Maximising the Impact of Immersive Technologies for Training and Education

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ABSTRACT

Virtual, Augmented and Mixed Reality (collectively known as XR) are rapidly maturing technologies that have attracted a great deal of attention from the Training and Education (T&E) research community. XR has the potential to radically transform T&E within UK Defence, but in order to realise the potential benefits of XR technology, UK Ministry of Defence (MOD) must develop its understanding in this area.

To explore the benefits of XR for T&E the UK's Defence Science and Technology Laboratory (Dstl) initiated Maximising the Impact of Immersive Technology for Training and Education (MIITTE), a 3-year activity. MIITTE comprised of a number of activities such as human volunteer trials, systematic reviews, technology watches, and the development of decision support tools. The aim of this task was to produce the evidence, advice and guidance, needed to enable T&E stakeholders across the MOD to make appropriate and effective use of XR for T&E.

This paper summarises the MIITTE research findings. This includes assessments of the benefits and limitations of XR technology within the context of the current provision of military T&E, and what future research is needed to explore various promising uses of XR technology.

1.0 INTRODUCTION

Immersive training technologies such as Virtual, Augmented and Mixed Reality (collectively known as XR) have matured rapidly since the release of the first Oculus Rift VR head mounted display in 2012 [1] and are starting to be used heavily in a number of domains such as education, medical and heavy industry. XR technology has the potential to radically transform how Training and Education (T&E) activities can be delivered within the military sector to make T&E more effective and more efficient. However, to date these technologies have not been widely adopted within the military sector. To explore this issue the United Kingdom (UK) Ministry of Defence (MOD), tasked UK Defence Science and Technology Laboratory (Dstl) to conduct research to develop MOD's understanding of XR technology and support the acceleration of XR technology where appropriate.

The lack of empirical evidence that clearly demonstrates the ability of XR to enhance T&E is a key barrier to the wide spread adoption of XR technology. Coupled with that there is a lack of understanding about what the composition of the learning ecosystem needs to be to successfully implement XR training solutions if they are found to be effective. For example, cybersecurity is well known issue within the defence and security context, yet there is very little advice and guidance to support users in understanding how to implement XR within their learning ecosystem in a secure manner.

There are numerous use cases, to which XR training solutions could be applied, and generating the supporting evidence for every single use case would have taken more time and funding than was available. To remedy this the XR for T&E (XR4TE) approach [3] was developed by Dstl in partnership with industry and academic organizations, led by QinetiQ Training & Simulation Limited. In addition to the systematic review and generation of evidence relating to the effectiveness of XR technology, the study team also conducted research that sought to support the implementation of XR technology solutions and mitigate the blockers to adoption which were identified through the research process. This research was conducted under the Maximising the Impact of Immersive Technology for Training and Education (MIITTE) activity and evidence was collated within the XR4TE Portfolio of Evidence (PoE).

The overall aims of the MIITTE activity were: (1) assess the state of the evidence relating to the effectiveness of XR technology, (2) where gaps exist in the literature, generate empirical evidence relevant to the military and (3) Generate evidence-based advice and guidance that increases the likelihood of successful XR adoption by the UK MOD.

2.0 THE MIITTE APPROACH

The MIITTE activity was broken into five half-yearly Delivery Cycles (DCs), with each DC defining, contracting, and delivering a package of activity, each of which provided a specific contribution to MIITTE's overall goal. Each DC was further divided into a series of smaller sub-tasks, such as targeted studies, engagement events, and activities relating to the planning and execution of evidence gathering trials.

Research activities and outputs were designed to both generate evidence for the XR4TE PoE and ensure evidence was effectively exploited by defence. key activities and outputs are highlighted below:

