart	The validity of the MRTS Flowchart was confirmed by Magnus Østebrød, project technical Manager from Energy Innovation AS.(M. Østebrød, personal communication, 11 June 2021).
MRTS Worksheet	The validity of the MRTS worksheet was confirmed by Magnus Østebrød, project technical Manager from Energy Innovation AS.(M. Østebrød, personal communication, 11 June 2021).
MRA Workflow	The validity of the MRA Workflow was checked by developing a demo MR model and the steps provided in the MRA workflow helped in producing the demo MR model. The validity of the MRA Workflow was confirmed by Magnus Østebrød, project technical Manager from Energy Innovation AS.(M. Østebrød, personal communication, 11 June 2021).
MRA Framework	The validity of the MRA Framework was confirmed by Magnus Østebrød, project technical Manager from Energy Innovation AS.(M. Østebrød, personal communication, 11 June 2021).
The Demo MR model	The validity of the demo MR model was also checked by using peer debriefing technique, I wanted to check if the user felt convenient about the model. The model was Upload in Youtube and users were asked to validate, provide feedback of the model's relevance. The comments in uploaded MR model Youtube Videos are considered to be validation from both users and from Industrial experts. The validity of the demo MR model was confirmed by Magnus Østebrød, project technical Manager from Energy Innovation AS.(M. Østebrød, personal communication, 8 June 2021)

Table 23: Research Concurrent and Convergent Validation Measure

Thesis Outputs	Concurrent Validity Definition: This is to compare the model results with other results from any other similar model which is known to be valid.	Convergent Validity Definition: This is to compare the model results with other research methods and to check if they provide similar measurements of the concepts.
MRTS Flowchart		The MRTS Flowchart (Figure 79) can be validated by comparing it with the article (Sepasgozar, 2020). The article also speaks about developing a flowchart for mixed reality modules for online education.
MRTS Worksheet	The MRTS worksheet (Table 20) can also be validated comparing with the risk identification table from a validated and published article (Gupta & Varghese, 2020). Both the worksheets emphasize the importance	The MRTS worksheet (Table 20) can also be validated with a published article (Buttussi & Chittaro, 2018) which has a similar table describing the effects of different hardware platforms displays. The main idea is the

	of classify the scenario into simple training steps.	classification into simple steps and choosing the relevant technology for each step.
MRA Workflow	<p>The computerize stage of the MRA Workflow (Figure 80) is similar to a validated and published article (Gupta & Varghese, 2020). The chart from the article is mentioned in Figure 43 and the MR model development chart (Figure 81) can be validated from it.</p> <p>The development of the MRA Workflow (Figure 80) can also be validated with the Proposed virtual reality-based accident causation mode from the article (Dhalmahapatra et al., 2020). Both captures the workflow for safety training and VR modelling.</p>	The development of the MRA Workflow (Figure 80) clearly shows the stages that needs to be followed. This matches with the DfHFinI4.0 framework from the article (Suarez-Fernandez de Miranda et al., 2020). Both capture the entire lifecycle analysis.
MRA Framework	The MRA framework (Figure 82) can also be validated comparing with the DMAS framework (Figure 42) from a validated and published article (Gupta & Varghese, 2020). Both the framework emphasis the importance of performing a risk assessment and then creating a demo computer model and validating it.	The MRA framework (Figure 82) can also be validated comparing with the design and implementation flowchart of immersive VR-SG from the validated and published article (Checa & Bustillo, 2020).Both the framework emphasis the importance of capturing the user needs at the start of any MR development and to receive the user feedback in the end to improve the MR Model performance.
The Demo MR model	The demo MR model can be validated for its effectiveness of application to safety training by comparing it with the similar artic safety training model developed in the article (Druzhinia et al., 2019).	The scenario modelling chart (Figure 47) can be validated comparing with the article (Jeelani et al., 2020) which also tries to build such similar scenario modelling techniques before starting to actually computerize the model.

6. Discussion

Chapter Outline:

The chapter starts with recalling the research objectives and mentioning the steps taken to achieve these objectives. First the systematic literature review (SLR) and GWO training experience is discussed in detail, mentioning the key outcomes, implications, limitations, and some future recommendations. Second the discussion chapter contains the relevant discussions of each of the analysis steps, which is the six-step methodology developed for this case study.

The research objectives of the thesis case study are:

1. To develop a worksheet to identify the critical training modules/scenarios and further classify them to check if implementation of mixed realities is needed or not?
2. To develop a workflow which will help to implement mixed reality technology into training activities of the wind sector.
3. To develop a flowchart which will help to recognize the technical specifications like the suitable hardware platform, suitable software platform and relevant tracking technique.
4. To develop a framework which will capture the method to implement mixed reality technology.
5. To design and create a demo MR model based on the workflow developed in order to validate the workflow and understand the associated practical challenges like complexity of such mixed reality technologies and user familiarity.

In order to achieve these objectives, a six-step methodology was applied which includes: (1) system analysis, (2) use case analysis, (3) conceptualize, (4) computerize, (5) construct and (6) verify, validate and visualize. The case study started with system analysis which mainly deals with extracting the industrial needs and requirements. The system analysis includes two sub steps. First, is to perform a detailed systematic literature review (SLR) to understand the state of art in VR/AR/MR in the wind industry and other relevant industry. Second, an empirical exploration were the author attended a 5day GWO wind safety training at the Eigersund energy hub to personally experience and understand the training scenarios which will be crucial and beneficial to have a mixed reality application from both technician and company perspective.

6.1. Discussion: Systematic Literature Review (SLR)

Key Outcomes:

The key finding from the systematic literature review (SLR) was that the article by (Palmarini et al., 2018) showed the application and implementing of AR/VR/MR in maintenance scenarios. The authors observed that AR/VR/MR are used the least in the training sector. The authors argued that it can be justified as the aim of using AR/VR/MR in maintenance is to reduce the need for training and improve the maintenance operation in real time

However, I feel and argue when the quality of training is improved by the effective use of mixed reality application, it will have a positive effect while going for real maintenance operations later. Energy Innovation AS <https://www.energyinnovation.no/home> (case company) also believes and thinks in this same way, since they already are seeing good results by implementing AR/VR for first aid and advanced rescue safety operation (offshore) with companies like Bouvet <https://www.bouvet.no/> and SAFER <https://www.safer.net/>.

The SLR also helped to identify the certain research gaps such as lack of clarity on how to effectively design such mixed reality technology in training sector (Palmarini et al., 2018). Lack of clarity in the most suitable hardware platform (like headgear or handheld device), software platform (video mixing technology or optical combination) and the suitable tracking technique (model-based tracking or sensor based tracking) are identified by (Dini & Mura, 2015) and (Renganayagalu et al., 2021).

The article (Renganayagalu et al., 2021) speaks on level of user familiarity to such technology as important challenge.

Result Interpretation:

From the SLR, it was very evident that none of the literature has specifically focused upon implementing the mixed realities for safety trainings in the wind sector. There also exists a lot of ambiguity related to the technical specifications in implementing mixed realities technologies like AR/VR and MR.

Related to the complexity associated with such technologies. In my opinion AR/VR must be designed to make work simpler and error free. However, in some cases if using the technology itself is creating some complexity than the actual work. Then the technology must not be used in such cases. Otherwise proper training related to the use of such technology must be given and the user must be made familiar first before the actual implementation.

Implications:

The implications from SLR is that it gave us an opportunity to explore this research gap and an opportunity to develop the workflow or a framework which will help in implementing mixed reality in the safety training of the wind industry.

There is also a need to identify which is the most suitable hardware platform, software platform and the suitable tracking technique for implementing mixed reality applications in safety training of the wind sector?

Limitations:

One important limitation with the SLR is that although the study covered the published literature in the area. However there can be some workflow or framework that big wind industry companies like Vestas <https://www.vestas.com/> can be using for their internal purposes. Frank Emil Moen, Energy Innovation AS Managing director was also indicating such a possibility during the interview with him.

Recommendation:

In the future, if possible, during any conference or webinar with managers of big service companies in the wind sector, such a workflow or framework can be discussed to get more insights into industrial practices.

6.2. Discussion: 5 Day GWO Training:

Key Outcomes:

The 5 Day GWO training program which I took to personally experience and understand the training scenarios which will be both crucial and cost beneficial to have a mixed reality application from both technician and company perspective was very exciting experience.

