5G-encode

Final Report

WP3.1.3: AR Assisted Training

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Issue Details

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1	Initial issue

About 5G-Encode

The 5G-ENCODE Project is a £9Million collaborative project aiming to develop clear business cases and value propositions for 5G applications in the manufacturing industry. The project is partially funded by the Department for Digital, Culture, Media, and Sport (DCMS), of the UK government as part of their 5G Testbeds and Trials programme. The project is one of the UK's biggest investments in using 5G to modernise manufacturing.

The key objective of the 5G-ENCODE project is to demonstrate the value of 5G as part of industrial use case delivery within the composites manufacturing industry. It is designed to validate the idea that using private 5G networks in conjunction with new business models can deliver better efficiency, productivity, and a range of new services and opportunities that would help the UK lead the development of advanced manufacturing applications.

The project will play a key role in ensuring that the UK industry exploits the 5G technology and remains a global leader in the development of robust digital engineering capabilities when implementing complex composites manufacturing processes.

The project will highlight how 5G features such as neutral hosting and network slicing can be applied to transform a private 5G network into a dynamically reconfigurable network able to support a wide range of applications (URLL/eMBB/MMTC) including industrial applications of Augmented Reality/Virtual Reality (AR/VR), asset tracking of time sensitive materials and automated industrial control though IoT monitoring and big data analytics. Such a dynamic network would enable new business models and creation of bespoke virtual networks tailored to specific applications or use cases.

A state-of-the-art test bed was deployed across three sites centred around the National Composites Centre in the southwest of England. In support of the West of England Combined Authority (WECA) industrial strategy, the NCC plans to keep the test bed as an open access facility for the experimentation and development of new products and services for the composites industry after the completion of the 5G-Encode project. The location and nature of NCC's business would ensure the creation of an industrial 5G ecosystem involving multiple industry sectors and SMEs.

The project consortium, led by Zeetta Networks, brings together leading industrial players (e.g., Siemens, Toshiba, Solvay), a Tier 1 operator (Telefonica), disruptive technology SMEs covering all aspects of network design, deployment, and applications (Zeetta Networks, MatiVision, Plataine), application performance as measured by probes (Accedian), world-leading 5G network research group (High Performance Networks Group in the University of Bristol) and the NCC representing the high value manufacturing industry.

Executive Summary

Training courses with practical elements are typically carried out by trainers either within their training facilities on-site or at a suitable location at the customer site. Both scenarios have economic and environmental costs related to travel, with most being infeasible within the recent COVID-19 climate. Although there are distance learning options, and internet-based courses available, they are limited to webinar style 2D solutions. The use of 5G and more immersive technologies provides a unique opportunity to engage more effectively with the trainer and the practical elements of the training course.

The use case presented within this report evaluates the use of latest AR software, hardware, and 5G connectivity to demonstrate a fully immersive AR remote training solution. This solution is used to guide the user through the manual composite manufacturing process of one of the practical courses offered by the NCC. On-screen text instructions, overlayed 3D graphics, and tutorial videos support the trainees wearing the AR headgear. The work package also relies on 5G's reliable, safe, high bandwidth and low latency connectivity to facilitate high quality two-way communication (video and bi-directional audio feeds) between trainer and trainee.

The use case development was split into two testing phases. The first phase was conducted on 4G LTE and limited to a controlled setting at the NCC with four trainees across two sessions. None of the participants indicated that the solution was of sufficient quality to justify its use over conventional on-site training. The root cause for this was not found to be the network connectivity, but the initial development of the AR application.
The second phase was conducted using the 5G test bed deployed at the NCC. The testing was extended to an external location and opened to a wider testing group of at least 20 trainees. Even with the expanded scope, almost 79% of users were satisfied with use of the package over on-site courses. The network provided sufficient connectivity to enable the two-way communication function with good quality which was appreciated by all users. Metrics exceeding 700 megabits per second download speed and around 3 milliseconds latency were recorded.

The immersive technologies tested in this report are shown to be a good option for remote training but require high quality digitisation and integration in the process. The 5G technology was shown to be reliable and high-performance with no significant or lasting

interruptions throughout the two days of demonstration sessions at Millennium Square. However, the use case was not very heavily reliant on the network because the only feature relying on it - i.e., two-way communication, was only used intermittently for relatively short periods of time.

Future developments can include features that increase the use of 5G with the development of online libraries containing interactive digital content. This development should also modularise the solution and improve its adaptability and cross application re-use.

The AR technology must reach a more mature and robust stage before being applied in real-world cases. To enable this wider-scale adoption access to operational public or private 5G networks is a prerequisite.

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Abbreviations

2D	*Two-Dimensional*
3D	*Three-Dimensional*
3G	*Third Generation Mobile Network*
4G LTE	*Fourth Generation Long-Term Evolution Mobile Network*
5G	*Fifth Generation Mobile Network*
AP	*Access Point*
APC	*Automated Pre-Forming Cell*
AR	*Augmented Reality*
CPE	*Customer Premises Equipment*
DCMS	*Department for Digital, Culture, Media, and Sport*
DL	*Downlink*
eMBB	*Enhanced Mobile Broadband*
IoT	*Internet of Things*
IP	*Internet Protocol*
Kbps	*Kilobits Per Second*
KPIs	*Key Performance Indicators*
LRI	*Liquid Resin Infusion*
Mbps	*Megabits Per Second*
MMTC	*Massive Machine-Type Communications*
NCC	*National Composites Centre*
NCC HQ	*National Composites Centre Headquarters*
NCCi	*National Composites Centre – Filton Site*
NR	*New Radio*
NTP	*Network Timing Protocol*
P2P	*Peer-to-Peer*

PTP	*Precision Timing Protocol*
RAN	*Radio Access Network*
SA	*Standalone*
SMEs	*Small and Medium-Sized Enterprises*
UEs	*User Equipment*
UL	*Uplink*
UoB	*University of Bristol*
UPF	*User Plane Function*
URLL	*Ultra-Reliable Low Latency*
VMs	*Virtual Machines*
VR	*Virtual Reality*
WECA	*West of England Combined Authority*

1. Introduction

Effective knowledge transfer through training is a core part of people development and is essential for social sustainability. Classroom and workshop training where all attendees are co-located within the same demonstration space are a proven method to facilitate this.

Traditionally, such practical training courses provided by the NCC to customers across the UK have been carried out by trainers either within its training facilities on-site or at a suitable location at the customer site. However, both scenarios can be linked to significant economic and environmental costs due to travel, accommodation, and transportation of equipment. As such, with the continuous drive for sustainability over the past two decades the work developing alternative solutions has become more vital.

Additionally, the recent COVID-19 pandemic put extra pressure on training providers and on companies in need of practical training. This was due to the stringent restrictions put in place such as barring all non-essential travel and gatherings for a significant period.

Though there are distance learning options, and internet-based courses available, the capability to engage effectively with the trainer and deliver practical aspects of a course is difficult. More immersive solutions need to be proposed to address this industry challenge.

The augmented reality practical training demonstrator that is presented in this report will highlight the latest AR wearable technology as an example of an advanced distance learning solution. Practical training for the manual lay-up of composite materials through the 'Introduction to Pre-preg' manufacturing training module offered by the NCC is selected as the use case.

The solution aims to exploit the capabilities of the 5G technology available to enable extra functionality and provide trainees with a real-world experience similar to when on site with the trainer. This is realised by a two-way communication stream back to the trainer.

1.1 AR Project Objectives

The main project objective was to evaluate the effectiveness of applying the AR technology over a fully functional 5G network to improve user experience and training performance of interactive remote training and collaboration. The technology was designed to effectively emulate a physical classroom or workshop without the need for the trainers and trainees being physically in the same space.

The use case was created to fill the gap for virtual practical training courses. This is particularly pertinent in current times due to the COVID-19 pandemic and sustainability drivers as outlined above. Additionally, this demonstrator can create a work package which has wider implementations in the manufacturing industry for more immersive demonstrations remotely in a variety of scenarios.

One opportunity from a working AR demonstrator is the ability to cascade the digitalisation methodology into other similar courses within the composite manufacturing industry. However, there is also the possibly of applying this more widely within the manufacturing sector as well as outside, as there are various practical courses which could benefit. Example applications may include repairing scenarios, overhauls, and maintenance work.

The potential benefits for companies of all sizes across the UK because of this are numerous. These include:

- Drastic reduction in costs for supplementary activities such as travel, accommodation, and transport.
- Sizeable decrease in emissions as a result of training activities.
- Overall improvements in workforce ability and skill due to more effective training.

1.2 Purpose of 5G in AR Assisted Training

To create a comprehensive virtual training experience and achieve an equivalent knowledge transfer as with traditional courses, the network and any associated internet connection must have sufficient bandwidth to service network traffic created as result of running an on-line experience.

5G has the potential to realise this without the need for a wired connection as its radio performance, capacity and flexibility capabilities are significantly enhanced from its predecessor, 4G.

The use case has several specific requirements for the network connection.

- Achieve a high average data throughput speed so the video and audio quality in the two-way communication between trainer and trainee is not limited and end user service quality is good.
- Provide sufficient bandwidth to enable the two-way communication function on multiple devices.
- Ensure latency does not impact the overall quality of the two-way communication and knowledge transfer from trainer to trainee.

With average speeds theorised to be at least an order of magnitude greater than 4G LTE, 5G shows a significant improvement. Further, the use of higher frequency bands that have been less widely used thus far allows 5G to drastically increase its available bandwidth. As a result, the number of additional devices that can be connected is theoretically much larger. Finally, depending on the location, usage, and maturity of the 5G network, the latency theoretically predicted ranges from below 2ms to 10ms. This is a sizeable difference to the average results of around 20-40ms from 4G LTE, though this can go up to 200ms.

Therefore, it is possible to see that 5G offers significant improvements in all three parameters from the previous generation network and those are the biggest justifications for its use in this work package.

1.3 Use case overview and architecture

The conventional 'Introduction to Pre-preg' practical training course involves the manual lay-up of a simple part in the form of a frustum using pre-impregnated (pre-preg) composite materials and a foam core material.

Trainees have the chance to try the process for themselves following several live demonstrations by the trainer that outline the key steps and skills necessary to complete the process successfully. This provides the trainees with more manageable tasks to follow. The process, itself, includes details about working with the different materials and using specific tools, alongside theoretical explanations from the trainer which make the visual and auditory cues crucial to learning.

The suggested AR training course provides an effective individual guide program for each trainee to use and progress through the method to be executed at their own pace. This package aims to be stand-alone and have all the necessary information for the practical course within it. Delivery is in the form of on-screen three-dimensional (3D) graphics, text instructions and tutorial videos.

The additional 3D graphics are added as an overlay on top of the physical environment to enable visualisation of the respective instructional information for each step. Where needed, the tutorial videos provide further support for the trainees by enabling each trainee to replay their instance of the video to improve their knowledge of the process.
Additional functionality also allows for the collaborative training aspect through real time two-way communication, to an instructor offering extra support to trainees and an enhancement of the learning experience. This function is called 'Expert Helper' and is a live video and audio call where the trainee can show and discuss over any issues with the trainer using the camera on their connected mobile device.

Figure 1 below shows the fundamental architecture of the proposed AR solution. The 'Expert Helper' function is driven from the NCC Headquarters (HQ), while the trainees are based in a remote location with the required hardware.

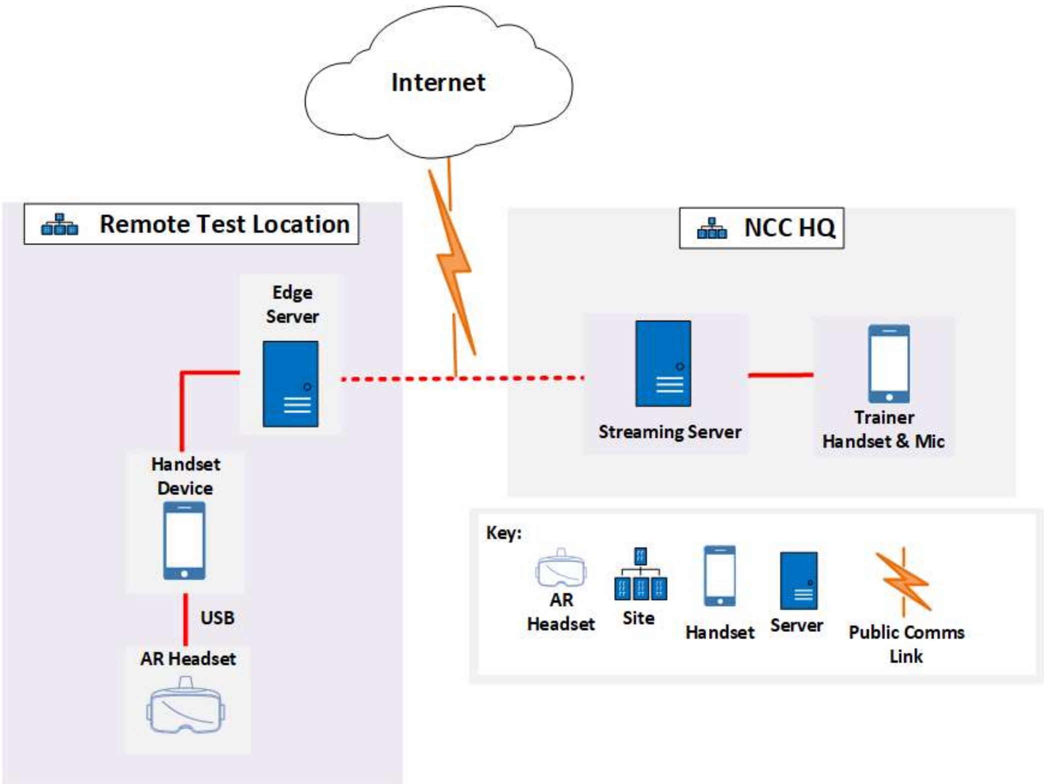

Figure 1 – Fundamental use case architecture

As outlined earlier, in Section 1.2, the 'Expert Helper' feature is heavily reliant on the 5G network, to maintain the required quality throughout the course duration.