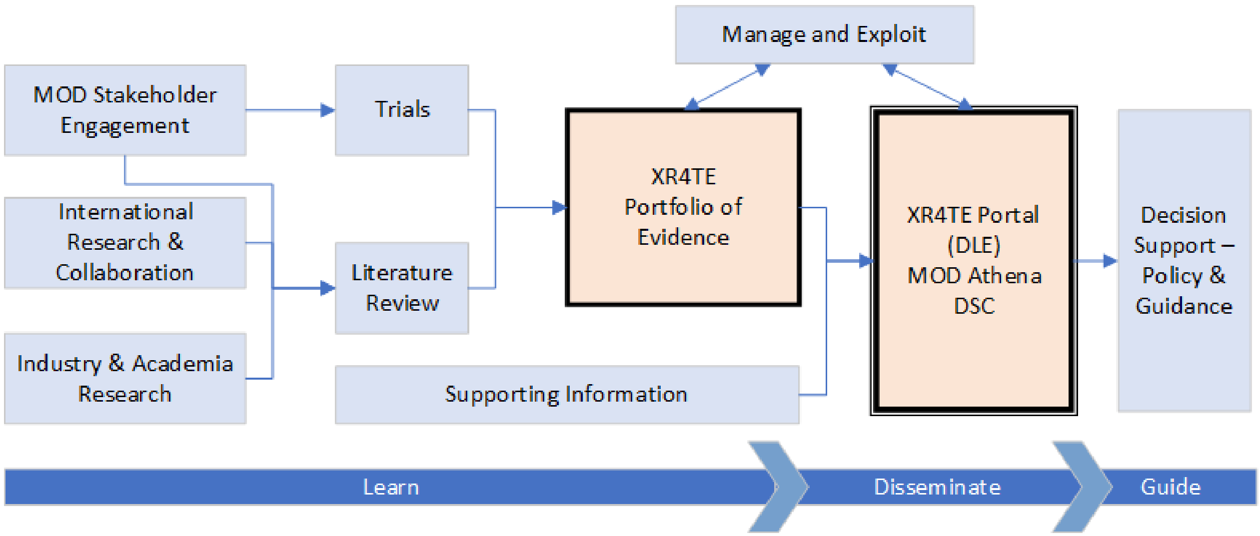

Figure 2-1: Key research activities leading to accessible advice and guidance to MOD

2.1 Maturing the XR4TE PoE

MIITTEs primary route to exploitation was to mature the XR4TE POE evidence base, adding further open-source literature and undertaking human participant trials as required to fill in evidence gaps relevant to Defence & Security needs.

Throughout the project, the PoE was continually updated with over 160 pieces of evidence reviewed and entered into the PoE. Many of these came from literature review activity with evidence sourced from relevant journal articles and conference proceedings. The evidence largely originated from the medical and general education domains which reflects a general trend in the literature, given the degree of assurance needed for medical use cases and the relative proportion of training and education that occurs in institutes of learning.

Early analysis of the PoE evidence suggested gaps in areas such as teamwork and advanced training, and much of the evidence was focussed on a narrow set of skills to be trained. Where extant literature could not be identified to fill these gaps the MIITTE activity sought to run trials to generate the required evidence.

Over the course of the research the MIITTE activity ran four human participant trials, collaborating with academia and industry, and sourcing participants from universities, the Royal Air Force (RAF), the Royal Navy (RN) and the RN Reserves (RNR). The trials addressed such questions as: ‘Could training throughput be increased by using Virtual Reality (VR) prior to live training?’; ‘Is training using VR more effective that using desktop systems?’; ‘Does VR training increase knowledge retention?’; ‘How can VR support instructors in delivery of team training?’; and ‘How does a VR solution compare to existing methods of training?’.

2.2 XR Guidance

While the PoE highlights available evidence, decisions on adoption of XR cannot be made using this alone. PoE users would need to read some PoE assets in full, along with other XR guidance, and have a good understanding of the training requirement. The MIITTE research therefore sought to understand the optimum ‘user journey’ for someone procuring an XR training system, identifying guidance material that could support the process and highlighting potential blockers along the way.