I personally appreciate the need for safety after attending the training. I started appreciating importance of simple safe practices like making sure the slings of the harnesses are tightly secured. I was shocked when I heard that one technician when working in the top of the nacelle near the generator was pulled into the generator as the sling was hanging loose out from the harnesses. The training instructed that two technicians must always enter the wind turbine, and each must check themselves for their safety gears and must check his partners safety gears.

The fall arresters (Y-line) is a very important safety gear. I attended the course as beginner level. So, I was instructed to use the fall arresters (Y-line) along with self-locking slider on flexible guide (Hazap) every time I climb the steps of the ladder. Refer (Figure 31) to see the safety gears. Experienced technicians can climb the ladder only using the hazap or the self-locking slider on flexible guide. One interesting observation that was made in the presentation of the training was that at lower altitudes, there is a tendency to take safety more lightly. 15-20% of fatal accidents of working at heights are fall from lower heights of 3-7 meters (Bentsen, 2021). This is where the negligence of not using the safety ropes kicks in, but in the end turns out to be most dangerous. The standard recommends that there must be railings or other protective measures whenever the height is greater than 2 m.

The importance of simple safety practices like closing the hatch of the doors after climbing each platform level inside the wind turbine was well illustrated in the training. It was said that forgetting such simple tasks led to the technician fall to lower. But in case the hatch door was closed, the fall could have been less. The participants of the course are always requested to have the fall arresters connected with a fall factor of 0 or 1, this is explained in the theory part. Further all the participants was asked to connect the Y-line to the yellow anchor after reaching every level of the platform and while at the top of the wind turbine for safety purposes Refer Figure 34.

The initial steps of training were interesting and was easy to follow. The training become tougher when the basis rescue techniques was taken. There are two ways to rescue a person, either you start from a level lower or start from a level higher than the injured person. There a lot of steps that you need to remember and do it in the exact same way to rescue a person. These steps are the best practices and will save time and will also make sure that you are not hurting more the person who needs to be rescued. I learned that there is a practical way you need to secure the injured person with you. So that his body will travel along with you. The training was done with a demo doll, however in the real situation, there is a chance, if the injured person is also bleeding and if she/he is unconscious. Then as a rescuer you need to have the mental strength and the quick decision-making abilities under pressure situations to handle this situation in a clam manner. Hanging trauma which is the stress experienced by the person who is hanging for a long period of time needs to be considered in the rescue operations. A person hanging in a harness can becomes helpless, unconscious and in the worst consequence he can die from the injuries. The patient may enter an unconscious state even before 10 minutes have elapsed (Bentsen, 2021).

The module also provided the needed knowledge of how to secure safely oneself against falls to a lower level and quick evacuation techniques in case of fire (Figure 32). I learned how to effectively use the Milan and descend downward safely. For the evacuation jump in case of fire emergencies. I learned that there will always be an evacuation gear at the top platform of the wind turbine. Until that point the lift inside the wind turbine goes. The evacuation gear is kept to help in case of fire emergencies. During fire situation technicians are required to risk assess the situation and decide whether it is safe to climb down the stairs or is it better to perform the evacuation jump from outside part of the tower. In case the smoke is filling fast inside the tower, it's very risky to climb down the tower since the smoke might affect the visibility. The training also taught me the safety steps to ensure like connecting the Hazap before doing the evacuation jump.

Implications:

The important implication of attending the 5-day GWO training personally are it helped:

- To classify which safety training scenarios (example, safety while working at heights) are essential to be modelled as AR/VR as it is not imperative to have all the training scenarios modelled as a mixed reality application.

- The need to have a demo MR model to check the possibility of user familiarity.
- To understand the training needs and requirements of the wind sector.
- The need for risk assessment of all working at height scenarios be it 5 meters or 100 meters and the person working at heights must be aware of the accident and health hazards that may be associated with the work.
- To understand the consequences associated with each of the training steps, this helped in interpreting the risk matrix (Figure 46).

The training gave me the idea to develop the MR model scenarios like to use VR to aid in climbing the turbine ladder safely and performing evacuation jump in case of fire emergencies. The fire emergency jump requires a lot of courage, so with VR app the participants can practice such jumps, so they will be emotionally fit in case of the actual situation.

It was told in the training, that technicians with around 15 years of experience have not done such jumps even once in real time, since such fire accidents are really rare to happen. But when happen its very fatal. That's why having a VR can help to make the user well prepared to handle the situations.

It's good to have an AR application to aid in locating the safety hook and to locate the first aid kits and emergency evacuation gears inside the WT. Complacency to such simple tasks often leads to injuries and deaths. Therefore, having a MR model will enforce this safety idea again and again, so it gets fixed in the minds of the workers.

Recommendation:

I strongly recommend any developer of mixed realities for training situations across different industry to experience the training physically before designing the MR model.

These words must be strongly remembered that technology is to supplement training at a training center not as a substitution.

6.3. Discussion: Systems Analysis

Key Outcomes:

The system analysis mainly deals with extracting the industrial needs and requirements. The results from the interviews with five managers from Energy Innovation AS, Espeland Energie AS and SAFER helped to capture the wind industry safety needs and requirements.

The managers spoke about the enormous growth the wind industry will achieve in the next decade. They agreed with the Figure 1, Figure 2 and Figure 3 of this thesis. They also stressed that this enormous growth would create the need and demand for qualified workforce.

The major need of the safety training in wind sector is that to make the workers understand the risks and challenges associated with the wind industry, to make the workers understand the relevant standards and safety procedures associated with working at heights and with high voltages and in challenging offshore environment.

Another major need is to emphasize the workers that unsafe human practices might lead to serious injuries or deaths. At present the industry is showing video documentaries in the training to

emphasis this fact. They feel if the demo MR model helps to achieve this need, it will be a useful tool for the industry.

Some interesting observation from the interviews with five managers are explained in detail at section 5.1. All the managers agreed with the need to develop an innovative solution like MR for the training sector (Figure 38).

One important purpose of this case study is to develop a demo MR model, so the managers of Energy Innovation AS decided not to do a cost benefit analysis for this situation. However, Energy innovation AS was very interested to classify the training modules and develop a worksheet for this purpose. The need to understand the technical specification like the suitable hardware, software and tracking technique. associated with AR/VR/MR was strongly present.

The Industrial needs are very clear, that they wanted some practical solution, which was evident from the fact that there was a mixed opinion to the need of developing a framework and workflow. However, some managers suggest the strong need for that.

Energy innovation AS was also happy and open to the idea of publishing this case study as an article.

Result Interpretation:

I agreed with the managers of Energy Innovation AS regarding the exclusion of cost benefit analysis for this case study. However, I felt that in the future, when Energy innovation AS realizes the potential for implementing MR for the entire training modules (all crucial scenario's), then surely a cost benefit analysis must be carried out. Therefore, the importance of carrying out a cost benefit analysis will be emphasized in the workflow and framework developed.

I strongly stand for the need to develop a workflow and framework. The reason is that it is very essential to document the steps that will clearly illustrate the method to implement mixed reality into safety training of the wind sector. Thus, in future, the industry can use the same framework to implement such technology into maintenance, operations and inspections.

I agree with the lack of clarity around the technical specification associated with AR/MR/VR. In my opinion, the worksheet and the flowchart are very important tool, since it will classify the scenarios and helps the industry to decide if AR/MR/VR is needed or not. It is very important to remember that not all the training tasks requires the implementation of such technology.

Implications:

The results of the interview are very useful to recognize the industrial needs and requirements. Some of the suggestions from the managers gave some practical application of AR/VR. Like from Magnus, he feels that augmented reality (AR) this can be used for remote training and Inspection activities. For example, in case of Inspection, he feels that AR glasses in future might run real-time AI detection programs to help the inspector finding flaws and might even combine different methods of nondestructive testing. Odin feels that implementing a system for VR support from a blade repair expert to a blade repair technician to create a dynamic support system for on-field operations.

6.4. Discussion: Use Case Analysis

Key Outcomes:

The use case analysis deals with the creation of the case context which includes selecting the critical training module based on accident data from literature review and to identify one similar framework in other engineering industry.

The first major outcome from the use case analysis is that it suggested that working from heights is the most critical training module within the GWO training module based on the accident data from (Asian et al., 2017) and from Figure 41: WT Accident Data (Wind Turbine Accidents Data, 2021).

The second major outcome from the use case analysis is that the Decision Making Accident Scenario (DMAS) is a framework used in the construction industry which uses an android VR application which enables the users to improve their risk identifications and to decide on suitable mitigation techniques based on different accident scenarios (Gupta & Varghese, 2020) is found inspiring for this case study.