To satisfy all the recognised requirements and overcome any digitisation challenges, MatiVision, an immersive technologies expert company were consulted for support in this use case. Based on their experience, it was possible to steadily produce different concepts that would enhance the course content. From the initial discussions, plans were made to create the necessary 3D graphics and demonstration videos alongside the supporting NCC staff. MatiVision could then begin work on the 'Expert Helper' streaming platform.

1.4 Use case and network metrics

To quantify and recognise whether the objectives have been met, two use case sub-categories have been introduced:

1. Use case monitoring
2. Network monitoring

The first sub-category covers the user experience of the AR course and is measured through user feedback. The main points are whether the user would be happy to use this style of training over conventional on-site practical training and based on a one-to-five grading, rank the experience.

The second sub-category measures the network performance using a selection of metrics collected from the radio network.

Tables 1 and 2 below define all the measurable quantities for the use case and the test bed, respectively. These are taken from the 'Benefits Realisation' document which contains all requirements defined by the project partners and sponsors during the project inception.

Table 1 – Use case monitoring measurable quantities

Use case metric	Target audience	Measurement type	Unit of measurement
Would use alternative AR course instead of on-site course	Uptake by NCC (and industrial partners)	Feedback from survey after course	Yes / No
Would use alternative AR course instead of on-site course	Uptake by academic institutions	Feedback from survey after course	Yes / No
Quality of guided instructions	All	Feedback from survey after course	1 – 5 Grading* (1 = Extremely dissatisfied, 5 = Extremely satisfied)

* Note – need to score 4 or above to class as a high score.

Table 2 – Testbed monitoring measurable quantities

Network metric	Counter	Description	Units
Server to user bandwidth	Total downlink IP throughput	Total downlink throughput (all users)	Kilobits per second
Server to user bandwidth	Total downlink IP throughput	Total downlink throughput (each user)	Kilobits per second
Latency tolerance	E-RAB level IP latency in downlink	Mean IP latency in downlink at the E-RAB level	Milliseconds
Jitter tolerance	NTP mean jitter	Mean value of the jitter estimator between AP and NTP servers averaged over granularity period	Milliseconds
Packet loss tolerance	Downlink PDCP SDU air-interface loss rate	Fraction of IP packets (PDCP SDUs) which are lost on downlink interface	Percentage
Packet drop – downlink	Downlink PDCP SDU drop rate	Fraction of IP packets which are dropped on the downlink	Percentage
Packet drop – uplink	Uplink PDCP SDU drop rate	Fraction of IP packets which are dropped on the uplink	Percentage

1.5 System Requirements Development

As described in Section 1.3, the proposed solution is aiming at providing a comprehensive practical course remotely which has thus far been a great difficulty. This has been the case because of the issues of capturing the required level of detail without having the trainers on-site presenting the course and answering any questions.

However, with the latest advancements in AR hardware and supporting software solutions, the first difficulty has been alleviated as the AR glasses can be pre-programmed with all required information and 3D graphics.

The ever-growing interest in video games, which use the same software approach, has resulted in more accessible and affordable solutions usable for training and assistance use cases in the manufacturing industry.

As the technology is still in an early growth phase there are several AR glasses available on the market in quite a wide price range. The Nreal glasses picked and used for this work package are a sensible compromise between quality, functionality, and cost. Additionally, these are one of very few other alternatives which can be directly connected to a 5G network.

This is possible because the Nreal glasses are not standalone but require an additional piece of hardware to provide power and network connectivity, and store and run the course application. This hardware is also necessary to enable the 'Expert Helper' functionality which would otherwise not work with the Nreal glasses central processing unit (CPU). As such, a mobile device could be chosen with the specific CPU and network connectivity capability integrated to enable all the functionality and 5G connection.

As there is a live stream element in the 'Expert Helper' functionality, the system relies on peer-to-peer (P2P) streaming to keep the latency down to a minimum. This means that the server is only used to relay messaging and the actual streaming takes place between the devices themselves. This keeps the hosting requirements to a minimum.

1.5.1 Project Methodology

To gauge the performance improvements of a 5G network and understand the capabilities of an already proven and tested network, the use case testing was split into two testing phases:

- Phase 1 – implement a 4G LTE network architecture to capture baseline data of the performance of the setup.
- Phase 2 – implement a 5G network architecture to test the capabilities of the newer technology and make an analysis of performance when compared with the 4G technology.

The Phase 1 results and discussions were presented in an earlier report but will be briefly summarised within this report for completeness and ease of reference.

Sections 2.4.1 and 2.4.2 describe the approach for delivering each phase of the use case.
Sections 2.5.1 and 2.5.2 detail the relevant phase results and discussion.
Sections 3.1.2 and 3.1.3 document previous 4G network testing results and outcomes.
Sections 3.1.5 and 3.1.6 present 5G network testing results and outcomes.

2. Use Case Development and Investigation

2.1 Use Case Architecture

The system setup of the use case was split across two locations:

1. The main NCC Headquarters (HQ)
2. A remote test location

The equipment and connections within the NCC HQ side did not change through both phases 1 and 2. The equipment only included a control mobile device for the trainer running the 'Expert Helper' function on which they can view the trainee video capture and communicate accordingly. This was connected wirelessly to a 4G small cell in phase 1 and a 5G small cell in phase 2.

The video and audio capture from the trainer's mobile device was transmitted to a streaming server via a wired network connection. The streaming server managed the feed and transmitted it to a caching server which received it in a one-to-one relationship and managed the necessary connection requests. The main differences between the two testing phases related to the remote test location side of the setup and will be described in further detail in Sections 2.1.1 and 2.1.2.

2.1.1 Phase 1 – 4G LTE Architecture

Phase 1 – 4G LTE trials used two sites: NCC HQ and a remote test location at NCC, Filton called NCCi. NCCi is located around 5 miles away from NCC HQ. The specific hardware used for the trials at NCCi included two pairs of Nreal AR glasses connected to two mobile handset devices through USB and a separate master control device. A 4G small cell provided the 4G connection and transmitted video and audio data from the caching server to the mobile handset devices and a master control device. Figure 2 below combines and visually summarises the architecture described in Section 2.1 and 2.1.1.

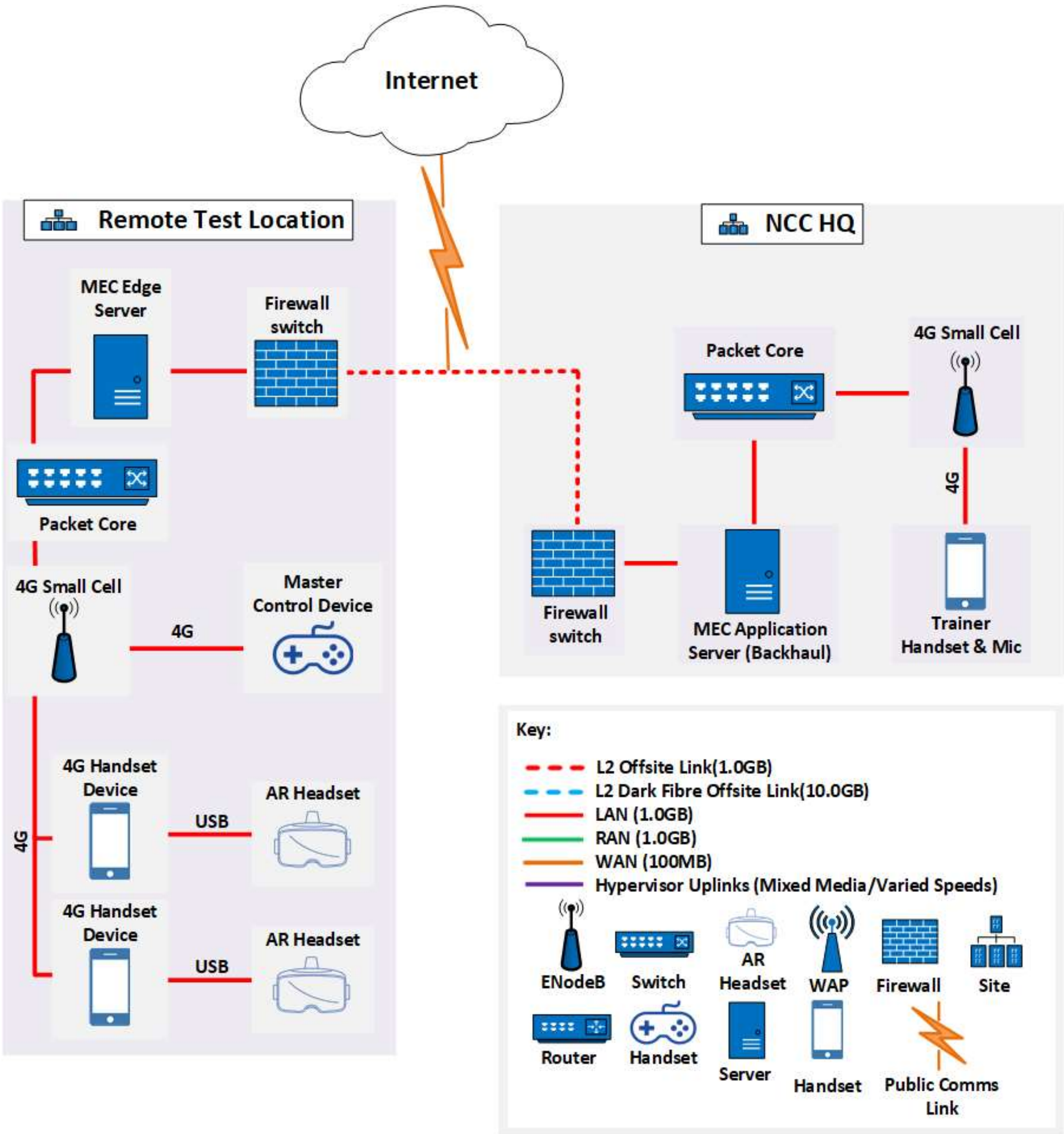

Figure 2 – Phase 1 - 4G LTE trials architecture map

2.1.2 Phase 2 – 5G Architecture

Phase 2 – 5G trials used NCC HQ and a remote location in Millennium Square, Bristol. Millennium Square is located approximately 8 miles from the NCC HQ. The hardware necessary for the trial was increased to five pairs of Nreal AR headsets connected to five mobile handset devices through USB and a separate master control device. The handsets powering the AR glasses were connected to a customer equipment device (CPE) over Wi-Fi while the CPE was linked to a 5G small cell over a Nokia 5G connection. Figure 3 below combines and visually summarises the architecture described in Sections 2.1 and 2.1.2.

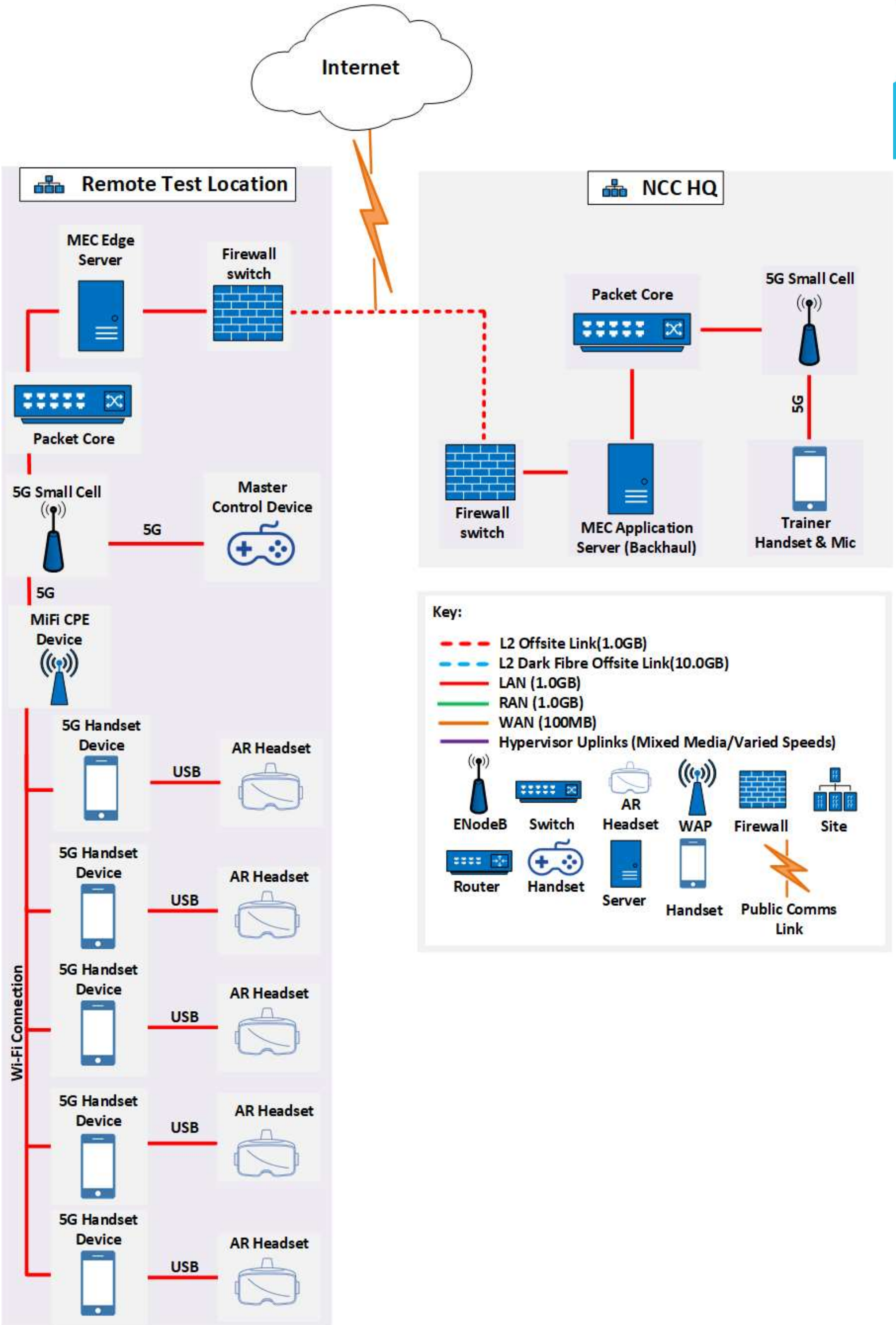

Figure 3 – Phase 2 - 5G trials architecture map

2.2 Use Case and Network Benefits

With a successful outcome from the project the use cases will prove that there are significant benefits for similarly positioned work packages using AR technology and a 5G network.