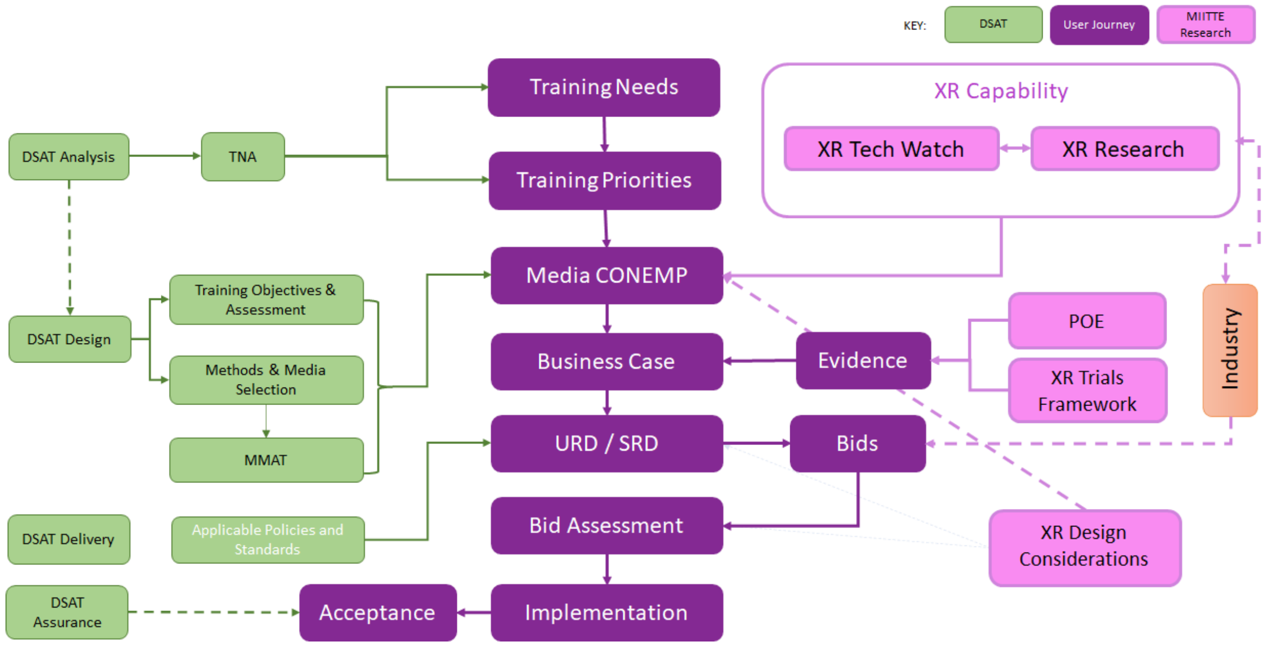

Figure 2-2: User Journey for procurement of an XR training system

The diagram above illustrates through the purple boxes the user journey, with the pink boxes indicating relevant XR guidance. UK MOD training solutions are governed by Joint Service Publication (JSP) 822 guidance, the Defence Systems Approach to Training (DSAT) policy. The diagram therefore highlights the various DSAT processes and MIITTE outputs relevant to technology insertion. However, it should be noted that DSAT is not a linear process, and in some cases does not apply (such as replacing an extant system). Therefore, although the user journey illustrated in the diagram aligns with DSAT, it does so loosely.

Several supporting artefacts were highlighted as beneficial in supporting the decision process and hence these were developed under the MIITTE activity:

- **Decision Support Framework Tool**: The tool supports stakeholders in the process of adopting XR by supporting them through the decision process. This included highlighting the potential suitability (or not) of XR and the factors that may impact their decision.
- **Design Considerations Guide**: This report covered design considerations specific to the procurement and use of XR systems for military T&E, spanning hardware, software, and human factors.
- **XR Policy Guidance**: A review of current UK Defence, NATO, and Industry standards and UK defence policy was carried out. The aim of this review was to provide advice on the implications of XR technology on UK policy, either to support future updates on policy or to signpost guidance material that may be relevant for the implementation of that policy within an XR context.
- **VR Pedagogy Biscuit Book**: This light guidebook identifies clear and effective pedagogic frameworks specific to the use of VR in learning and presents these frameworks in a readily digestible form.
- **Quality Assessment Framework**: This framework delivers a bespoke evidence output review protocol combining best practice methodologies and quality criteria from existing industry frameworks with technology factors specific to the use of XR.

- **Trials Planning Framework**: The Trials Planning Framework delivers a modular and adaptive framework designed to support the evaluation of disparate training and assessment goals relating to new XR technologies.

2.3 The XR4TE Portal

The over-arching motivation of MIITTE was to provide guidance to those planning a programme of T&E on how XR technologies can help them achieve their goals. To best exploit MIITTE research the PoE and research outputs were made accessible and searchable via an online portal currently hosted on the UK Defence Learning Environment (DLE). Development of this portal was a key activity during the research activity.

3.0 RESEARCH OUTCOMES

3.1 The XR4TE PoE

The XR4TE PoE currently contains over 340 evidence assets pertaining to the effectiveness of XR for a range of training domains, levels, and skill types. Since inheriting the PoE from a previous research stream MIITTE has added over 160 new assets and refined the structure of the PoE to improve search capability.