Result Interpretation:

The human negligence and unsafe practices are the most common reasons for accidents in the industry. This became clear to me after attending the training program myself and listening to experienced technicians. Energy Innovation AS also agreed with the selection of the working with heights as the most critical module.

The DMAS is an inspiring framework and its very relevant to our study as it helps to clearly demonstrate the steps to develop a VR model (Figure 43). I strongly agree with the fact that risk assessment of the accident scenarios is the first step which is the same also the DMAS framework follows.

I liked the idea of how the VR model of the DMAS framework was created. They used a simple mobile application as the hardware component in order to achieve low cost and reach a lot of people. They allow the user to himself as an avatar. and he is then presented with an accident scenario. The user needs to identify the identify the risks associated with the scenario and then need to select the correct precaution that he needs to take to mitigate the risk. After making the final decision regarding the accident scenario, the user can test virtually if his precautions are correct. The avatar might end up in an accident if the precautions selected by the users are wrong. This will help to increase the awareness of the users and the impact of selecting a wrong precaution in real life scenario (Gupta & Varghese, 2020).

Quality and Validity:

The article (Asian et al., 2017) provides some useful insights regarding the WT accidents, some of the relevant ones for this thesis are:

- The main accident cause in maintenance stage is human.
- The deaths are mainly reported in the construction and maintenance stages.
- The human cause lead accident is highest also in transportation stage and the authors recommend the use of some virtual reality simulations to reduce human error.

This helps to confirm that Energy Innovation AS and my personal perception of selecting working with heights as critical module where humans' actions are mostly involved is justified.

Additionally, the idea to develop a demo MR model to improve safety practices is also being validated by the author of the above article.

Implications:

1. The DMAS framework emphasized the need to further classify the chosen critical module.
2. The DMAS framework emphasized the importance of risk identifications and to decide on suitable mitigation techniques
3. The DMAS framework emphasized the need to develop the steps of the scenario for MR modelling
4. The DMAS framework emphasized the importance of deciding the potential technical specifications and to identify the steps of 3D modeling, MR modelling and the game output capture.

These implications helped me to decide and confirm on the need to develop the critical module classification chart (Figure 44) and to develop the scenario modelling chart (Figure 47).

Limitations:

One limitation is that the DMAS framework does not indicate that this development of the VR application is an iterative process. However, I respect the view of the author and DMAS framework is relevant for the construction industry. I personally believe that the development of this MR/VR/AR is an iterative process. I have mentioned in this point in the MRA framework.

The DMAS model does not focus too much on the immersive experience, but still categorizes itself into the virtual reality (VR) domain. I agree that the model can be upgraded to give an immersive feel to the user. However, that will update the hardware component to a headgear from mobile device and will increase the associated cost. This change of the hardware component will also create a need to change the associated software platform and the tracking technique.

6.5. Discussion: Conceptualize

Key Outcomes:

The first outcome of the conceptualize stage is the decision critical module classification (Table 19). This table helps to classify the training scenarios into simple training steps and then classify the complexity of each training step as low/medium/high based on the risk matrix (Figure 46). This classification will also help to check if the mixed reality is required to be implemented for each of the training step or not.

The second outcome is the scenario modelling chart (Figure 47) which helps to select the training tasks which are about to be modelled in the computer.

Result Interpretation:

The safety training scenarios and the training tasks classification for the critical module working with heights in the Table 19 are very subjective approach for this case study. It is based on my personal perception and the notes I took during the 5-day GWO training. However, I have got the MRTS worksheet validated with Energy Innovation AS managers. The important observation I wish to make is the steps are important and is valid. For example, if in future Energy innovation AS plans to classify other modules. A team can agree on the safety training scenario and individual training task.

Another important part of the Table 19 is that of risk analysis of the steps. I have used coarse risk analysis as the approach. This is a very basic risk analysis approach, but highly effective. However, any risk analysis method can be used based upon the industry and the subject area concerned. The important point I want to make is to emphasize the importance of doing the risk

analysis. The classification as low/medium/high is done based on the consequence associated with each of the training steps. The consequences and the likelihood and the impact rating which are used in the risk matrix shown in (Figure 46) are decided after talking with industrial experts in the training field and with my personal experience from the 5-day GWO training.

The decision to implement mixed reality for a particular task in Table 19 depends on

- If the risk is identified as high, then go for implementation of mixed reality.
- If the risk is identified as medium, then go for implementation of mixed reality provided it is related to working with heights.
- If the risk is identified as low, then go for implementation of mixed reality only if happens in an emergency situation.

Again, these guidelines are only for this thesis, however similar such guidelines can be developed for other purposes in the future. However, the procedure remains the same. The guidelines are from personal perception and discussion with managers of Energy Innovation AS.

The second outcome which is the scenario modelling chart (Figure 47) gives the complete picture from 3D modelling to taking the game as an output. However, only the step 4 of the chart is developed in this conceptualization stage.

The reason why I recommend having such a chart is to get the team to understand the bigger picture and the path one need to take to implement mixed reality. Thus, the team will understand how the steps are related to each other.

Quality and Validity:

The method and the importance to identify the risks associated with each of the training steps before selecting them to implement mixed reality technology matches with the DMAS Framework (Gupta & Varghese, 2020). Both stress the importance of risk identification.

Implications:

The major implication of creating the animation is for the science meet industry webinar which was organized by Norwegian offshore wind cluster <https://offshore-wind.no/event/webinar-science-meets-industry-floating-offshore-wind-in-norway/> for which I was selected as a speaker to present my master thesis case study. There was around 400 participants and I presented it in the studio in Stavanger, Norway (26th May 2021). The concept was well appreciated. The animation stressed the importance of implementing mixed realities into the training activities.

Limitations:

The final decision to implement mixed reality or not from the Table 19 might prove wrong for some low risk category. But I have clearly mentioned that the entire process is an iterative process and based on the implementation and user feedback the chart can be improved.

The training steps which are selected for MR modelling based on the factor which are easier to model with the possible time frame and with my level of expertise and knowledge.

The below limitations are because of the time frame and the level of my expertise. This can be overcome by having expert validation and better training. But again, every work is a learning curve. My learning about this area of subject has improved a lot in the 4 months.

Recommendation:

For the scope of this thesis, the purpose is not to do advanced risk analysis. However, I suggest having the risk analysis done by an expert risk analysis outsourcing company, capturing various uncertainties and consequences. This cost can also be considered in the cost benefit analysis of implementing such technologies into training activities.

I also recommend Energy Innovation AS builds an active team to build such MR models in the future.

6.6. Discussion: Computerize and Develop MR model**Key Outcomes:**

The major outcome from the computerize phase is the 3D model of the training tower and then the Desktop PC game.

Result Interpretation:

The 3D model of the training tower by itself is created from the 2D drawings of the tower. However, the internal elements inside the tower, I have added my imagination to it, it is not directly to scale. It is easily possible to create the exact model of the lift if the 2D drawing of the lift is available. The character modelling can be improved to a larger extent if a lot of time is spent. Meanwhile, it does not add learning experience to the user. But if the company want to improve the appeal its possible.

The Important observation I learned is that for creating the game environment, we need to have a lot of movement reference as shown in Figure 70 . I had only a few actual movement pictures. That's the reason certain game movements (Watch YouTube, link provided) are not exactly matching with real time movements.

It is important to remember that before creating any animation in Blender, the body movements must be recorded real time as shown in left side of the Figure 52. The person climbs the ladder to demonstrate the safe way of climbing and the time required and style of climbing. This will help to match the timing that is required for every movement. In the same way face expressions are also recorded in real time first and then animated.

Quality and Validity:

The demo MR model can be validated for its effectiveness of application to safety training by comparing it with the similar artic safety training model developed in the article (Druzhinia et al., 2019). Both of the model tries to capture the important safety steps that needs to be remembered.

The DMAS model does not focus too much on the immersive experience, but still categories itself into the virtual reality (VR) domain. In similar way this demo MR model, can be upgraded to proper MR experience by investing in proper hardware and upgrading the game coding (scripts). But the idea is possible and proven with the desktop pc game.

Implications:

The demo MR model helped to validate the MRA workflow, since it was created using the workflow

Energy Innovation AS will use the demo model to speak to potential companies like Bouvet, to explain their needs and requirement in a better way.

The initial modelling phase always takes time. Energy innovation AS can improve the model to a greater extent for this phase.