2.2.1 Use Case Benefits

Being able to effectively digitise practical training courses unlocks similar use cases spanning a variety of industry sectors not limited to manufacturing.

This will be significant in the development of remote working packages and will improve the training outreach throughout the UK. A functional AR solution will reduce the need for travel, accommodation, and transport of equipment to and from provider and customer sites. This will be crucial in decreasing the overall financial as well as environmental costs associated with these services. As a result, the products will experience long-term cost reductions that will make them more affordable to small and medium-sized enterprises (SME).

As mentioned above an effective remote working solution such as this one will contribute to the overall environmental sustainability goal of enterprises such as the NCC by using less energy in a more efficient capacity. This will lead to a sizeable carbon footprint reduction that will be a further contributing factor. In time these benefits will be able to cascade down into the wider manufacturing and advanced engineering fields and have a greater effect on the UK net zero strategy overall.

The use case can also have social sustainability benefits as well. A matured solution has the potential of improving the training experience and knowledge transfer to the trainees and thus producing a more skilful workforce.

Further, in terms of specific benefits relating to composite manufacturing, the AR solution can enable quality assurance to be included all the way through the laminating process. The technology provides the capability to verify the steps carried out by the operator against an acceptable standard and ensure quality compliance. This will also result in a reduced scrap rate and a saving in cost and energy consumption.

2.3.2 Network Benefits

Based on the predicted capabilities of a 5G network, the use case can specifically benefit from the lower latency, the higher bandwidth, and faster average speeds.

The shorter latency of 5G allows for real-time communication with the trainer which can improve the trainee experience and understanding. The lower latency can also improve the capabilities of time sensitive signals such as those in precision machine control applications. This is pertinent in the liquid resin infusion (LRI) use case within the 5G-Encode project and more details can be found regarding this in that final report.

The wider bandwidth available in 5G will enable a much larger amount of data to be transferred from one location to another at any one time by single and multiple devices. As such, larger cohorts of trainees can be accommodated in each course delivery. For other use cases this can aid substantial amounts of data acquisition and transfer from various sensors to a processing unit. This is crucial in the automated pre-forming cell (APC) end effector upgrade use case within the 5G-Encode project and more details can be found regarding this in that final report.

The speed itself will provide better video and audio quality to the 'Expert Helper' function of the AR solution. Additionally, for other use cases it can increase efficiency due to a better productivity overall. This will specifically aid the asset tracking use case within the 5G-Encode project and more details can be found regarding this in that final report.

2.3 Use Case Development

To ensure that the hardware presented throughout Section 2.2 and the ancillary software work effectively for the specific use case, developments had to be made over the project timeline. These were as follows:

- <u>AR glasses audio capability:</u>
  The 'Expert Helper' function as well as the extra tutorial videos in the application require audio capability. Available AR hardware with in-built audio functionality were selected. The Nreal glasses cover this requirement having dual microphones and dual speakers integrated in their frames. No additional hardware, for example, headphones were required. This both reduced costs and complexity of kit setup.

- AR glasses ergonomics:
  The user ergonomics as well as the operational safety while using the AR hardware was particularly important for the use case. The Nreal glasses aided both considerations based on the extra features integrated into the design. A variety of nose pads were available for each user to select based on comfort, and a cable hook allowed for the cable to secure the glasses onto the head of the user. The latter feature both ensured that the glasses would not move or fall off, but also reduced the risk of catching the cable while working on the course.

- Mobile handset CPU:
  The AR application that facilitates the digitised training course required a specific computational power to run properly. As a result, this led the decision on the specification of the mobile handset device that had to used. A Snapdragon 865 CPU was the minimum requirement and the OnePlus 8T device was chosen as a suitable compromise between robustness, quality, and cost.

- Mobile handset 5G capabilities:
  Additionally, the mobile handsets were chosen for their 5G capabilities. These enabled the phones to function over the N77 and N78 5G bands which would be used in the Phase 2 trials and thereafter.

- 'Expert Helper' streaming capability:
  A bespoke server application was created to initiate the P2P streaming functionality. This server-side application allows two remote devices to relay messages with each other without knowing the network topology beforehand. The application can also be used to relay the expert helper stream in case the devices cannot open a P2P channel between them.

- Training course program:
  A custom real-time application was created to fulfil the requirements for the practical 'Introduction to Pre-preg' training course. Each step was carefully created as a real-time 3D graphics step. Each object, placement, tools to be used, all were created in 3D so the user can have an exact view of the objects and an overview on how to use them for each step.

- <u>Ancillary equipment:</u>

  A specific environment needs to be maintained while working with pre-preg composite materials. This ensures the workstation is clean, free of all debris or contaminants and the user can safely use all the equipment and constituents. As such, additional belts and phone cases with clips had to be procured, to allow for the phones to be used from an easy to access yet safe place.

- <u>Additional footage and graphics:</u>

  A key consideration of the project was to provide a comprehensive training experience which is easy to understand and follow by users from various knowledge backgrounds. Multiple types of instructions, tips and information were created within the course to provide multiple learning channels for trainees with differing skill levels. These sources included offline tutorial videos performed by the trainers and supplementary documentation and drawings in the form of on-screen graphics.

- <u>Course trainer setup:</u>

  For the use case proof of concept stage, it was found that a single trainer available for the 'Expert Helper' function was sufficient. This may have to be reconsidered should the trainee cohorts be larger, and the support need increased e.g., for more complicated processes in training deliveries.

2.4 Use Case Testing

In both Phase 1 and Phase 2 the testing programme was the same. Workstations were setup for the users with the necessary composite material and consumables kit, all specific tools, and the AR hardware. The number of users and their location changed from Phase 1 to Phase 2. Phase 1 users were based on the 4G network capabilities, while the Phase 2 was based on revised network capabilities and latest COVID guidelines. Further details and the results of the trials are presented in the following sections.

2.4.1 Phase 1 – 4G LTE

As described in Section 2.2.1 the Phase 1 trials were carried out within the available NCC premises between the HQ and the NCCi site at Filton. The trainee workstations for the course demonstration at NCCi are shown below in Figure 4.

Figure 4 – Phase 1 trainee workstations setup for course demonstration

During the Phase 1 tests the mobile handset devices USB tethered to the AR glasses were connected to 4G LTE using SIM cards. To be able to link the users to the 'Expert Helper' function, the trainer's mobile device was connected to the same 4G network. Figure 5 below shows the trainer workstation at the NCC HQ working on the 'Expert Helper'.

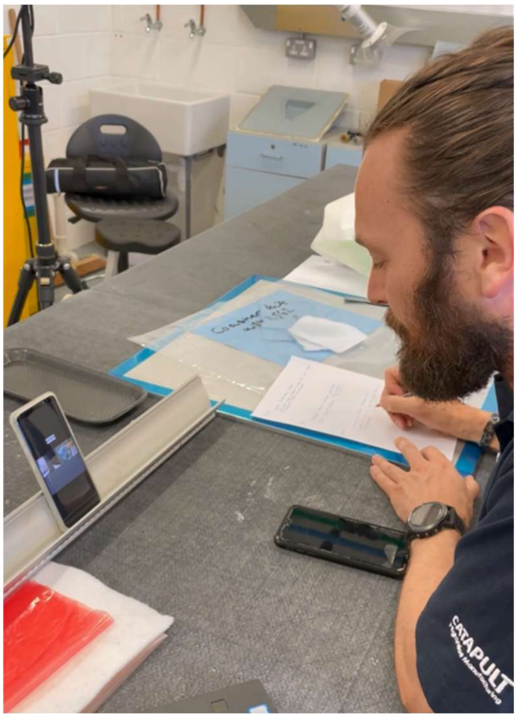

Figure 5 – Phase 1 trainer working on 'Expert Helper'

The trainer was able to observe all the video feeds streamed from the trainees and offer help accordingly. Figure 6 below shows that view, however 'NCC' text boxes have been added in places where IP needs to be protected.

Figure 6 – Phase 1 ‘Expert Helper’ screen view

The graphics viewed by the trainees within the augmented reality included ply placement indications alongside the text instructions. This aided the lay-up process and ensured the part was made correctly. A screenshot of the view with the AR glasses is presented below in Figure 7.

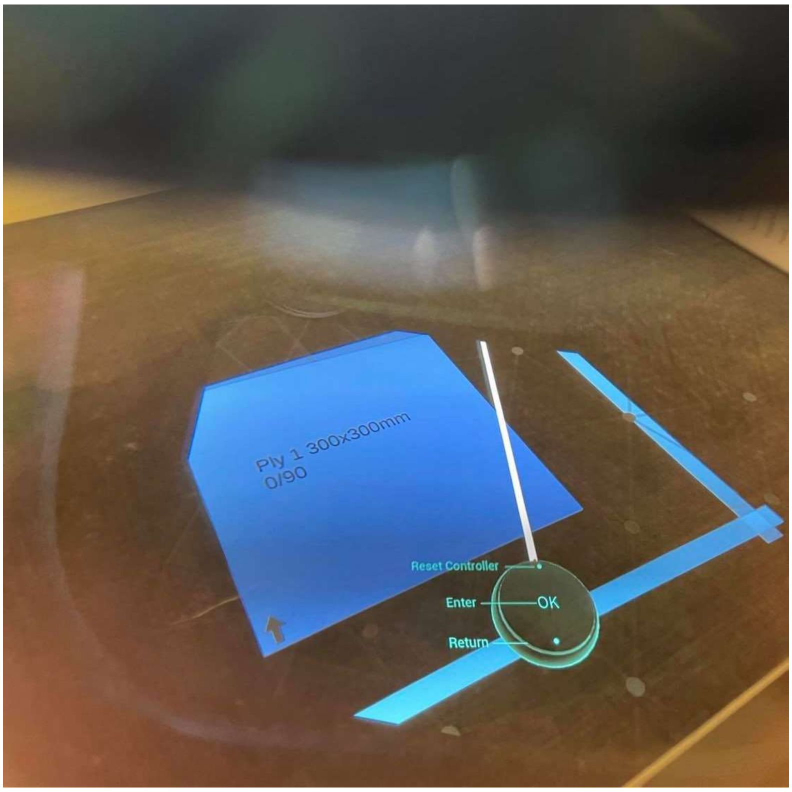

Figure 7 – Screenshot of Phase 1 AR vision system ply indication graphics

As outlined in Section 1.2, user feedback was collected to quantify the use case performance as experienced by the trainees. Figure 8 below presents the results regarding the satisfaction of the trainees with the guided instructions presented in the AR program, while Figure 9 shows how many would use AR instead of on-site training.