There are many ways to explore and visualise the data in the PoE. MIITTE selected some key categories to look at individually and in combination, but an exhaustive analysis was not carried out. The analysis highlighted that there are gaps in the data: there remains limited evidence of efficacy for training teams and advanced users; Mixed Reality (MR) is an emerging technology and has great potential to address some of the limitations of VR, but MR currently only makes up 7% of the evidence base so far; defence users are not creating and sharing high quality evidence and hence much of the data comes from industry and medical domains; many of the studies used subjective assessment and only ran a single iteration of training hence data quality varies within the PoE.

The PoE suggests (bearing in mind evidence gaps discussed above) that XR can offer an effective training solution, and in some cases can be more effective than traditional methods. This is consistent with a previous meta-analysis exploring the presently available, empirical findings on transfer of training by Kaplan et al [4]. However, the PoE also highlights potential benefits beyond effectiveness (cost, user preference, improved safety etc.) which have only been subjectively assessed. It is not clear what impact these additional benefits have on effectiveness or any decision to adopt XR for training, and hence further research is required.

While there are issues with the PoE content and structure, it does have several benefits:

- It is a comprehensive resource that will be useful for having a ‘first look’ and a high-level analysis of the type of evidence available without having to read numerous research documents in depth.
- It helps to highlight the key takeaways and weaknesses as well as give context for each piece of evidence, as each one has been categorised and summarised by a Subject Matter Expert (SME) in XR training,
- It provides an indication of where there are research gaps; and,
- It can be used as a tool to gain an indication of changes in findings over time as technology matures.

It should also be noted that XR is a rapidly developing technology and regular systemic reviews will be needed to ensure the POE remains current.

It has also been observed that many of the Use Cases within the POE, and within more recent MOD uses, use XR as an evolution of existing training approaches, i.e., XR is used to add immersion, but training is delivered in the same way and without consideration of the unique opportunities and characteristics of XR, thus limiting its benefits. XR requires careful human centred design to maximise its effectiveness and system developers should be considering pedagogical and instructional design techniques when designing XR experiences.

The PoE evidence suggests that increased immersion (presence, embodiment, situational awareness) alone is not sufficient to guarantee greater training effectiveness. XR will not solve all training problems or benefit every scenario. The learning objectives and outcomes are a key driver in whether XR is a beneficial solution, the technology itself does not guarantee success and better technology does not always result in a step change in effectiveness.

XR has also not been considered as part of a blended training approach. Studies within the PoE compare XR to traditional training methods with the intent of replacing the existing training provision. XR should be treated as an additional tool within an existing training toolbox, not a direct replacement for traditional training methods. In many cases XR will be able to enhance and compliment other training methods, a steppingstone from classroom to live training, which achieves it maximum effect by complimenting these, rather than replacing them.

3.2 Features and Benefits of XR

To understand how XR might be used effectively, it is necessary to understand how it compares to other training media. As well as analysing the PoE, MIITTE conducted several strands of research to compare XR to current training methods. Many of the benefits of XR solutions are also seen with simulators in general (e.g., repeatability, reduced cost, reduced risk, hard to train tasks and remote training), and therefore if a desktop or physical simulator has already been deemed effective it's likely XR would also provide a comparative solution. However, XR has some additional features which are unique to immersive solutions and may address some of the limitations of other training media.

- **Presence**: XR experiences generally enclose the user's field of view and synchronise their display to the user's movement through space to create the illusion of presence. Rather than Human-Computer Interaction (HCI) through keys on a keyboard, gamepad, or mouse, the user typically navigates using controllers which track arm, hand, and sometime finger positions, and allow the user to interact with and explore objects in a more natural way. A headset-based VR experience can therefore give the user a greater sense of presence compared to a desktop 3D simulation; the user "feels" like they are in the environment and that the environment is real [5]. This results in less "real-world" distractions and users can often behave more as they would in the real world (psychological fidelity). This can also lead to greater engagement [6][10] which may improve the impact of training and could help with retention (although further research is required to investigate this hypothesis).
- **Embodiment**: With XR users can appreciate where their body is within the environment and how their movements impact the environment and objects around them, giving them a greater appreciation of their physical capability 0. This could be of particular benefit to situations where a trainee's stance could impact safety (a trainee must crouch to avoid a moving object) or where body position could influence the actions of others (hand signals to indicate the start of a particular action). Haptics can further enhance the feeling of embodiment [8][9], providing a response to touch or recoil when firing a weapon, which may strengthen certain learning points.
- **Spatial Awareness**: In contrast to desktop training, XR allows the user to visualise the full environment through subtle head and body movements. Headsets do still impose some Field of View (FoV) limitations meaning the user will sometimes still need to move the head when in the real world a side movement of the eye would be sufficient, but generally the movement is more natural and hence quicker for users to orientate themselves.
- **Environment Control**: Common to desktop simulation XR allows for greater control over the environment. However, in contrast to desktop, VR can also block out the physical training room and other distractions. Where the physical training environment remains, such as in Augmented Reality (AR) or MR, the software can blend simulated objects with the real world or adjust the appearance of real-world objects. This allows the user to train in a more natural environment and use real objects which provide