Limitations:

The major limitations are that the Demo MR model is just desktop based. I tried to make it mobile based and I have developed the .APK file and the mobile game works in my mobile. However, the app is still not checked for virus, so I cannot promote it.

This process of having the android mobile application has a lot of challenges by its own to solve. For example, this developed demo app cannot be downloaded in the Google play store since this process requires the developed application to undergo various virus checks and quality checks determined by google. Finally, the service needs to be pay. Thus, it is not in scope of the thesis. The demo application that will be developed is planned to be used in the android mobile devices by people who trust this demo application. Also due to Covid-19 restrictions, multiple people cannot experience the oculus head gear.

The Oculus headgear <https://www.oculus.com/quest-2/accessories/> supports only VR. I tried to connect it the mobile game, but there a lot of scripting errors and control errors which needs to be solved.

To achieve MR experience, Microsoft HoloLens is needed. <https://www.microsoft.com/en-us/hololens> this is very expensive but a very relevant tool.

Recommendation:

I strongly recommend Energy innovation AS to invest in the Microsoft HoloLens to experiment the demo MR model in a better way.

6.7. Discussion: Construct Flowchart and Worksheet

Key Outcomes:

The major outcomes are the mixed reality technical specification (MRTS) flowchart and the mixed reality technical specification (MRTS) worksheet.

Result Interpretation:

The mixed reality technical specification (MRTS) flowchart is used to identify the suitable type of technology for a particular situation and then also helps to identify the suitable hardware platform, software platform and associated tracking technique.

The mixed reality technical specification (MRTS) worksheet data is used to select the training tasks for which mixed reality implementation is required.

Quality and Validity:

The MRTS flowchart (Figure 79) can be validated by comparing it with the article (Sepasgozar, 2020). The article also speaks about developing a flowchart for mixed reality modules for online education. Even though the flowchart is outside the industrial domain, still the logic of selection matched.

The MRTS worksheet (Table 20) can also be validated with a published article (Buttussi & Chittaro, 2018) which has a similar table describing the effects of different hardware platforms displays. The main idea is the classification into simple steps and choosing the relevant technology for each step.

Implications:

The mixed reality technical specification (MRTS) flowchart can be used to fill in the mixed reality technical specification (MRTS) worksheet.

This MRTS Worksheet is a very useful spreadsheet for Energy Innovation AS, as they can look the classification of a critical module along with the technical specifications in a single table.

Limitations:

The real limitation of the mixed reality technical specification (MRTS) flowchart will arise when the company is not able to recognize if they want an immersive experience or not. The flowchart just works one way from top to bottom. For example, if one company was already invested in the VR headset. Then they can't use the flowchart to determine the type of technology. However still they can use the flowchart to find the associated software platform and the tracking techniques based on their VR headset. As I have repeatedly suggested, the entire work of implementing mixed reality is an iterative work. So, there is a chance that after implementation of VR, the company might realize AR is more suitable for their application. Meanwhile this is an expensive mistake, that why this MRTS flowchart tries to avoid such costly mistakes.

The risk analysis approach can vary from industry to industry. The risk analysis done for this thesis is based on my personal perception of the training risk along with the expert opinions from Energy Innovation AS. Therefore, if the same risk analysis is done by a different researcher, the risk classification might vary.

Recommendation:

At present the flowchart starts with also giving the steps to build 3D model. It is a limitation as it might confuse the user. However, since it helps to build demo MR model, this is left like that since it's the first trail of the flowchart and in future version. It can be made clearer.

For the scope of this thesis, the purpose is not to do advanced risk analysis. However, I suggest having the risk analysis done by an expert risk analysis outsourcing company, capturing various uncertainties and consequences. This cost can also be considered in the cost benefit analysis of implementing such technologies into training activities.

6.8. Discussion: Construct Workflow and Framework

Key Outcomes:

The major outcomes are the mixed reality analysis (MRA) workflow and the mixed reality analysis (MRA) framework.

Result Interpretation:

The mixed reality analysis (MRA) workflow has five different stages and the hexagon inside each stage represent the main task to be performed. The techniques to perform the tasks (inside hexagon) are also indicated by text boxes inside each of the stages. The MRA workflow suggest the sequence of steps when followed will be the most ideal way to design mixed reality application. For example, the hazard identification must be done before deciding on the suitable type of technology to implement.

Inside certain stages, there are more than one main task to be performed. In such cases the hexagons are indicated to be interdependent on each other. For example, the MRTS flowchart will aid in creating the MRTS worksheet.

The mixed reality analysis (MRA) framework clearly indicates that the design to implement the mixed reality is an iterative process.

Quality and Validity:

The computerize stage of the MRA Workflow (Figure 80) is similar to a validated and published article (Gupta & Varghese, 2020). The chart from the article is mentioned in Figure 43 and the MR model development chart (Figure 81) can be validated from it. Both the charts clearly represent the steps that need to be followed while modelling.

The MRA framework (Figure 82) can also be validated comparing with the DMAS framework (Figure 42) from a validated and published article (Gupta & Varghese, 2020). Both the framework emphasize the importance of performing a risk assessment and then creating a demo computer model and validating it.

Implications:

The MRA workflow chart (Figure 80) is a quick and self-explanatory visual representation that is presented to the managers of Energy Innovation AS.

The MRA workflow chart also contains the MR model development chart (Figure 81). This is a very useful chart to create MR Models.

The mixed reality analysis (MRA) framework can be used in the future with certain modifications to design for implementation of mixed realities into maintenance, operation and inspection.

Limitations:

One limitation of the MRA workflow is that the sequence of tasks to be performed inside each stage is not mentioned. To overcome this, the MRA workflow needs to be used along with the MRA framework.

The present limitation of the MRA workflow is that it's not been implemented and checked for its flow of work for a real time model development. However, the demo MR model was developed using the same MRA workflow and this is a positive validation for the MRA workflow.

Recommendation:

It is better to discuss the MRA workflow and the MRA framework with different industrial managers and check with them if they agree with the work processes and receive their feedback and improve the chart.

6.9. Discussion: General Observations

1. The reason why I was interested in the implementation of mixed reality (MR) and not individual VR or AR is because with MR the technician during training can experience the situation (immersive) of being in offshore wind turbine and practice the scenarios like the fire evacuation jump. Then I agree that AR will be most useful when performing repair operations in real time. Therefore, MR gives the best of both the worlds and it's the future and it's better to stay prepared for the future starting now.
2. One very interesting observation from the SLR was that all the articles which helped to recognize the research gaps are very new one, in fact most of the articles I used in this thesis as reference were published like 2018-2020. Therefore, I guess the trend will continue and there will be a lot of publications in the coming years. I am also planning to publish my work.

3. The technical specifications captured in this case study are the hardware platform, software platform and the tracking techniques in top level. The subcomponents classification will be an interesting future work to do in this area.
4. The complexity associated with implementation of these technologies cannot be fully captured in this case study. As already mentioned within the time frame only the design part was possible. It was difficult to check the implementation. However, the user level of familiarity was checked using the demo MR model. But again, that's just to ask a verbal feedback or to request them to comment in the YouTube video. A detailed study regarding this in the future will be very useful.
5. The case study was unable to provide a critical review of such mixed reality application based on the potential unintended consequences of having such a technology. The optimal tradeoff considering both the risk and the ambiguity. The level of constraints such technology will have on operations. What's happens if something goes wrong. What is the backup. The main reason for this is the lack of implementation of the mixed reality. However, the framework clearly indicates that this development process is an iterative process. Therefore, after receiving the user feedback (in case the technology is causing more stress to technician), The company will revise its needs and requirements and check again the need to implement mixed realities.
6. The case study checked this complexity issue in the interview stage with all the managers. The best opinion I got was "*it is important to use it as a supplement to training at a training center not as a substitution*".
7. To create the Demo MR model, I initially learned Sketchup as a modelling tool and then found it was lacking a certain tool to create 3D image of training tower. Then I found out Blender as a better option. Similarly, with the gaming software, Initially I tried Unity and then I learned Unreal. To mention there is no lab for such MR modelling in University of Stavanger. Therefore, this is a new learning environment. I have clearly mentioned my level of expertise and the time frame, for the errors and bugs in the demo MR model. However, I personally feel it's a learning process and the initial part of learning any technology is the most challenging phase.
8. The reason why I excluded Scopus from the literature review was due to the time frame. I wanted to check the one university search engine and another market search engine (google scholar). The main scope of my thesis is not just the SLR. I had a lot of other academic requirement to finish this master thesis.
9. The 5-day GWO training was conducted in Norwegian as there were another 8 participants who was comfortable with the Norwegian language. However, Energy Innovation AS tried their best to translate it in English for me. So certain specific words like (Milan), I think its Norwegian word, I have used in my thesis.
10. The reasons to collect the relevant pictures related to animation scenes are because it is very essential to make the real visual representation of the images before modelling.
11. There are very few data regarding the wind turbine accidents. This is clearly mentioned by (Asian et al., 2017) in their article. The way I linked the Table 16 to the Table 1 is subjective, but not really out of scope. I have provided the justification of linking it in section 5.2.