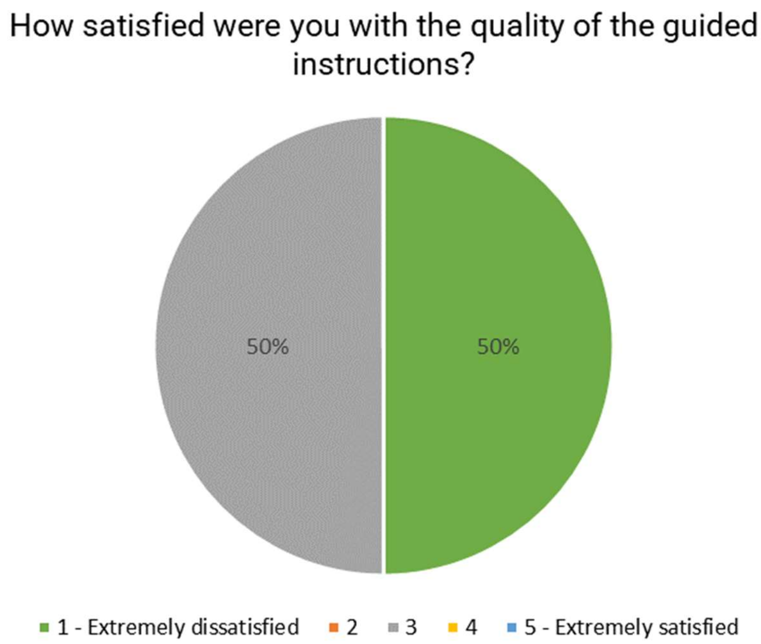

Figure 8 – Phase 1 user feedback regarding satisfaction with guided instructions

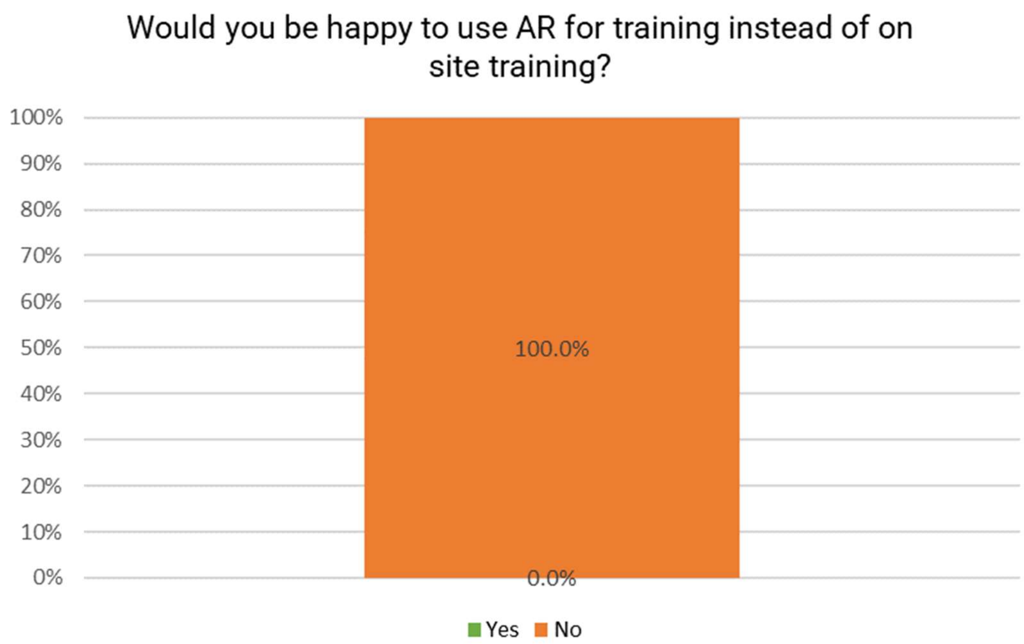

Figure 9 – Phase 1 user feedback regarding the use of AR instead of on-site training

The feedback forms included more questions to aid the understanding and development of the use case. These questions focused on the displayed graphics, 'Expert Helper' performance and knowledge transfer of the technology. The results from these have been included in Appendix A.

2.4.2 Phase 2 – 5G

The Phase 2 trials as outlined in Section 2.2.2 were carried out on Millennium Square in the Bristol City Centre as part of a two-day continuous demonstration made up of four separate user sessions. The number of workstations used simultaneously was increased to five based on bigger hardware capability and larger bandwidth available. However, the specific setup was similar to that used in Phase 1 as it was found to be working as necessary and the kits prepared were satisfactory. The overall setup is shown in Figure 10 below, while Figure 11 shows a different angle of some of the workstations in use.

Figure 10 – Phase 2 trial setup on Millennium Square, Bristol

Figure 11 – Phase 2 trial AR workstations in use

For the Phase 2 trial the mobile handsets USB tethered to the AR glasses were connected via Wi-Fi to a CPE device as outlined in Figure 3 which in turn were connected to a small cell through 5G. This was easier to setup and was less likely to run into networking issues when used at the remote location of the tests.

The ‘Expert Helper’ capability was implemented from the NCC HQ in a similar fashion to the Phase 1 trial. The trainer was able to review the live stream of the trainee seeking assistance and give advice using the two-way communication. Figures 12 and 13 below show the ‘Expert Helper’ workstation and the view of the trainer on their mobile handset device, respectively.

Figure 12 – Phase 2 ‘Expert Helper’ workstation

Figure 13 – Phase 2 ‘Expert Helper’ view on mobile handset device

From Phase 1, additional graphics were added to the AR guide program as well as re-worked text instructions to better capture the course content. Captured photos from within the AR glasses in Phase 2 can be seen in Figure 14 below.

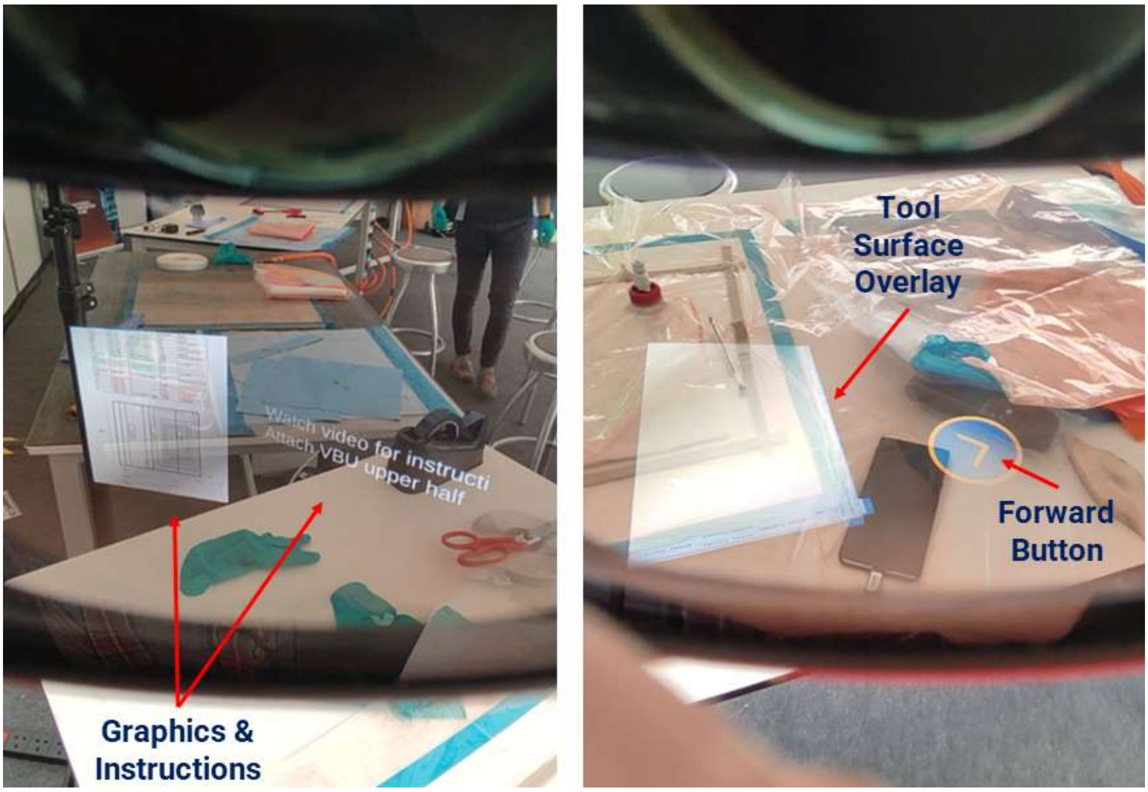

Figure 14 – Phase 2 AR glasses views: graphics and instructions (left), tool surface and navigation button (right)

Similar to Phase 1, user feedback was collected from all the AR sessions within the Phase 2 demonstrations and at least 20 sets were collected which resulted in a more comprehensive view of the experience. Figure 15 shows the latest results on the satisfaction of the users with the AR guided instructions, while Figure 16 presents the percentage of users who would use AR over on-site training.

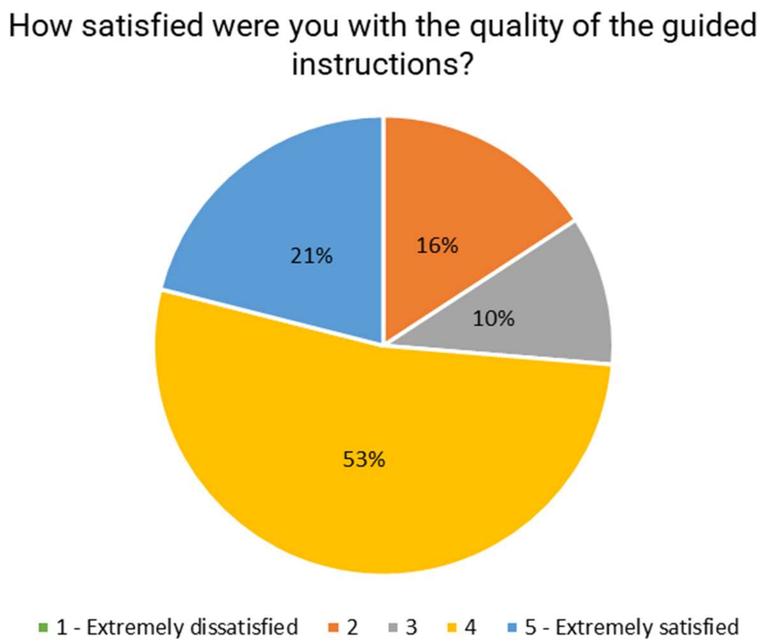

Figure 15 – Phase 2 user feedback regarding satisfaction with guided instructions

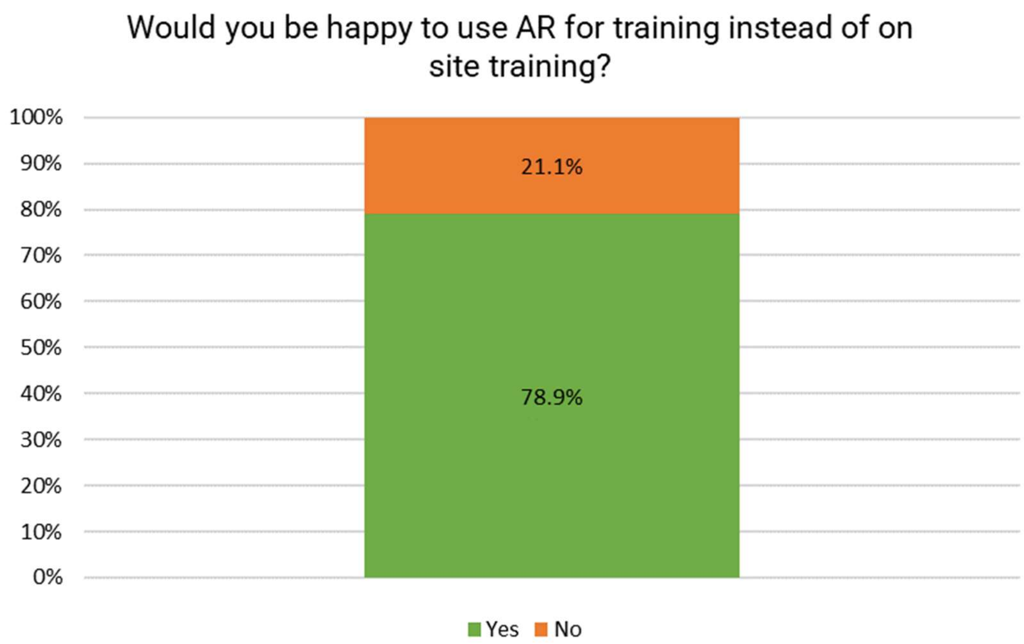

Figure 16 – Phase 2 user feedback regarding the use of AR instead of on-site training

Further user feedback from the Phase 2 VR trials has been presented in Appendix B.

2.5 Use Case Discussion

2.5.1 Phase 1 – 4G LTE

From the results of the user feedback presented in Figures 8 and 9 as well as the additional figures in Appendix A it was clear that the experience in the 4G trials was not of a satisfactory level. The data shows that the users were not convinced that the technology could be applied in a real-life scenario in its current format. However, the trial allowed for the use case to be run in its entirety to users not involved to the program development. This was crucial at that stage of the project to highlight key parts which worked well and those that needed improvement. Also, the trial allowed for the baseline 4G network metrics to be gathered which were important for the overall aims of the project.

The poor outcome of the trial could be explained by the relatively low development of specific digital content that went into the course. This showed that more effort was required in modifying the content to better suit a virtual presentation rather than simply re-using the existing conventional information. This was key to the future improvements made in the use case to enhance the user experience in the Phase 2 trial.

Phase 1 did allow for all the capability to be tested, and in particular the 'Expert Helper' functionality. This was seen to be working well with qualitative and quantitative feedback from the users showing that the communication with the trainer was good and latency was low enough for real time conversations.

2.5.2 Phase 2 – 5G

The results of the user feedback data in Figures 14 and 15 showed promising improvements in the AR experience. 74% of all users were left very satisfied with the guided instructions presented. Approximately 79% expressed interest in using the technology instead of a conventional on-site training course. As per the project objectives, data was recorded separately for this statistic depending on uptake – i.e., industrial, or academic. This total percentage was made up of 80% positive response from the industrial users and just under 78% from the users with an academic background.

From the additional feedback in Appendix B, over 75% of users were satisfied with the 'Expert Helper' function and its latency which enhanced the experience overall. Additional confirmation of this were the physical outcomes of the manual lay-up with a sizeable portion of users able to progress efficiently through the course after following the instructions and some using 'Expert Helper.' Finally, 14 of the users identified the technology as immersive and captivating which is extremely hopeful and clearly works towards reaching the main objective for the use case.

Nevertheless, even with these optimistic findings, the demonstration was extremely useful in highlighting several limitations or points for future work.