'real' haptic feedback, but with the benefit of simulated objects which are not available 'live' or overlaid training information which guides the user through the training.

- **Muscle Memory**: AR and MR can support training using real equipment allowing for build-up of muscle memory. Using headsets such as HoloLens or VR headsets with pass-through cameras negates the need for additional haptic devices; allows the real objects to be augmented with instructional data or their visual representation adjusted to reflect the training situation [11]; allows trainees to see instructors and team members and their interaction with the equipment.
- **User Data Capture**: Common to any desktop and physical simulator, XR will support capture of After-Action Review (AAR) data, with replay showing multiple views and user interactions logged. In addition to this, XR can extend data capture via the addition of eye and body tracking, which is becoming available in many commercial headsets as standard. This allows appropriately instrumented XR solutions to track the users gaze, which can inform the instructor what the trainee was focusing on, how quickly a trainee responded to a visual cue, and whether the trainee is really engaged in the learning. There is also commercial technology that can measure stress and fatigue based on eye behaviour, which can be used to assess the impact of training.

3.3 XR Limitations and Blocker to Adoption

Commercial VR headsets do still impose some FoV limitations, accurately judging distance in VR remains a challenge [12] and full body tracking can be expensive without which the resultant avatar representation can look unrealistic. There have also historically been limitations in AR and MR technology, such as limited FoV, and correlating the real and simulated environments to correctly anchor objects in MR. This area has limited research and evidence to date, but technology is advancing, and these technologies are likely to become more viable.

In addition to technology limitations the research also highlighted several blockers to adoption which need addressing:

- **Security**: A greater understanding is needed regarding the use of Bluetooth and Wi-Fi; the impact of greater data collection capabilities (camera and biometric data for example); and the storage of potentially sensitive data on wearable devices.
- **Safety**: For VR solutions cybersickness remains a significant concern. Cybersickness refers to the discomfort that users may experience during or after the use of XR device, which is similar to motion or simulator sickness. While cybersickness can be mitigated to some extent, there may be a minority of users who are so susceptible to cybersickness that they are incapable of using the technology regardless of mitigations. Tethered devices which present a trip hazard and VR headsets which restrict the user view also raise safety concerns which must be understood to be mitigated successfully.
- **Cost Factors**: While an XR solution is likely to be cheaper than a live solution it may not be cheaper than other training solutions, such as desktop solutions. Further research into cost factors is required to support future cost-benefit analysis of XR solutions.
- **Culture**: XR is often viewed as an alternative to live and traditional simulated training, rather than part of a blended solution. This can lead to training managers being resistant to its introduction.

4.0 FUTURE RESEARCH DIRECTION

During the lifetime of the MIITTE contract, the commercial XR landscape has continued to evolve, including innovative and potentially disruptive new concepts and technologies. This rate of change seems unlikely to slow considering the continued investment from the commercial sector and anticipated entries into the market from big players such as Apple. Additionally significant world (i.e., the War in Ukraine and a changing threat profile) and political events (the UK's Integrated Review [13]) have meant that the PoE will need to be adapted to support emerging training requirements. It is likely that to help MOD maintain and develop a strategic edge over adversaries, research will have to move towards the evaluation of novel XR training concepts rather than simply replicating current training in XR.

Broadly speaking there are two areas of the research that should be considered. Firstly, the combination of several emerging XR training solutions such as eye tracking, haptics, and Brain Computer Interfaces (BCI) need to be evaluated to understand if they can provide benefit to MOD training activities. Secondly develop MOD's understanding of which Generation-After-Next (GAN) XR training solutions (e.g., The Metaverse, quantum computing) are likely to cause significant disruption to T&E and conduct research that will develop GAN XR concepts into capabilities that can be used by MOD stakeholders. While there will be a significant focus on the development and evaluation of emerging and GAN XR concepts, there is a need to conduct research that reduces the barriers to implementation that were mentioned in the section above.