12. The thesis follows the format of explaining certain relevant theory in the same chapter as need. I felt it will be easy for the reader to remember the theory better. Moreover, the thesis initially started only with the objective to create a framework, however, it was realized later a combination of flowchart, worksheet and framework was needed to capture the complete design of MR. The demo MR model requires multi-disciplinary teamwork and skills. The scope of model was heavy. The demo model was very essential since it was required to present in the webinar science meet industry (follow the whole webinar, it is available [here](#) :time 2.23.00). Therefore, only sufficient theory just to explain the concepts related to the case study was discussed.



Figure 83: Presentation at Science meet Industry Webinar 26th May 2021

7. Conclusion

The main research question of this thesis is how to effectively design mixed reality applications for safety training in the wind energy sector. The thesis concludes that the safety training provider needs to develop and rigorously apply the following (1) mixed reality analysis (MRA) workflow, (2) MRA framework, (3) mixed reality technical specification (MRTS) flowchart and the (4) MRTS worksheet in order to effectively design mixed reality applications for safety training in the wind energy sector. Consequently, as the result of the six-step methodology this thesis has provided new knowledge regarding four concepts: (1) sequence or workflow (2) the need for continuous and iterative process to design mixed reality (3) the logic and the rules for the selection of technical specifications (4) worksheet to classify the scenarios and to define training complexity.

The MRA workflow provides the sequence that can enable the industrial practitioner to design MR application in a cost-effective and fit to purpose manner which includes screening out low risk scenarios. The mixed reality analysis (MRA) workflow has five different stages and the hexagon inside each stage represent the main task to be performed. The MRA workflow is verified and validated for its effectiveness by building a demo MR model based on it. Furthermore, it is recommended to apply the MRA framework to emphasize the fact that the design of mixed reality applications is a continuous and iterative process based on user needs and user level of familiarity. The MRA workflow and the MRA Framework is validated by the industrial experts from Energy Innovation AS and they felt the fact that the MR design process is iterative is highly valid.

The MRTS flowchart provides the logic to identify the suitable type of technology for a particular scenario, along with the suitable hardware platform, suitable software platform and associated tracking technique. The MRTS flowchart must be used along with the MRTS worksheet which can help to identify the critical training modules/scenarios and further classify them to check if implementation of mixed realities is needed or not. For example, in the case of designing demo MR model for the training tower. The MRTS worksheet indicated that working with heights is the most critical module. It identified the four training tasks out of fourteen as highly critical to be assisted with MR. The MRTS flowchart is then used to select mixed reality (MR) as the most suitable type of technology for the four highly critical tasks. The mixed reality headset (MRH) is identified as the most suitable hardware platform and the video mixing technology is identified as the most suitable software platform. The hybrid tracking technology which combines the use of both model-based tracking and sensor-based tracking technique is selected. The MRTS flowchart and the MRTS worksheet is validated by the industrial experts from Energy Innovation AS for its easy of use and effectiveness to capture all the technical specifications in one sheet.

The demo MR model is created using the Blender software for 3D modelling purpose and the Unreal engine for creating the game environment. The model provides the user (technician) an immersive experience of being inside the wind turbine using virtual reality (VR) technology and at the same time allows the user (technician) to interact with the evacuation gear at the top platform inside the wind turbine using augmented reality (AR) technology. Therefore, the MR model combines the features of both AR and VR. However, due to the lack of availability of MR gear (HoloLens) for this case study and the due to the multi-disciplinary requirement and time frame only one iteration of design is done. However, there is hope to update the model in the future to make it fully functional. The demo MR game was validated by Energy Innovation AS managers for its ability to make the users (technician) being aware of the safety aspects to be followed while inside the wind turbine.

To conclude the case study, it is important to mention the lessons learned with the case study. The main observations are:

- Capturing the risk associated with each training tasks early in the design helps to classify if the implementation of mixed reality is really needed for that task or not. Such a risk analysis is a big cost saving option for industry as they can save a lot of money in identifying only the crucial scenarios for which the implementation of mixed realities is really needed.
- The key personal observations from the 5-day GWO training program is to understand the consequences and risks associated with each of the training steps. I personally appreciate the need for safety after attending the training program. I recommend any MR design personnel to attend the physical safety training or the physical maintenance and inspection activity before the design process.
- The process of creating MR Model is a continuous and iterative process like every other game development.
- It is observed that different stakeholders (Companies) preferred different research outputs. For example, Energy Innovation AS being an end user of the MR model was very satisfied and preferred the MRTS flowchart and MRTS worksheet. SAFER being a developer of MR technologies was interested in the MRA workflow and MRA flowchart.

Thus, it becomes very clear that to design mixed reality technology we need to use all the four developed outputs of this case study and also develop and mainly implement the MR model to check for its functionality. The thesis outputs are acceptable for this stage of development. However, we need further studies to make the research outputs more matured.

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Appendices

Re: Data Collection/ Interview for my master thesis

Frank Emil Moen <fem@energyinnovation.no>

Sun 18/04/2021 07:59

To: Sharath Chandar Joghee <sc.joghee@stud.uis.no>

Cc: Magnus Østebred <magnus@energyinnovation.no>; Kjetil Bentsen <kjetil@energyinnovation.no>; odin <odin@espelandenergi.no>; Idriss El-Thalji <idriss.el-thalji@uis.no>; jonas@subdco.com <jonas@subdco.com>; Kjetil Torgeirsen <kjetil.torgeirsen@safer.net>

Hi Sharath,

I am happy that you are satisfied with the GWO training.

See my answers below. I also copy in Jonas Hovland from Subdco (he is also a hired instructor for us, and also helps out with the QMS system development, new courses etc.) and Kjetil Torgeirsen from SAFER (we have a collaboration with SAFER especially for the enhanced first ad part - they have a strong evidence based approach when it comes to training). They may have input for you as well. An intervju with them would have been interesting for you I think.

Br

Frank Emil

17. apr. 2021 kl. 21:24 skrev Sharath Chandar Joghee <sc.joghee@stud.uis.no>:

Dear all,

Good day, I had a wonderful 5 day GWO training. I really enjoyed and learned a lot from it.

I will appreciate your response to the following questions which will be beneficial for me to complete the thesis. Please be free to answer whatever you feel its best.

1. Do you think that implementing mixed realities will be one of the innovative solutions to improve the effectiveness of the training programs?

Yes, for sure! This will - if done right, a important supplement both for training skills and for better understanding of the challenges in different situations (which may be difficult to do in practice when time is limited). It will also be very helpful in the process of digitalization of the courses (we are working with getting part of the training online) having a blended approach: some onsite in Egersund, some as a digital "pre study" before entering the training centre. We also have a plan for setting up «train-the-trainer» sessions in different disciplines - and even maybe «train-the-educationsystem» for emerging markets. Having these tools available will for sure rise the possibilities for higher effectiveness and quality of these trainings.

2. Do you know the crucial training scenarios for which an AR/VR application will be beneficial?

Here I think it is better to let the experts on copy answer, but my general though is that complex situations in complex environments these technologies will have great added value for skill training in rescue procedures, and better understanding of the various situations (as in the nacelle, in the blades,

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4/18/2021

Mail - Sharath Chandar Joghee - Outlook

in the basement and in offshore environment transfer training to/from transition piece offshore turbines and rescue from helicopter as some examples).

3. Do you think it is beneficial to do cost benefit analysis in case of implementing AR/VR into the training programs?

Well, I believe it is more about quality improvement. However - very good AR/VR training systems should reduce the need for on site training, and then reduces travel (and will have a positive climate effect) accommodation costs and loss of labour hours, as the training could be run in periods in between working periods.

4. Do you wish to create a demo model which you can use while making the final decision to implement such mixed realities?