One limitation was the connecting cable between the AR glasses and mobile device. This caused discomfort when carrying out the manual lay-up steps as the users had to be careful with knocking the phone off the workstation or risk of disconnection.
Unfortunately, the Nreal glasses do not have further capability which allows for Bluetooth connections. Additionally, there were difficulties experienced by some users with operating the augmented reality glasses and software.

The technology is new and requires some time to get used to it, but this can be facilitated by having an AR tutorial section at the beginning of the course in the future. The location of the trial had high natural light exposure which degraded the AR overlays and graphics effects. This showed the limitation of the technology in very bright and reflective locations.

For the AR program there are some improvements to consider for the overall layout of the content in the field of view. Specifically:

- The navigation buttons should be re-positioned and re-worked to include a highlight when in use.
- The sizing and position of the 'Expert Helper' portion on-screen could be optimised to allow for an easier use and improve visibility from both trainer and trainee. A setup more similar to a video phone call in terms of size of the outgoing and incoming video window would suit better.
- The content of the course itself needs to be refined and further considerations made into its digitisation.

There are outstanding challenges which would benefit the application and use case in the future, these include:

- Addition of quality control features or instructions within the AR guide. There are methods that can be added to aid the user ensure the part being made is up to an acceptable standard. These need to be studied and digitised. However, at the maturity level of the technology at the time of the outlined trials it was decided the priority for this will be lower and its consideration delayed.
- Development of composite manufacturing specific content and in particular tutorial videos that aid complex process steps. This has the potential to be integrated into the server enabling the 'Expert Helper' function which will allow for videos and other media to be streamed directly to the AR hardware.
- Enable 'Expert Helper' to be able to view from the camera on the AR glasses rather than using the mobile handset.
- Introduce the 360° camera from the 360° video streaming VR use case in the trainee area to allow the trainers back in NCC HQ to view the progress of the course. This would also enable further aid to be given to struggling trainees and improve the experience.

2.6 Use Case Conclusions

The use case development outlined within this report shows progress in terms of the performance of the package and the experience achieved for the users. It is recommended that this progress be considered alongside the progress made in the Virtual Reality (VR) use case. A summary of this is included in Appendix C. As a result, the objective of producing an immersive and comprehensive practical training course in augmented reality can be considered completed at this stage. However, the set of trials carried out thus far have identified improvements that can further enhance AR and course delivery.

From the results presented in Sections 2.4.1 and 2.4.2 it is possible to draw several conclusions:

1. The use case proved viability for a sizeable group of users to competently progress through the practical training course remotely.
2. The immersive experience demonstrated the feasibility of transferring knowledge to trainees efficiently. This was supported in the user feedback regarding the use of AR courses instead of conventional ones. However, this is quite heavily based on the quality of the instructional content and the 'Expert Helper.'

3. Correlating this feedback with that of the 360° video streaming VR use case shows that there is a need for further development to be made before the same level of acceptance is reached.
4. Improvement tasks have already been identified methodically based on qualitative feedback from the users, the NCC trainers and the development teams.

The ‘Expert Helper’ feature was found to work well in both trials and did not show any improvement when the network changed from 4G to 5G. The quality of the communication was approximately similar in both trials which meant a substantial improvement from greater bandwidth or speeds could not be clearly observed.
The trials were inconclusive in terms of the number of trainees able to connect to the feature using a 4G network and whether this figure can be improved with 5G.

Lastly, there were usability difficulties with the technology which could be related to the technological background of the trainees. Differences in proficiency could also be observed based on age. However, all of these can be alleviated with additional consideration into the introduction of the AR kit and application to the trainees. As stated earlier, developments are planned in this area and usability should improve in the future.

3. 5G industrial Assessment

3.1 4G LTE and 5G Network Testing

As described earlier, to make a reasonable comparison between 5G and existing network technologies, a trial was conducted using a 4G LTE network which acted as the experimental baseline. The use case testing was also fundamentally the same which ensured that the improvements from one trial to another could be identified.

Apart from the developments within the use case scenario itself, data was also recorded from all trials to quantify the network performance, as outlined in the following sections.

3.1.1 4G LTE Test Setup

The 4G LTE system setup was outlined in Section 2.1.1. However, one specific consideration that was necessary during the baseline testing was surrounding the other work packages within the 5G-Encode program. To gauge the AR network usage and not hinder the use case performance the trial was carried out independently from other use cases. This ensured that the available bandwidth was maximised and would enable the best possible presentation for the experience.

3.1.2 4G LTE Network Metrics

Network performance was reviewed during the AR Phase 1 trial. The AR demonstration was conducted between 14:00 and 16:00. The ip.access 4G RAN network was configured to accumulate metrics for 60 mins, sending a log to the log server at every hour. This logging characteristic is reflected in the charts presented in this section.

Figure 17 below displays the 'Total Uplink IP Throughput', and this measurement provides the total uplink throughput in kilobits per second (kbps). The uplink throughput in kbps was calculated by dividing the count of the total volume of uplink data received in kbits, by the time taken to receive the data in seconds. The maximum achieved uplink throughput and target ranges for this measurand are displayed in Table 3 below.

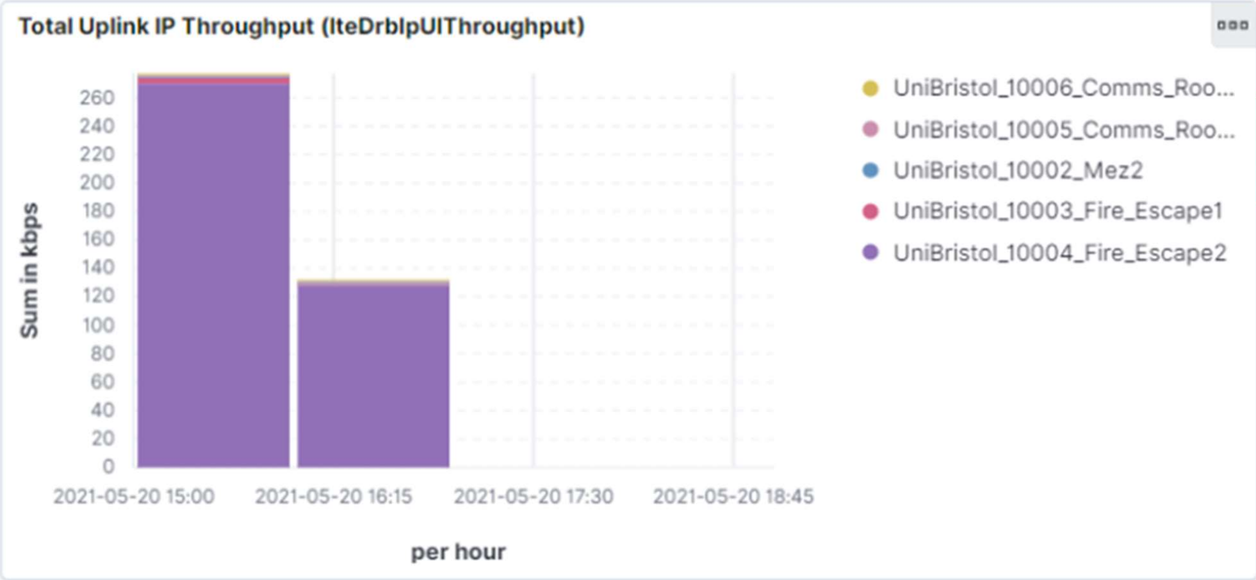

Figure 17 – Phase 1 total uplink IP throughput

Table 3 – Total uplink IP throughput targets

	Maximum Recorded (kbps)	Phase 1 Target (kbps)	Phase 2 Target (kbps)
Total Uplink IP Throughput	~260	1,000 - 10,000	10, 000 - 100,000

Figure 18 displays the 'Total Downlink IP Throughput', i.e., the total downlink throughput in kbps. The downlink throughput in kbps was calculated by dividing the count of the total volume of downlink data received in kbits, by the time taken to receive the data in seconds. The maximum achieved downlink throughput and target ranges for this measurand are displayed in Table 4 below.

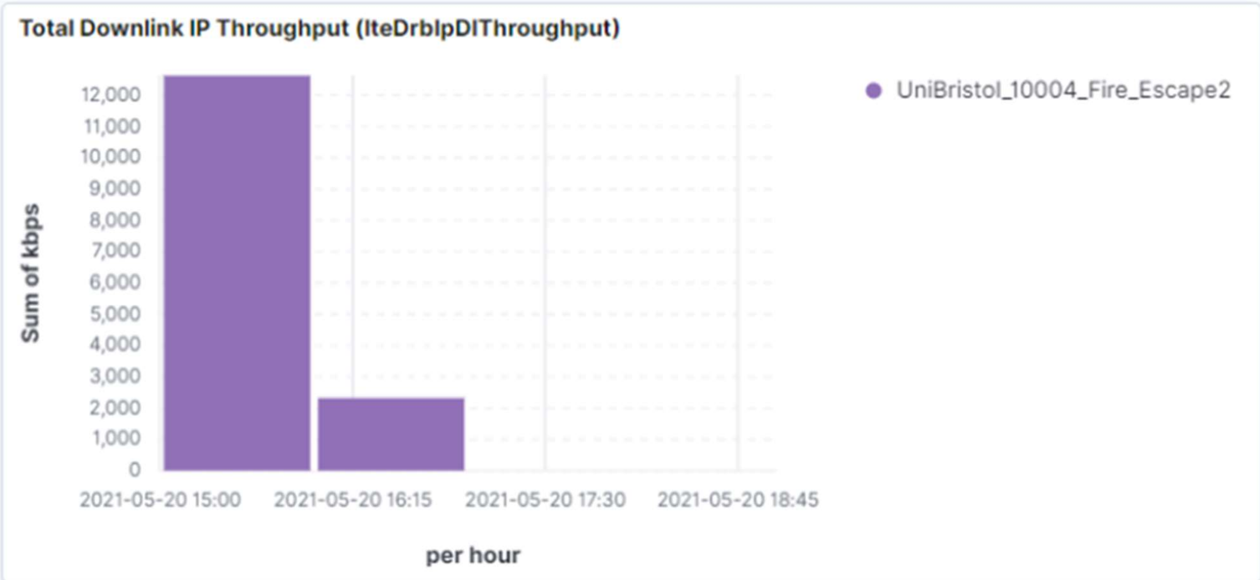

Figure 18 – Phase 1 total downlink IP throughput

Table 4 – Total downlink IP throughput targets

	Total data throughput recorded between 15:00 and 16:00 (kbps)	Phase 1 Target (kbps)	Phase 2 Target (kbps)
Total Downlink IP Throughput	~12,000	>= 4, 000	>= 20, 000

Figure 19 shows the measure of IP latency in the downlink for each radio unit passing data to support the use case. Latency between devices communicating over the network was on average 8ms. In the benefits realisation specification, the measured latency is significantly less than the stated value.

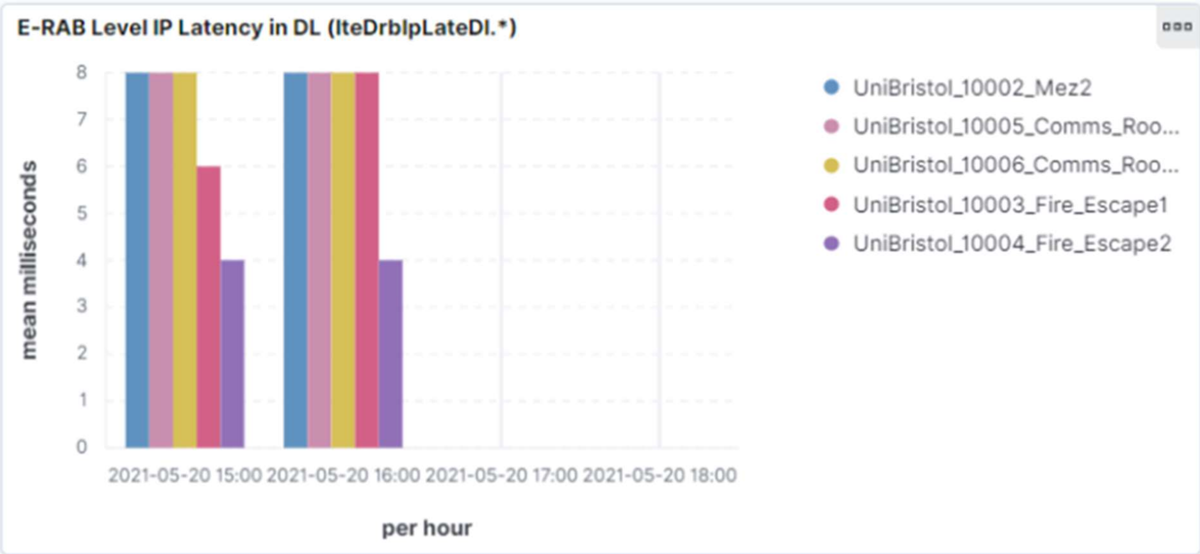

Figure 19 – Phase 1 IP latency downlink

Figure 20 shows mean packet jitter experienced during the use case Phase 1 test. In the benefits realisation specification packet jitter is specified in milliseconds, this relates to measurements possible in a wired network. Referring to Section 2.4.1 in the 4G/5G Network Performance Evaluation Guideline, packet loss and jitter are defined with the following statement:

"The main factors that cause packet loss and jitter are signal quality over the air interface, eNodeB load, and packet loss or jitter on the transport network. Poor air-interface signal quality may increase the packet error rate, which results in more packet retransmissions and segmentation. As a result, the number of lost packets and jitters increases."