4.1 Conclusion and next steps

The MIITTE activity has had a significant impact on MODs understanding of XR technology, as it has provided users with the empirical evidence and decision support tools that are required to support the appropriate implementation of XR technology within the learning pipeline. However due to changes in the strategic direction, advances in technology and research gaps identified under MIITTE, further activity is required to develop XR into a business-as-usual training tool and accelerate the development of GAN XR concepts. This research activity will be conducted under Dstl's Developing Education Learning and Training Advances project (DELTA), which aims to develop and test novel learning concepts to help UK MOD achieve superiority through its people capability. The specific XR research areas are likely to include:

- Horizon scanning to identify GAN XR concepts that will be assessed against real world military use cases to understand the how these concepts can be used to enhance military learning. Potential focus areas are:
  - Haptic devices
  - Brain computer interfaces
  - Realistic Avatars
  - Novel sensing technologies
  - The Metaverse
- The refinement of the XR4TE approach and the development of the PoE. This activity will look to build upon the XR4TE approach that was developed under MIITTE and adapt it to the changing XR technology landscape and to suit the needs of NATO partner nations and allies. This activity will also look to develop the PoE, by expanding the evidence base and developing an online evidence repository that is accessible to UK and NATO stakeholders. The majority of this work will be conducted via the NATO Modelling and Simulation Group (206) Common Framework for the assessment of XR technologies for use in Training and Education research task group, which aims to develop a standard NATO approach for assessing the benefits of XR technology.
- Targeted research activities that aim to reduce the barriers to adoption of XR technology within the MOD. Potential areas for focus are:
  - Understanding the human factors of XR technology. E.g., understanding what skills and experiences instructors will need to deliver XR content within courses.
  - Understanding the networks and infrastructure required to deliver XR at scale across the defence enterprise.
  - Understanding the policy and standards required to ensure the efficient and coherent delivery of XR content at scale.

REFERENCES

[1] Oculus (2012). Oculus Rift: Step Into the Game, https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game

[2] UK MoD. (2019). Defence Innovation Priorities, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831427/20190906-InnovationPrioritiesPub_Final_.pdf

[3] Cullingford, E. (2019). Augmented, Virtual and Mixed Reality Technologies for Training and Education (XR4TE) – Final Report, QINETIQ/19/00657. QinetiQ Ltd.

[4] Kaplan, A., Hancock, P., Cruit, J. & Endsley, M (2020)., The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis. https://www.researchgate.net/publication/339466878_The_Effects_of_Virtual_Reality_Augmented_Reality_and_Mixed_Reality_as_Training_Enhancement_Methods_A_Meta-Analysis

[5] J. Schuemie, P. Van Der Straaten, M. Krijn and C. & Van Der Mast, "Research on Presence in Virtual Reality: A Survey," CyberPsychology and Behaviour, vol. 4, no. 2, pp. 183-201, 2001.

[6] Makransky, G. & Petersen, G. (2021) The Cognitive Affective Model of Immersive Learning, https://link.springer.com/article/10.1007/s10648-020-09586-2

[7] K. Kilteni, R. Groten and M. Slater, "The Sense of Embodiment in Virtual Reality," Presence, vol. 21, no. 4, pp. 373-387, 2012.

[8] J. Fröhner, G. Salvietti, P. Beckerle and D. Prattichizzo, "Can Wearable Haptic Devices Foster the Embodiment of Virtual Limbs?," IEEE transactions on haptics, vol. 12, no. 3, pp. 339-349, 2018.

[9] G. Richard, T. Pietrzak, F. Argelaguet, A. Lécuyer and G. Casiez, "Studying the role of haptic feedback on virtual embodiment in a drawing task," Frontiers in Virtual Reality, vol. 1, no. 28, 2021.

[10] T. Haar, L. Kent and E. Matthews, "Value Proposition for Augmented Reality in Synthetic Training Environments," WisEngineering, 2019.

[11] Govan, T., MIITTE SSE1.4.2 CBRN Trial Exploitation Summary, NSC-820-1553, Issue 2.1, 8 February 2022

[12] F. El Jamiy and R. Marsh, "Survey on depth perception in head mounted displays: distance estimation in virtual reality, augmented reality, and mixed reality," IET Image Processing, vol. 13, no. 5, pp. 707-712, 2019.

[13] UK Cabinet office. (2021) https://www.gov.uk/government/collections/the-integrated-review-2021