Yes for sure. Are you able to conduct such a model by your self, or do we need in example a collaboration with Bouvet?

4. Do you believe that a framework which will indicate the crucial training scenarios and will suggest the most effective hardware and software platform for implementing mixed realities will be useful for the company?

Yes for sure!

5. Do you agree if it's a good idea to do a critical review of such mixed reality application based on the potential unintended consequences of having such a technology? The optimal tradeoff considering both the risk and the ambiguity. The level of constraints such technology will have on operations. What's happens if something goes wrong. What is the backup?

Well, I am not sure I fully understand what you are asking. I think it is more about seeing these tools as a possibility to rise the effectiveness and quality of the training, not as direct substitutes of existing on site training. However - as more of «what ever training» will be digitalized, these are reverant question in general.

6. The literature study shows that there is not any specific academic literature based on implementing AR/VR for safety and technical training in the wind sector, do you agree? Do you think that it's a good idea to publish an article based on this thesis?

I am not familiar with any studies, but we know that the turbine providers are using these tools in their in house training (Vestas is said to have the most advanced training systems in these aspect). I guess as these are in house, protected training and IPR, they are maybe restricted to run studies on these issues. So yea, I believe this is a very good options to do surveys on these issues. Here I think SAFER could be a very interesting collaborative partner together with us.

7. Which is more effective either to use AR/VR for training beginners or to aid experts for better efficiency and decision making?

I believe that AR/VR would be beneficial in both aspects, and difficult to say which one will be more effective than the other. The set up will probably be different, as the first will be more prepared -

4/18/2021

Mail - Sharath Chandar Joghee - Outlook

predefined scenarios, when the second could be more complex, using these tools in scenarios with a less predefined outcome.

8. Which is more effective either to use AR/VR for training beginners or to aid experts for better efficiency and decision making?

I believe the answer in 7. goes for this as well.

9. Do you think its ideal to have a flowchart which will indicate whether it is effective to use VR or AR based on the scenario?

Yes, for sure. Any documentation that will improve the understanding of the various methods and scenarios will be helpful.

kindly reply your answers (yes/no) and few words where it is necessary below the questions and send to me. Thanks

Regards
Sharath Chandar Joghee

Odin Moen:

09/2021

Mail - Sharath Chandar Joghee - Outlook

SV: Email Interview Regarding my Thesis

Odin Moen <odin@espelandenergi.no>

Wed, 09/09/2021 11:41

To: Sharath Chandar Joghee <sjoghee@stud.uib.no>

Dear Sharath,

Indeed, the statement from Frank Emil is correct, but it's difficult for both windfarm owners and service suppliers like Espeland Energi AS to get a hold of the information from turbine producers. Something I briefly talked about in the webinar I had with 2winners.

Here is the answers again, with slightly more context to help you understand the implementation of VR/AR and mixed reality for practice for technical personnel.

1. Yes, all though I am not sure how this implementation is supposed to be integrated but using mixed reality into one or multiple technical training courses would greatly increase the understanding of new turbines for new technical personnel. One of the hardest parts about being new in the wind industry is the fact that you can't realistically get the hands-on experience unless you are introduced to turbine maintenance and service. It will also greatly increase the hand-tool experience for technical personnel, so they are more familiar with the tools they are using for tasks like blade repair (external).
2. There is a multiple scenario where the usage of VR/AR could be crucial, the most important one in my opinion is health and safety related, practicing evacuation and first aid through VR/AR scenarios. With this application it is easier for technical personnel to be equipped to deal with emergency scenarios. It can be discussed that you can implement a system for VR support from a blade repair expert to a blade repair technician to create a dynamic support system for on field operators.
3. There is a demand to do a cost analyses of implementation to "screen" the actual cost effectiveness of implementation.
4. From Espeland Energi AS business case, it would be impossible to fund such a demo, note that yes, the usefulness of having a demo of mixed reality would be highly beneficial in terms of testing the implementation.
5. Yes, an overview of crucial training for technical personnel is very welcome in the industry, in the wind-farm industry problems occur dynamically, meaning that every problem area is not necessarily screened out in the industry. That means both service technical personnel and blade repair personnel must innovate according to the problem area that occurs on a case-by-case project. In terms of hardware and software, the usefulness of applicable mixed reality simulations can from my point of view be beneficial for the company it's applied to.
6. I've not yet had the time to research this properly, but in terms of all application of technology regarding wind industry taking a critical review of implication of mixed reality is highly advised. And as highlighted before, what is something goes wrong? is a highly crucial topic that must be reviewed multiple times to properly be prepared for when something dose go wrong. Especially with the now extensive experience that Norway has in offshore technology and experience.
7. There is no solidified academic literature study that I know of based of off implementation of MR towards safety and technical training. Note: I am not fully updated on this topic so this might be wrong.
8. From what I understand of VR/AR systems I'm leaning towards VR systems being more applicable from an expert to technician dynamic review or case by case problem solving. But I am not 100% up to speed on

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021

Mail - Sharath Chandar Joghee - Outlook

the current situation, and im lead to believe that it's not something people have done extensive resea on.

9. I would have to read the Thesis to properly answer this to the capacity you're requesting. But I have no reason to believe that an article on the thesis would be disadvantageous to the industry.
10. I can not say with 100% confidence that I am able to solidify an answer here, but in general a flowchar identify witch approach is more efficient for the cases occurring is a good idea.

PLEASE NOTE: I am by no means and expert on these topics, this is merely my understanding of the situation, would be easier to have a lengthy meeting discussing it with relevant participants. And review the questions.

I hope this is useful in terms of my role / our collaboration between industry and university.
Best regards

Odin Moen
Project Manager
Mob: +47 90 293 452



Langholmveien 6
4373 Eggerund
[HOME | Espeland Energi AS](#)

Magnus Østebrød:

121

Mail - Sharath Chandar Joghee - Outlook

SV: Email Interview Regarding my Thesis

Magnus Østebrød <magnus@energyinnovation.no>

Tue 01/06/2021 13:51

To: Sharath Chandar Joghee <sc.joghee@stud.uis.no>

Hi,

VR is more accessible in the market right now, and the prices are low on buying this equipment. This means that schools or companies can easily access and use programs that are made for VR world wide. I see a potential for making training scenarios, and selling this to a world wide market. For courses, or health and safety focused training for personal that will work in a new location. This makes it possible to get used to specific rules for a wind park. Most companies have a introduction (Site induction), and maybe vr would be possible to use for this training. For Energy Innovation it is interesting to make the training more interesting before doing real training in the field.

AR: This is a part of the future im shure. The prices for equipment is still expensive, but this will come down like all other technologies . I see the potential in this for training on specific tasks, and remote training. Having at technician in the field, and a specialist somewhere in the world following up on a specific task will be very useful. As a inspector, I would think that AR lences might run realtime AI detection programs to help the inspector finding flaws, and might even combine different methods of none destructive testing, where a specialist will be remotely looking at the performing, and reading the signals of the inspection from an office far away. Phased array is one of the methods where someone might perform the field work, and the specialist will be in his office in a place like Egersund Energy Hub. Blade inspection is often done with rope access personal, and this could also be monitored by client, or a specialist with AR glasses.

Just some ideas.

Regards

Magnus Østebrød

Fra: Sharath Chandar Joghee <sc.joghee@stud.uis.no>

Sendt: tirsdag 1. juni 2021 12:09

Til: Magnus Østebrød <magnus@energyinnovation.no>

Emne: Re: Email Interview Regarding my Thesis

Hello Magnus,

Thank you so much for the replies,

do you wish to add some general observation regarding these technology like MR/VR/AR. Like one or two lines which I will also mention in the thesis report ?

for example, you can speak about the future market scenario or like of you are aware if some companies are already using it, it can be anything you wish to speak about, Thanks.

see you soon with the report.