Thus, the metric generated was measured in mean packet jitter not milliseconds as documented in the benefits realisation guide.

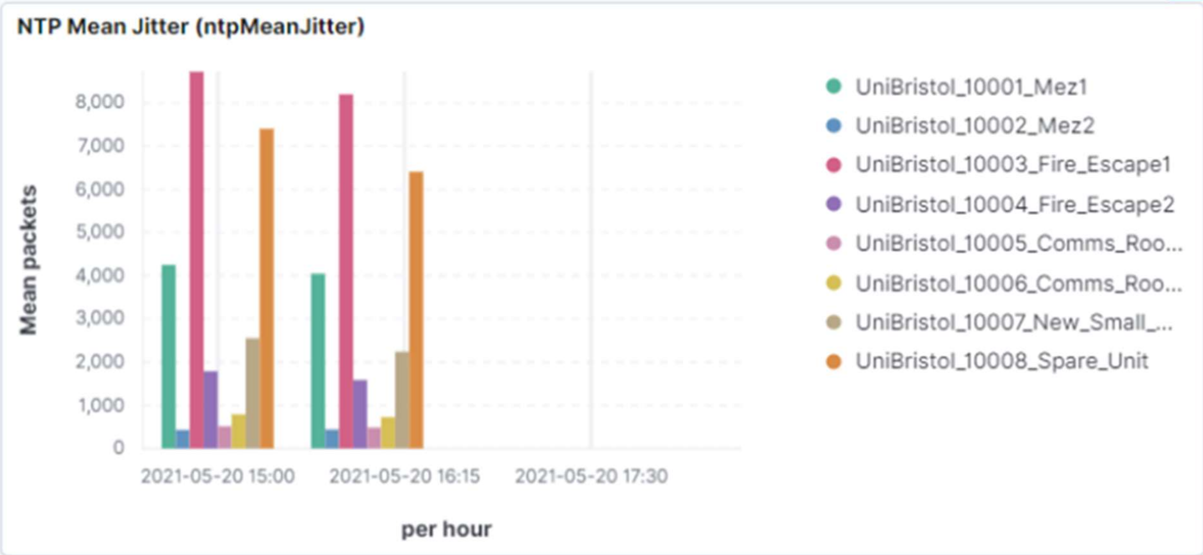

Figure 20 – Phase 1 NTP mean jitter

3.1.3 4G LTE Outcomes/Shortfalls

The maximum 'Total Uplink IP Throughput' recorded was approximately 26% of the lower bound of the target value (Actual ~ 260 kbps, Target = 1,000 to 10,000 kbps). During the AR trial, three devices uplinked video stream as part of the trial. Data suggests that more devices will be required to reach the target uplink throughput.

The maximum 'Total Downlink IP Throughput' recorded a 200% increase on the target value for the initial phase (Actual ~ 12,000 kbps, Target = 4, 000 kbps). Data suggests that three devices downloading the video stream were sufficient to evidence fulfilment of network downlink requirement.

The mean 'IP packet latency downlink' was recorded in milliseconds and was 96% lower than the target value for the initial phase (Actual ~ 8ms, Target = 200ms). This measurement was taken with no other traffic on the 4G radio network.

The mean 'NTP Mean Jitter' was recorded in packets and does not match the target value specified in milliseconds for the initial phase. This measurement was taken with no other traffic on the 4G radio network.

3.1.4 5G Test Setup

While 5G is already known to provide much higher throughput performance and lower latency compared to 4G LTE, it also provides the required network and data isolation by deploying network slicing as a standard (3GPP Rel.15/16). By doing so, the data arriving at the end-destination of the Independent (Public) networks can be effectively controlled and monitored, along with the network resources and equipment which can also be managed/orchestrated accordingly.

Based on the latency requirements of a use-case, the 5G Core and edge compute capability allow the user data plane (UPF) and application services (VMs, servers, applications, etc.) to run locally at the edge (closer to the end-users), significantly reducing the latency while minimising the backhaul requirements. The high throughput on the downlink (DL) along with the very low latency enable the provision of VR and AR services while also providing a large degree of freedom in terms of video quality and number of connected users.

When analysing network metrics consideration was required for the differing technologies, vendor implementation statistics and in the case of 5G, vendor software maturity to support statistics.

An example of a technical difference is the clocking used in 4G which is Network Timing Protocol (NTP) based and 5G which is Precision Timing Protocol (PTP) based.

For the radio technologies 4G was created using an ip.access solution and 5G created using an Airspan ORAN solution. In 5G statistics there are no measures in place to directly measure PTP, this impacts the capability to monitor, view and report on timing related latency and jitter.

The 5G-ENCODE network architecture between the Private Network (NCC), and the Satellite (NCCI) and Independent (UoB) networks for the VR/AR demonstration is shown in Figure 21 below. From a cellular network perspective, the independent network hosted by the UoB 5GUK test network, represents the public network and acts as an extension of a private network, i.e., NCC network.

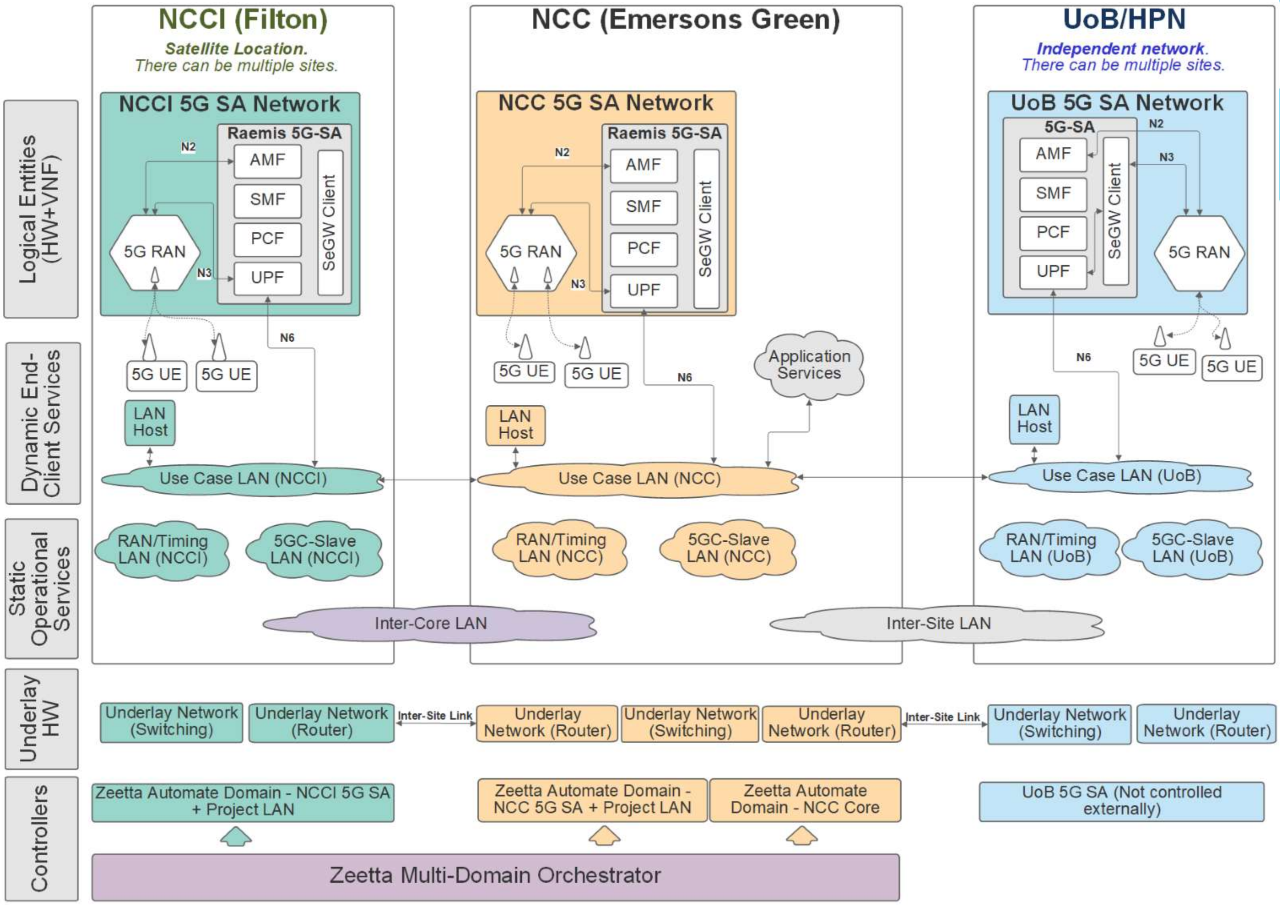

Figure 21 – 5G Encode network architecture

3.1.5 5G Network Metrics

Network performance metrics were collected during the final AR and VR demonstrations at Millennium Square and are shown in Table 5 below as KPIs (Key Performance Indexes). The network requirements for the AR demonstration were found to be quite low during the trial. This was based on the one-to-one interactions of the 'Expert Helper' function which were short and at random periods of time throughout the demonstration. As such, a brief test was devised to gather data on the usage where all five devices were connected to the 'Expert Helper' simultaneously.

Table 5 – Phase 2 5G measured network metrics

Measured KPIs	Value	Unit
Server to Users throughput (i.e., Total Cell Throughput) – Total Downlink IP Throughput.	16.1	Mb/s
Server to Users throughput (Individual User Throughput) – App-based DL Throughput on each end-user.	3.22	Mb/s
DL Latency Tolerance – Downlink IP Latency.	3.15	ms
DL Jitter Tolerance – Standard Deviation of the app-based latency.	2.05	ms
% DL Packet Loss Tolerance – Downlink PDCP SDU Air-Interface Percentage Loss Rate.	0.12	%
% DL Packet Drop Rate – Downlink PDCP SDU Percentage Drop Rate.	0.12	%
% UL Packet Drop Rate – Uplink PDCP SDU Percentage Drop Rate.	0	%

These KPIs were derived from a variety of metrics collected from the 5G network (5G Core – open5gs) and the UEs (User Equipment – Android devices/CPEs). The overall network performance was found to be satisfactory in terms of meeting all user service demands and enabling all necessary demonstrator functionality. The AR/VR service provisioning showed no problems or interruptions throughout the demonstration.

The total cell DL throughout was 16.1 Mbps on average, reaching a peak of 31Mbps, as shown in Figure 22 below. It should be noted the supported cell capacity was much greater than the one achieved during the demonstration. The wireless link between the 5G NR (New Radio) and the 5G CPE devices was tested before the demonstration, exceeding 700Mbps in DL. Consequently, the stress on the network during the AR/VR demo was well below its throughput limit. It is worth noting that there was a small packet drop in the DL due to some initial inconsistencies between the 5G CPE and the 5G NR. The number of packets dropped was negligible. No dropped packets were detected on the uplink (UL).

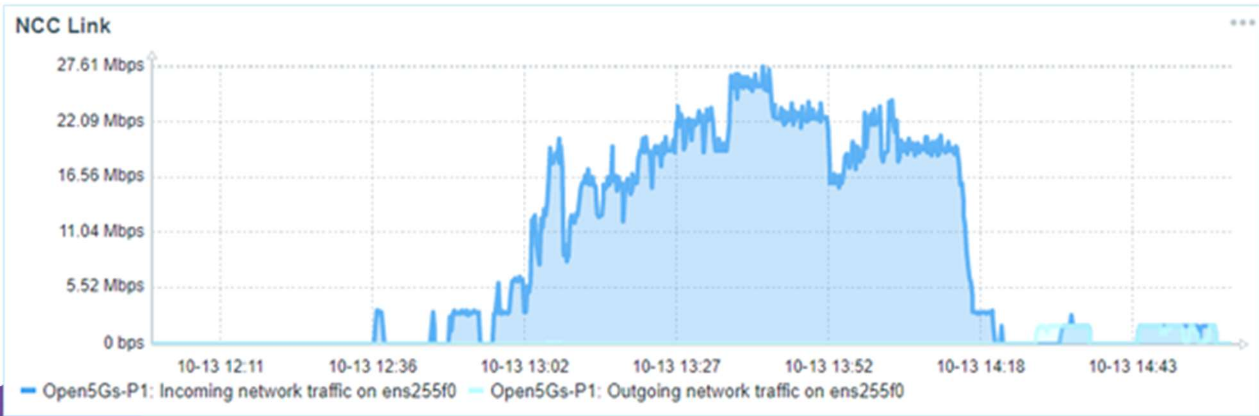

Figure 22 – Phase 2 5G downlink throughput

The average DL latency and jitter between the 5G CPE and the streaming/video server during the AR/VR service provision was measured at 3.22 ms and 2.05 ms, respectively. Hence, the latency performance of the 5GUK Test Network was also satisfactory in terms of end user experience. However, advanced optimization on the 5G network and 5G CPE devices could potentially drop these figures even further.

3.1.6 5G Outcomes/Shortfalls

Although all handsets used with the AR glasses were 5G capable, only 5G NSA operation was enabled on the devices by the manufacturers. This made the 5G SA operation of the 5GUK Test Network incompatible with the tested devices. Thus, CPEs were utilised instead and 5G network connectivity was provided to the end users through Wi-Fi.

Meanwhile, the involvement of an additional hub with a different RAT (Wi-Fi) to forward the packets introduced additional latency and limited the management of the devices which remained hidden from the 5G core behind the Wi-Fi network. Hence, the use case architecture was limited and did not allow the benefits from the 5G network to be fully realised in this demonstration.