Kjetil Torgeirsen:

1. Do you think that implementing mixed realities will be one of the innovative solutions to improve the effectiveness of the training programs? **[Kjetil Torgeirsen]**
Yes I think so. Because it will allow for "low dose, high frequency" refresher training (1). We know that remotely supported training sessions are well perceived by our course participants from the oil and gas sector (2)
2. Do you know the crucial training scenarios for which an AR/VR application will be beneficial?
I believe all scenarios where we aim for participants to implement certain behavioral patterns in critical situations where you need to act fast will benefit from this kind of training. However, it is critically important to consult personnel with knowledge of training/pedagogics to design these trainings and integrate them in a holistic training program.
3. Do you think it is beneficial to do cost benefit analysis in case of implementing AR/VR into the training programs?
Yes, I do. Especially since in cases where it will require investments in equipment for companies (training on site). Saving of travel and accommodation costs, overtime payment etc. is a significant cost for our existing customers. The cost savings from improved patient outcome for first aid scenarios is difficult to estimate, but we find patient stories to be helpful as well.
4. Do you wish to create a demo model which you can use while making the final decision to implement such mixed realities?
Yes, I think testing of a demo model and evaluate feedback + results would be very important. And again, also to implement the technology into a holistic training program.
5. Do you believe that a framework which will indicate the crucial training scenarios and will suggest the most effective hardware and software platform for implementing mixed realities will be useful for the company?
No, my experience is that companies (customers) don't have the competency to do these assessments. If you mean company as in my company, I believe that a collaboration to design the right tool for the right purpose would be the way to go. A good example of this is our collaboration with Bouvet and Energy Innovation.
6. Do you agree if it's a good idea to do a critical review of such mixed reality application based on the potential unintended consequences of having such a technology? The optimal tradeoff considering both the risk and the ambiguity. The level of constraints such technology will have on operations. What's happens if something goes wrong. What is the backup?
We think it is a good idea to use the same technology for real life situations (emergencies) as we do for training. The main reason is that frequent use of equipment will make it more likely that people can operate the equipment as intended. The use of mixed reality for medical consultations is a good idea, and will allow the medical expert to interact in a better way than radio/telephone consultation. Critical review to identify learning needs for the users, pitfalls, common mistakes (hardware design flaws), other issues that could arise in a critical situation is extremely important!
7. The literature study shows that there is not any specific academic literature based on implementing AR/VR for safety and technical training in the wind sector, do you

agree? Do you think that it's a good idea to publish an article based on this thesis?
Definitely!

8. Which is more effective either to use AR/VR for training beginners or to aid experts for better efficiency and decision making?

I think both, but I think it is important to use it as a supplement to training at a training center not as a substitution.

9. Which is more effective either to use AR/VR for training beginners or to aid experts for better efficiency and decision making?

10. Do you think its ideal to have a flowchart which will indicate whether it is effective to use VR or AR based on the scenario?

At least I think it is important to have illustrations to show how the technology could be implemented to visualize this for users, managers/organizations and collaborators.

Here is an example:

Chain of survival



References:

1. Mduma E, Ersdal H, Svensen E, Kidanto H, Auestad B, Perlman J. Frequent brief on-site simulation training and reduction in 24-h neonatal mortality—An educational intervention study. *Resuscitation*. 2015;93:1-7.
2. Torgeisen K, Vold K. Emergency Medical Training From an Onshore Simulation Center to Offshore Medics in the North Sea (Norway)—A Pilot Project. Available at SSRN 3812366. 2021.

2. Energy Innovation AS Worksheet: Hazards and Measures Documentation.

<input checked="" type="checkbox"/>	Working range: Wind Turbines: Mobile Rescue Simulator (MRS)	
<input type="checkbox"/>	Occupational group / person	
<input checked="" type="checkbox"/>	Activity: Training and education PPE, abseiling and rescue training with mastery of emergency situations	

Worksheet: Hazards and measures (documentation)

Information	Identified hazards and their description	evaluate hazards				Measures	Processor/ Adviser	Target date		Active	
		Risk			Action yes / no			done	yes	no	
		S	M	H							
ArbSchG BetrSichV BGI 657 BGR 198 BGR 199	<input checked="" type="checkbox"/> Workplace design: - Infrastructure / traffic ways - Fall, slip, stumble, sprain, misstep - Fall from high-altitude work places - Uncontrolled moving parts, bruises, falling objects - confined spaces	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	no	<input checked="" type="checkbox"/> Medical check-up according to G41 (participants) <input checked="" type="checkbox"/> Determine traffic ways, cordon off safety area <input checked="" type="checkbox"/> Keep traffic ways free <input checked="" type="checkbox"/> Keep escape and rescue routes free <input checked="" type="checkbox"/> Ensure the access for emergency services <input checked="" type="checkbox"/> Have rescue equipment on site <input checked="" type="checkbox"/> Hold the ladder and flat surfaces clean, especially remove oil and lubricants <input checked="" type="checkbox"/> Wear close-fitting clothing <input checked="" type="checkbox"/> Work with a second person <input checked="" type="checkbox"/> Wear protective shoes <input checked="" type="checkbox"/> Wear protective helmet <input checked="" type="checkbox"/> Wear protective gloves <input checked="" type="checkbox"/> Wear safety glasses <input checked="" type="checkbox"/> Use PPE for protection against falls <input checked="" type="checkbox"/> Use approved lifting equipment / lifting accessories <input checked="" type="checkbox"/> Ensure consistent backup <input checked="" type="checkbox"/> Access control (ladder, stairs, door) <input checked="" type="checkbox"/> Safe use on ascent and descent <input checked="" type="checkbox"/> Secure items for vertical transport and at working at height <input checked="" type="checkbox"/> Provide and use suitable anchor points <input checked="" type="checkbox"/> When working on ladders provide additional securing points <input checked="" type="checkbox"/> Implementation of rope-based work only after special training <input checked="" type="checkbox"/> Seal or cover open floor doors (hatches) / openings <input checked="" type="checkbox"/> Hold hatches free <input checked="" type="checkbox"/> Use hatches from secure area <input checked="" type="checkbox"/> Close hatches after use	Mr. Wefer Mr. Joens			<input checked="" type="checkbox"/>	<input type="checkbox"/>

Seite 1 von 3 BZEE 13.02.2012

<input checked="" type="checkbox"/>	Working range: Wind Turbines: Mobile Rescue Simulator (MRS)	
<input type="checkbox"/>	Occupational group / person	
<input checked="" type="checkbox"/>	Activity: Training and education PPE, abseiling and rescue training with mastery of emergency situations	

Worksheet: Hazards and measures (documentation)

Information	Identified hazards and their description	evaluate hazards				Measures	Processor/ Adviser	Target date		Active	
		Risk			Action yes / no			done	yes	no	
		S	M	H							
		<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	no	<input checked="" type="checkbox"/> When hatch is open carry out work from a secure area or provide fall protection <input checked="" type="checkbox"/> Ensure escape ways from confined spaces	Mr. Wefer Mr. Joens			<input checked="" type="checkbox"/>	<input type="checkbox"/>
ArbSchG BetrSichV BGI 657	<input checked="" type="checkbox"/> Failure to observe ergonomic principles: - Heavy physical work - Lighting - Information receiving	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	no	<input checked="" type="checkbox"/> While lifting and carrying pay attention of maximum load and use assistive equipment <input checked="" type="checkbox"/> Provide adequate lighting <input checked="" type="checkbox"/> Use lift systems <input checked="" type="checkbox"/> Use approved work equipment <input checked="" type="checkbox"/> Attention to adequate fluid intake <input checked="" type="checkbox"/> Ensure communication	Mr. Wefer Mr. Joens			<input checked="" type="checkbox"/>	<input type="checkbox"/>
ArbSchG BetrSichV BGI 657	<input checked="" type="checkbox"/> Mechanical influence: - Hazardous surfaces such as sharp edges - Falling Parts	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	no	<input checked="" type="checkbox"/> Periodically inspection of work equipment by visual inspection <input checked="" type="checkbox"/> Wear protective shoes <input checked="" type="checkbox"/> Wear protective helmet <input checked="" type="checkbox"/> Wear protective gloves <input checked="" type="checkbox"/> Note the operating instructions <input checked="" type="checkbox"/> Carry out work only after special instruction <input checked="" type="checkbox"/> Secure items against falling	Mr. Wefer Mr. Joens			<input checked="" type="checkbox"/>	<input type="checkbox"/>