Nevertheless, the network requirements of the AR demonstration and the ‘Expert Helper’ function were quite low. No significant issues were reported during the short periods of usage (typically <5 minutes) at sporadic intervals throughout the course. Furthermore, users made use of the ‘Expert Helper’ function at random times, avoiding high throughput peaks, thus reducing the network connectivity requirements.

The 5GUK Test network was stable throughout the demonstration and without any issues. During this demonstration one of the three inhouse developed CPEs presented instability with its network connectivity due to a malfunctioning SIM card. However, the 5GUK team was able to resolve the problem and restore the service for the duration of the demonstration.

3.2 5G Discussion

3.2.1 Benefits of 5G

Benefits recorded by the Phase 2 trials based on the 5G connectivity have been outlined throughout the report but in summary:

1. Data capacity due to available bandwidth (exceeding 700Mbps downlink):
   - Ensured good video and audio quality of 'Expert Helper' function for multiple concurrent users.
2. Average speed to each connected device:
   - Ensured good video and audio quality of stream to and from trainer.
3. Low latency (sub 10 milliseconds):
   - Improved trainee experience by decreasing delays between video and audio feeds of 'Expert Helper.'

A 5G network within the industrial setting of the NCC HQ also has the potential to facilitate different course locations. A matured and robust system would allow for the AR training course to be carried out throughout the factory as needed.

3.2.2 Limitations of 5G

Most of the 5G-capable devices currently on the market do not support 5G SA operation (disabled on software level), i.e., operating on a pure 5G cellular network without the anchoring 4G cells. 5G Networks and devices are not yet mature enough to support a fast and easy deployment of AR/VR services. Vendors have been slow to implement and support the basic 5G SA functionality, even to their most recent and flagship devices.

In order to overcome the limited support for 5G SA, the 5GUK engineering team of Smart Internet Lab has developed multiple in-house-built 5G CPE devices. By doing so, 5G SA connectivity could be established and demonstrated between the 5G CPEs and the 5G network, while enabling the provision of 5G services to the AR/VR devices through Wi-Fi 6. These devices are not planned for mass production.

The current inhouse development at Smart Internet Lab is hampered as Wi-Fi services are still pending their integration with the developed CPE devices. The chip-crisis around the world makes it exceedingly difficult and expensive to purchase Wi-Fi 6 Access Point Modules in small numbers (for creation of a Wi-Fi hotspot). Hence, external Wi-Fi 6 Access

Points (APs) were connected to the ethernet ports of the CPEs, and traffic was diverted from 5G, to ethernet, then Wi-Fi.

3.3 5G Conclusions

One main conclusion can be drawn regarding the 5G network based on the user feedback and data collected from the Phase 2 trials. The 5G network setup by the UoB team was sufficient to meet all user service demands during the trial and enable all the AR demonstrator capabilities. The 'Expert Helper' was of a consistent and sufficiently high video and audio quality. There was the scope for multiple users to utilise the two-way communication feature, though it was rare for that need to arise.

However, based on the two trials outlined and compared within this report, it is not possible to conclusively state that there were significant improvements from 5G over 4G LTE. This is because the network requirements of the use case were low and both technologies did not present many issues covering those.

To investigate the full capabilities of 5G in this application, a further trial would be necessary. In this test, devices will have to be continuously added on the 'Expert Helper' until failure of either the server application or the network limit is reached. Though, this occurrence in a real-world course of this use case is unlikely to happen in its current format. Additionally, by having the 360° camera as part of the system which feeds back to the trainers, the 5G element will be utilised further and the network performance tested.

There are further developments that can be made to the AR solution which sees a greater reliance on the mobile network. These developments involve the use of libraries of tips, graphics and tutorial videos on cloud or server storage. For this trial, the videos embedded in the AR application were kept to a minimum with consideration of the internal device storage. However, going forward these can be streamed from a library and as such the capabilities of the network will become much more decisive in the performance of the demonstrator and 5G is likely to be utilised nearer its full potential. This will lead to a more modular solution that lends itself to modification for other applications as well.

Regardless, the metrics recorded suggest that the 5G network has the capability to achieve all network targets set out for the project. The downlink exceeding 700Mbps as well as the 3ms and lower latency values were an impressive display for the technology. Based on further testing and optimisation the 5GUK team are optimistic that further improvements can be made to these.

Though as identified in Section 3.2.2, it is important to note that there are continuous difficulties in setting up a 5G SA network. This can be a considerable drawback to marketing and introducing 5G to the wider market of SMEs in the manufacturing sector and beyond. This was identified during the Phase 2 trials, as there was some instability in one of the CPEs which caused some delays in connecting the necessary hardware for the demonstration.

In summary, the benefits experienced by the use case from the 5G network were sufficient in enabling all functionality of the solution. However, this was not observed to be significantly better than that recorded in Phase 1. Nevertheless, the use case was able to reach its main objective. The experience was immersive and useful for the users and has the potential of being a viable innovative remote learning solution.

Appendix A – Further Phase 1 User Feedback

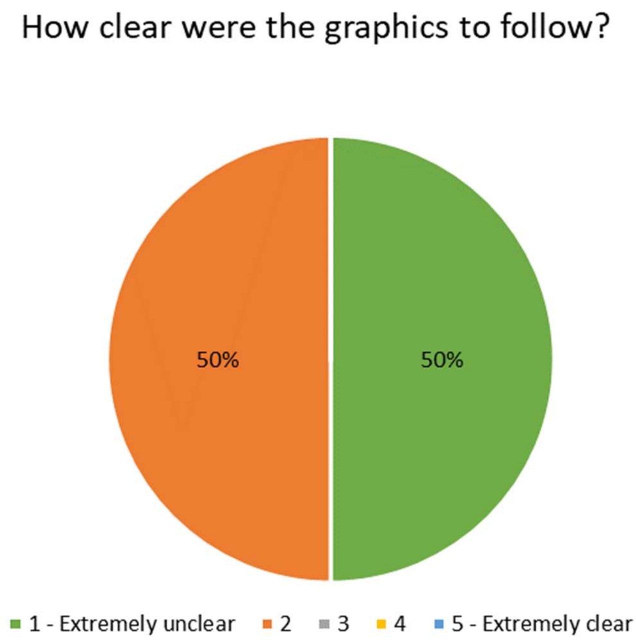

Figure A1 – Phase 1 user feedback regarding clarity of graphics to follow

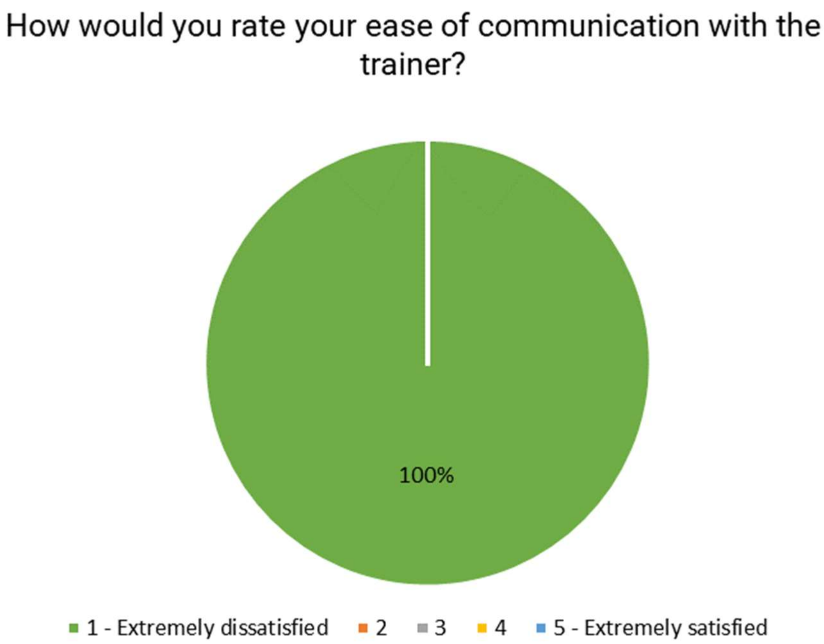

Figure A2 – Phase 1 user feedback regarding ease of communication with trainer

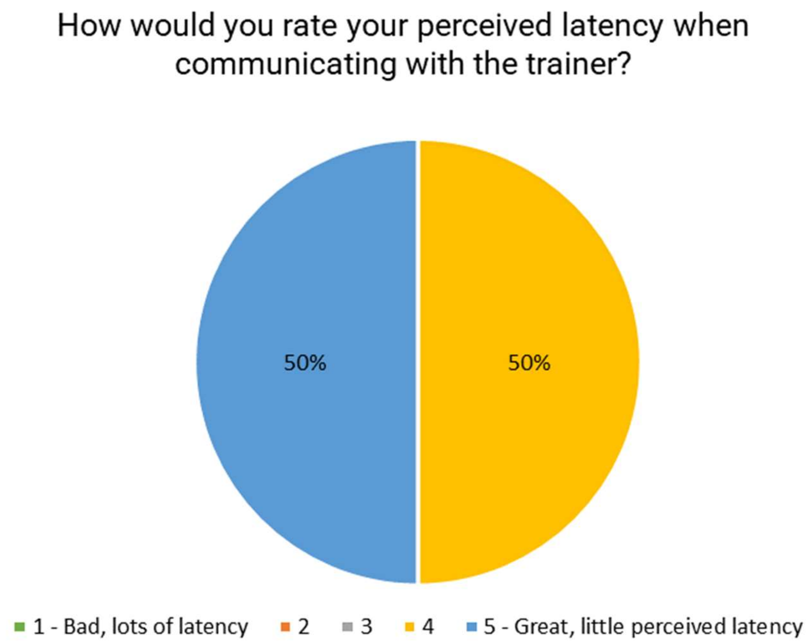

Figure A3 – Phase 1 user feedback regarding perceived latency when communicating with trainer

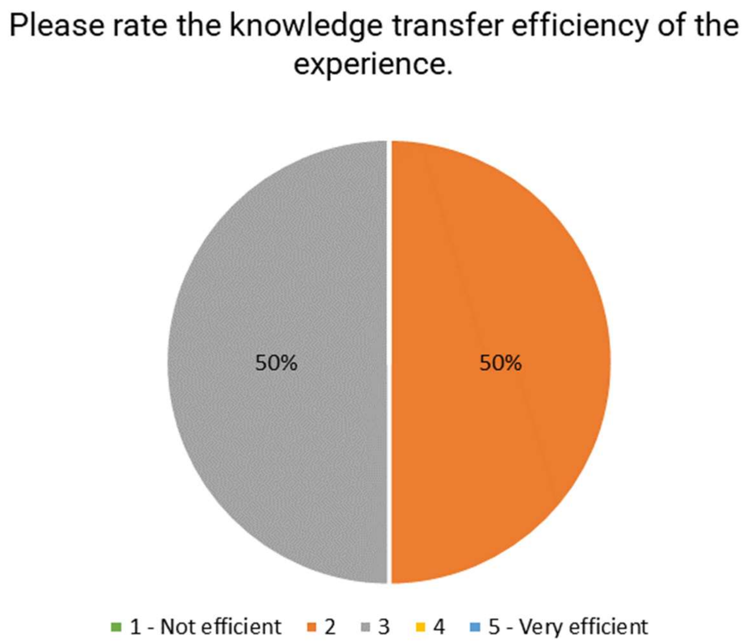

Figure A4 – Phase 1 user feedback regarding knowledge transfer efficiency

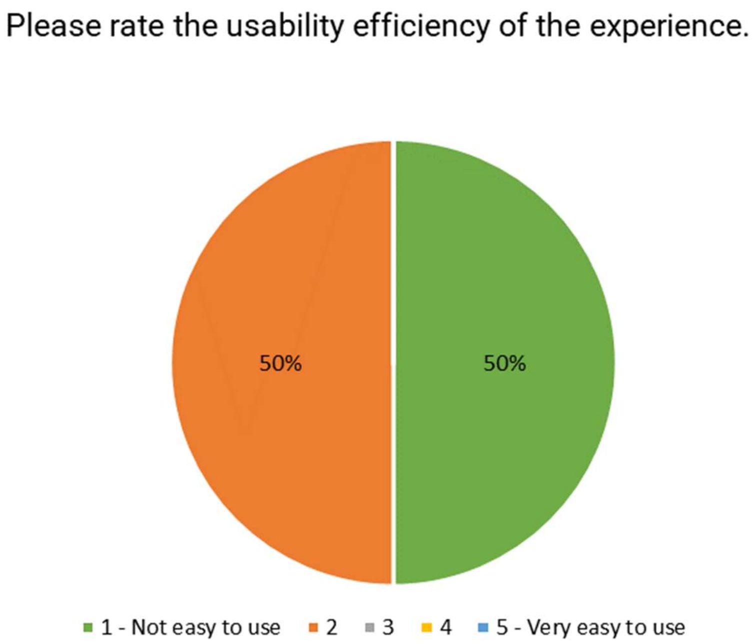

Figure A5 – Phase 1 user feedback regarding usability efficiency

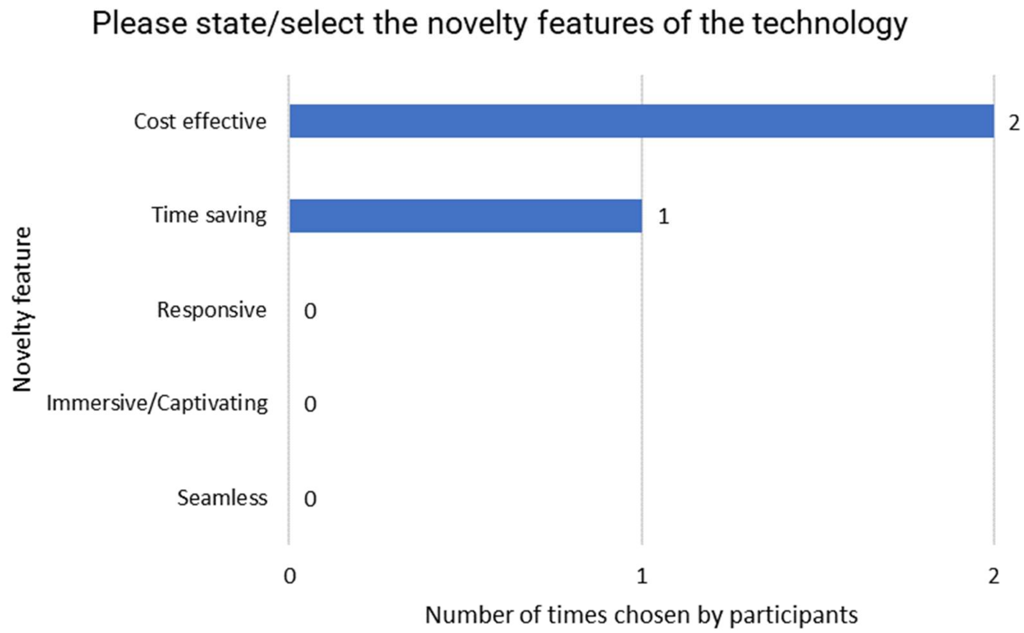

Figure A6 – Phase 1 user feedback regarding novelty features of technology

Appendix B – Further Phase 2 User Feedback

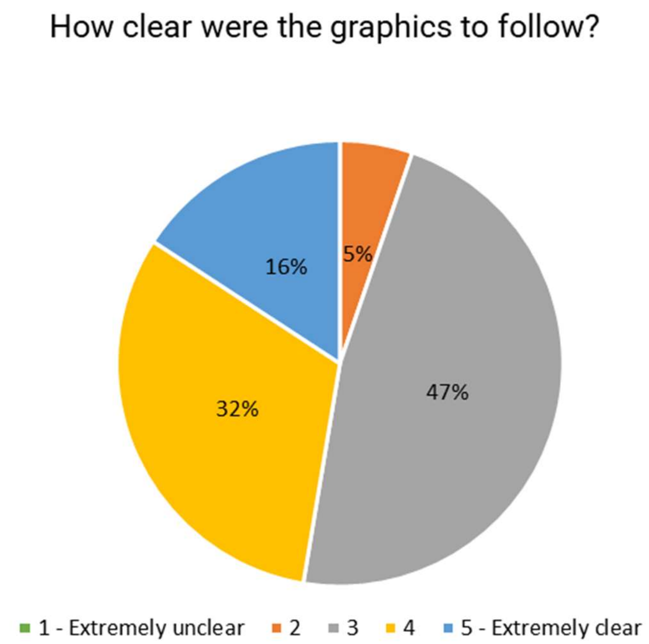

Figure B1 – Phase 2 user feedback regarding clarity of graphics to follow

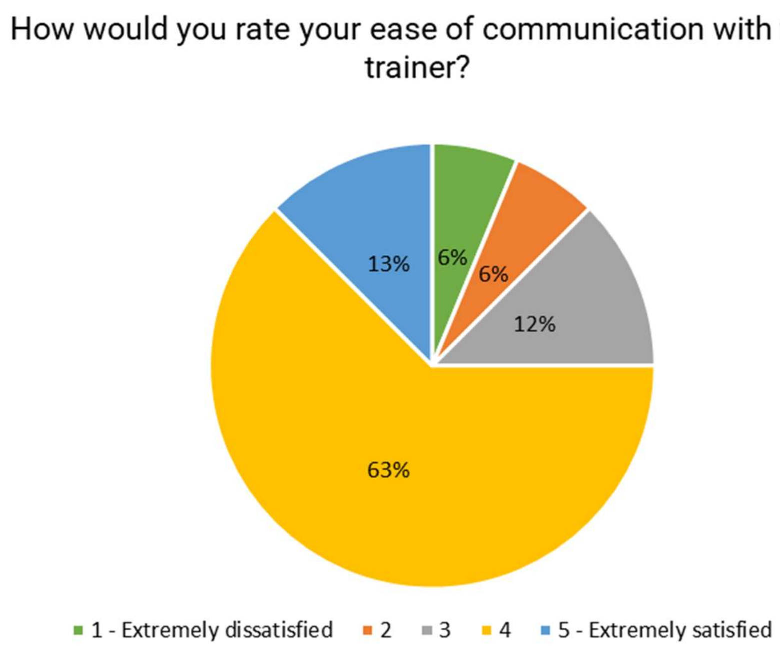

Figure B2 – Phase 2 user feedback regarding ease of communication with trainer

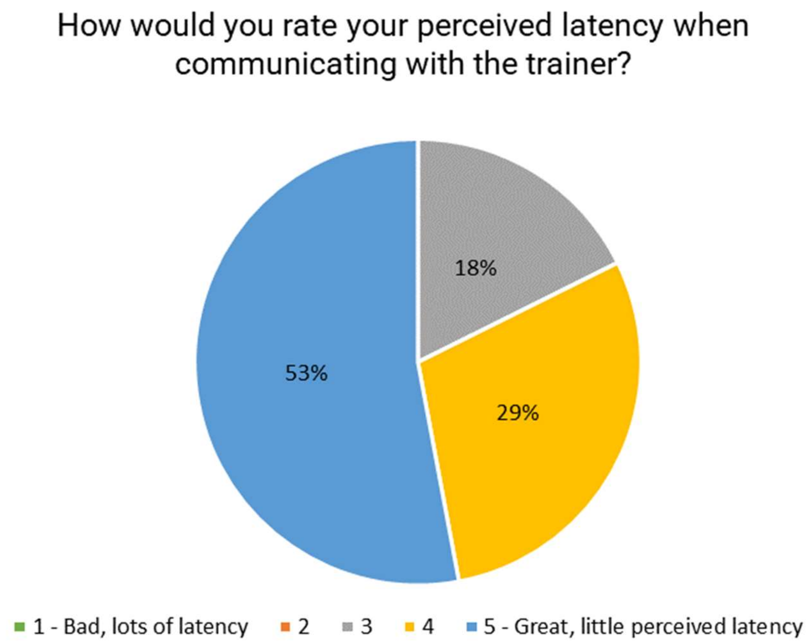

Figure B3 – Phase 2 user feedback regarding perceived latency when communicating with trainer

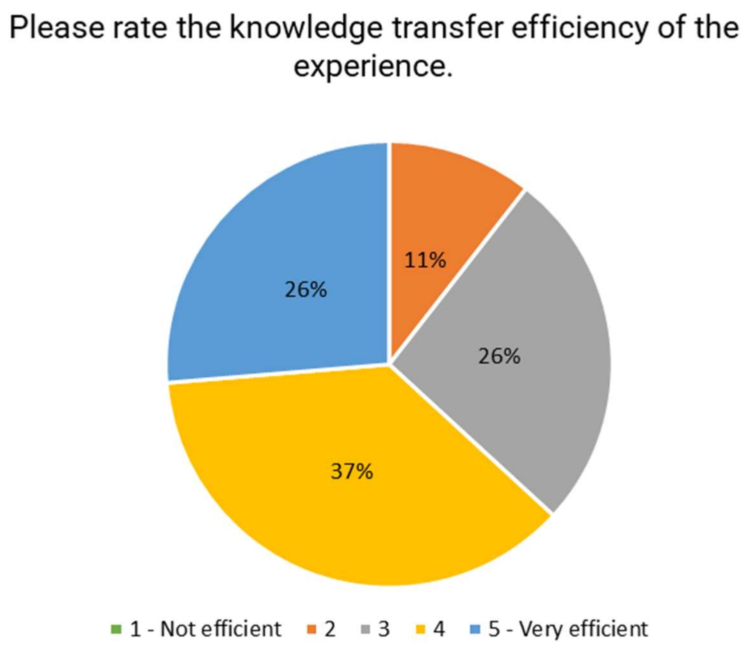

Figure B4 – Phase 2 user feedback regarding knowledge transfer efficiency

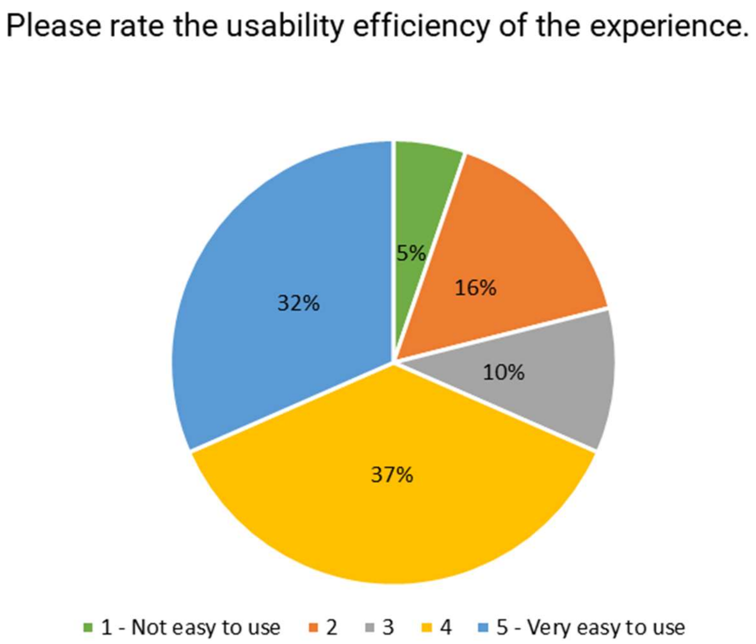

Figure B5 – Phase 2 user feedback regarding usability efficiency

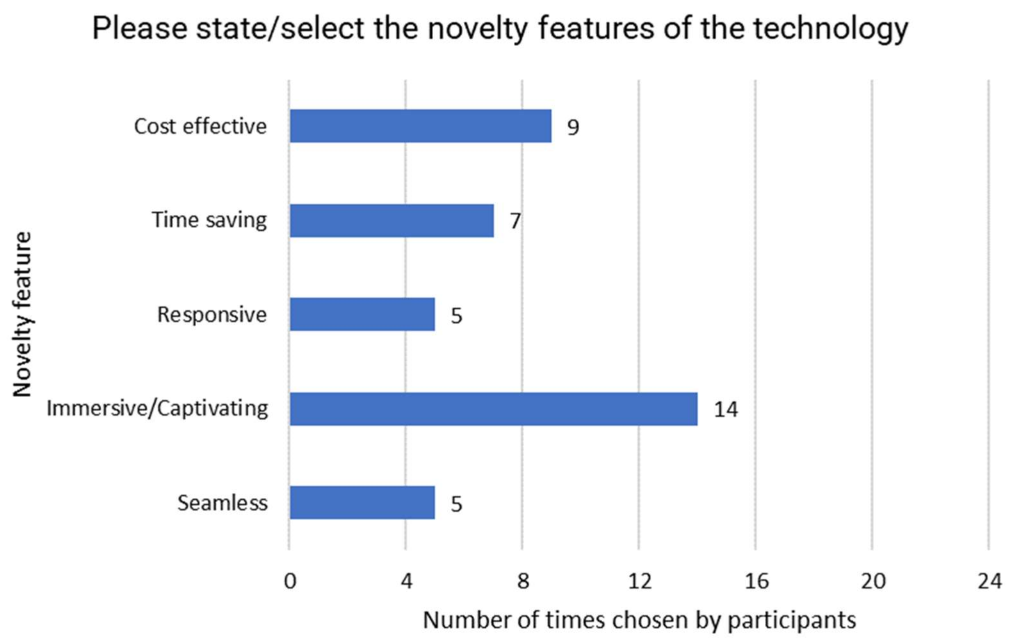

Figure B6 – Phase 2 user feedback regarding novelty features of technology

Appendix C – AR versus VR Use Cases

As part of 5G-Encode, the NCC created and trialled two remote learning solutions – one presented within this report utilising AR technology and one presented in another report utilising 360° video streaming and VR technology. The main motivations for both were relatively similar but the teaching elements that these use cases covered varied. More specifically, the AR solution aimed to completely digitise conventionally on-site practical training courses in a bid to enable effective remote training. While on the other hand, the 360° video streaming VR solution aimed to enhance more traditional webinar style teaching and allow for more immersive remote learning from practical demonstrations in real-time.

As was concluded by both reports on these work packages, the latest demonstrators of the solutions were of satisfactory quality and presented promising digital products. However, it was identified that, for the NCC the AR package has more potential in the long-term based on the significant technological developments that could be made. If it is used as a teaching or training tool, it is possible to create a framework system that could be easily configurable to various topics and courses. This will enable the NCC to offer a wider variety of remote training or create a platform for other providers to utilise as well. On the other hand, the AR packages also has potential of being an effective manufacturing aid. Adding functionality that can validate the composite layup and highlight any possible issues will considerably benefit companies that want to reduce scrap rates.

Nevertheless, the 360° video streaming package in its current format is still a useful capability for the NCC to have and can be implemented in various scenarios for real-time remote teaching. But to improve its immersivity element and fully extract the VR potential, more development must be made in the course setup. For example, having multiple stations around the 360° camera, so the whole field of view is utilised productively. Alternatively, different points of view can be added to allow the users to engage more fully with the practical demonstration presented.