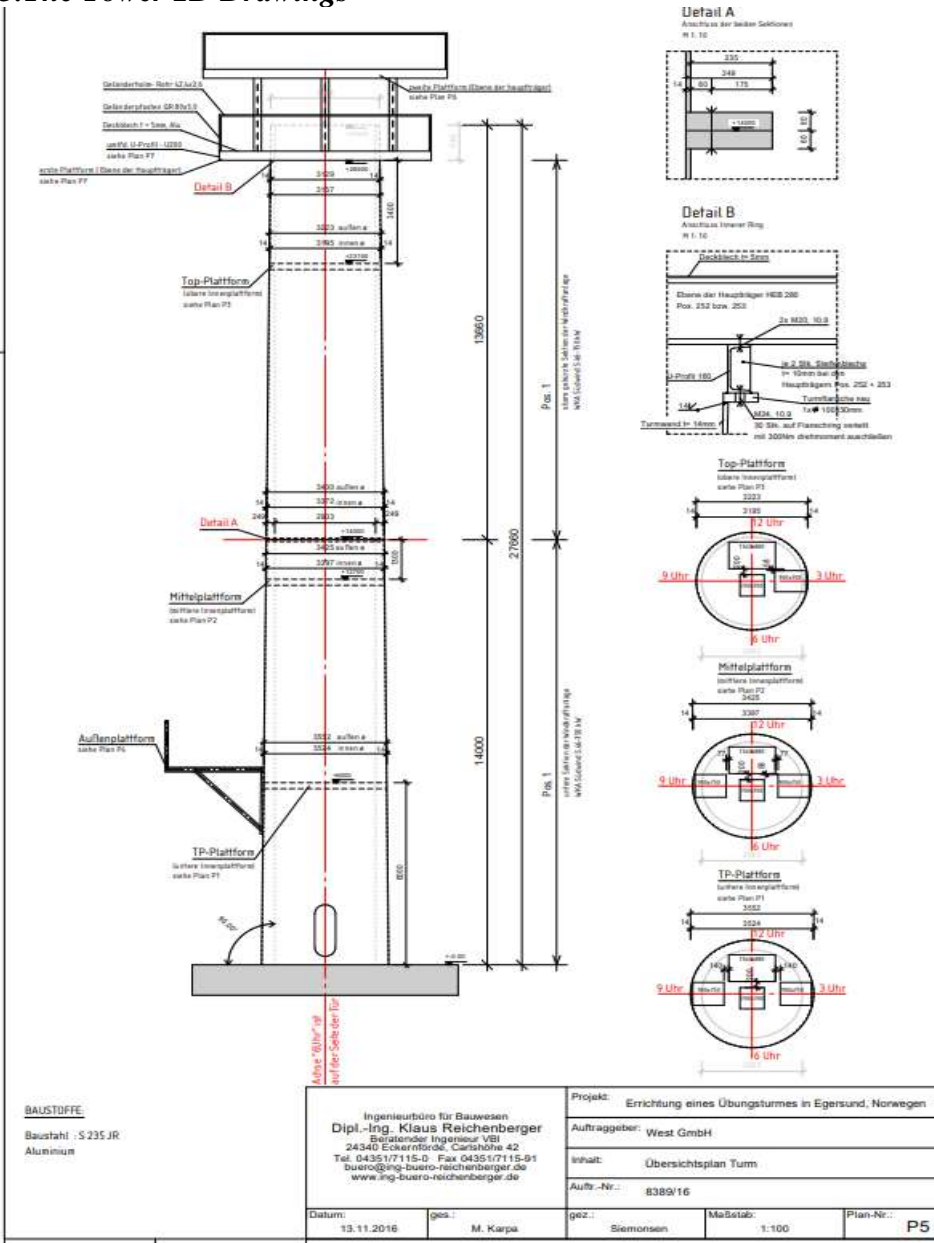
Seite 2 von 3 BZEE 13.02.2012

<input checked="" type="checkbox"/> <input type="checkbox"/> <input checked="" type="checkbox"/>	Working range: Wind Turbines: Mobile Rescue Simulator (MRS) Occupational group / person Activity: Training and education PPE, abseiling and rescue training with mastery of emergency situations	
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Worksheet: Hazards and measures (documentation)

Information	Identified hazards and their description	evaluate hazards			Measures	Processor/ Adviser	Target date	Active
ArbSchG BetrSichV BGI 657 LärmVibrationsArbSchV	<input checked="" type="checkbox"/> Hazards by special physical influences: - Hand-/ arm movements - Suspension Trauma / Orthostatic shock	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/> no	<input checked="" type="checkbox"/> Use approved lifting hoists and slings <input checked="" type="checkbox"/> Wear protective helmet <input checked="" type="checkbox"/> Help yourself by using equipment to prevent the orthostatic shock, such as stay rope, roundslings etc.	Mr. Wefer Mr. Joens		<input checked="" type="checkbox"/> <input type="checkbox"/>
	<input checked="" type="checkbox"/> Other possible hazards and strains: - Psychological stress factors	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/> no	<input checked="" type="checkbox"/> Avoid time pressure <input checked="" type="checkbox"/> Avoid interference by third parties	Mr. Wefer Mr. Joens		<input checked="" type="checkbox"/> <input type="checkbox"/>

3.The Tower 2D Drawings



4.The Validation of thesis outputs mail from Energy Innovation AS Manager.

SV: Regarding Validation of my thesis (Mixed Reality) research outputs

Magnus Østebrød <magnus@energyinnovation.no>

Fri 11/06/2021 16:27

To: Sharath Chandar Joghee <sc.joghee@stud.uis.no>

Cc: Idriss El-Thalji <idriss.el-thalji@uis.no>; Frank Emil Moen <fem@energyinnovation.no>

Hi,

Thank you for the good work you have done here, and we are very excited to see what you have done while being here at Egersund Energy hub.

Regards

Magnus Østebrød

Fra: Sharath Chandar Joghee <sc.joghee@stud.uis.no>

Sendt: fredag 11. juni 2021 15:11

Til: Magnus Østebrød <magnus@energyinnovation.no>

Kopi: Idriss El-Thalji <idriss.el-thalji@uis.no>; Frank Emil Moen <fem@energyinnovation.no>

Emne: Re: Regarding Validation of my thesis (Mixed Reality) research outputs

Dear Magnus,

Thanks for the validation meeting. It was very exciting to get your feedback and approval representing Energy Innovation AS. I have noted a few important points we discussed today

1. We discussed about the MRTS Flowchart which helps to identify the type of technology (AR/VR/MR) and the suitable type of hardware, software platform and tracking technique.
2. We discussed about the MRTS Worksheet which is helping to classify the training scenarios into training steps and is a quick one page chart to represent all the details extracted from the MRTS flowchart.
3. We discussed about the MRA Workflow and the MRA Framework and this gives the steps to implement MR into training activities or maintenance activities in the future
4. We discussed about the Demo MR model which is uploaded in YouTube and we discussed the pros and cons around it.

Magnus, was interested in the classification of the scenarios which can help to tell in which tasks AR/VR is really needed. he agreed with the fact of using the MRTS flowchart to decide if a headgear or handheld device is really suitable for a particular situation. He told the Workflow made sense.

He was interested in checking the possibility of using such technologies in digital learning scenarios. Magnus spoke about the work that Energy innovation is doing with Bouvet using Hololens which was very exciting to hear. He was telling that experts from Bouvet might help to develop my model further, help in correcting the errors and bugs.

Overall , I was happy with Energy innovation AS acceptance of the contribution I made through this master thesis project , which is the first step towards learning and documenting the challenges associated with implementing MR technologies into training, inspection and maintenance activities in the future.

SV: Regarding Validation of my thesis demo Models

Magnus Østebrod <magnus@energyinnovation.no>

Tue 08/06/2021 10:09

To: Sharath Chandar Joghee <sc.joghee@stud.uis.no>

Nice to see your work. I think there is a future Product for training here if we decide to follow up on this.

Med vennlig hilsen / Best regards

Magnus Østebrod

Project manager

Mob: +47 46 88 65 77

magnus@energyinnovation.no

www.energyinnovation.no



Langholmveien 24 - 4373 Egersund - NORWAY

Fra: [Sharath Chandar Joghee](#)

Sendt: mandag 7. juni 2021 kl. 19:47

Til: [Frank Emil Moen](#); [Magnus Østebrod](#); [Kjetil Bentsen](#); [odin](#); [Kjetil Torgeisen](#)

Kopi: [Idriss El-Thalji](#); [Mustafa Serkan Abdüsselam](#); [Jayantha Prasanna Liyanage](#); [Jan Frick](#)

Emne: Regarding Validation of my thesis demo Models

Dear all,
Good day,

I am very happy to present my results for the master thesis. I have created two products.

Thesis Topic : **Mixed Reality Applications for Safety Trainings in Wind Energy Sector: A Case Study**

1. Safety Animation Video (presented my me, for science meet industry webinar)

Youtube Link : <https://youtu.be/o5zzT9b630k>

2. Demo MR desktop based Model

Youtube Link : <https://youtu.be/6bEqzCGC93Q>

