VR, AR and MR

ADDITIONAL PROJECT INFO:
All i3P discovery phase 2 projects are match funded by the i3P and the MTC. Each discovery project is carried out over a timescale of 6-8 weeks, which makes use of input provided by the i3P within this timescale to support the projects. A review of industry best practices / technologies for each discovery project has been down selected according to criteria agreed with each discovery project sponsor.

Background

Problem Statement

Traditionally Construction and Infrastructure (C&I) is heavily reliant on the skill of workers. Work instructions don't tend to be written (relying on experience/skill), the quality of output should not depend on the skill of worker.

How do you get information on work instructions to the point of use?

The C&I industry is increasingly pushing towards greater digitisation and automation of work flows. Immersive technology has potential to drive this innovation even further through improved integration and communication between design and construction phases.

i3P members are keen to understand the use-cases and the real value of adopting the technology with some already piloting applications within their organisation.

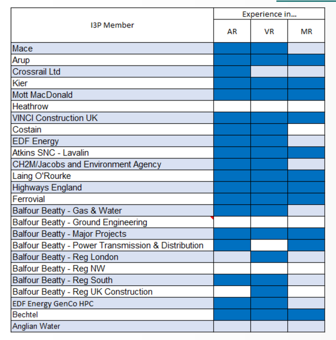
This research aims to benchmark the maturity and applicability of VR, AR and MR throughout the industry and propose a strategy to take this to higher TRLs. The research also captures examples of case-studies, human factor considerations and other barriers to adoption.

Primary research was conducted through surveys and speaking to industry experts, supported by desk-top research through the form of a market and literature review.

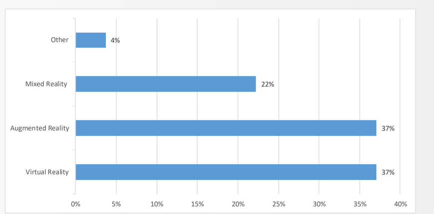
Key Observations (Summary)

1. Design visualisation is top investigated use-case for VR/AR/MR by i3p members
2. Challenges in system integration and lack of skills are perceived to be the two largest barriers
3. Human factors and safety issues need consideration early in the development stages of designing VR/AR/MR solutions particularly for head mounted devices (HMDs)

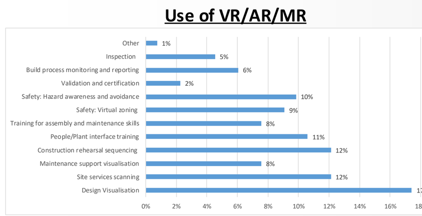
i3P Survey Responses



From the responses received from the i3P consortium representatives, it is clear that the majority have experience in at least one of the focus technologies.
Augmented Reality and Virtual reality are the most investigated.

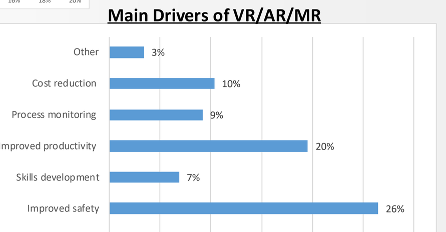


Use of VR/AR/MR



Each of the consortium members replied to the survey with their uses of the specified technology. The chart indicates the popularity of the different use cases. The most common use is for Design Visualisation, followed by Site services scanning, Construction rehearsal sequencing and Plant/People interface training.

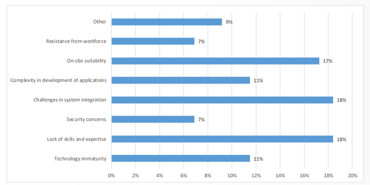
Main Drivers of VR/AR/MR



The chart on the right shows the main drivers for using the technology based on the survey responses.

The main drivers in the construction sector are improved safety, quality, and productivity.

Perceived Barriers to VR/AR/MR



The chart on the left indicates the most common barriers to VR/AR/MR technology in the i3P consortium.

The three main barriers are lack of skills/expertise, challenges in system integration and on-site suitability.

Current Best Practice – Creating a VR/AR/MR Application

1- Define the problem statement and create a system specification with the functional requirements
The first step is to define the problem that the application will aim to solve. This should include the functional requirements.
2- Brainstorm and down-select possible solutions in terms of hardware/software for the system
The potential solution should identify the hardware/software environment. Once the optimal solution is decided on, the development of the app can begin.
3- Development of the application
A variety of software is required to create an application, whether in VR/AR or MR. The core software used to build the application should be done using an authoring software such as a game engine. The MTC Visualisation team uses Unity 3D, however, other game engines, such as the Unreal engine may also be used. One of the main reasons for using game engines is that they are very flexible. Applications can be created for VR/AR and MR, in 3D or 2D using the same software.
4- Testing the software; functional and usability testing – user-acceptance
Even during development, the application must be repeatedly tested to ensure that every aspect of it works seamlessly. All aspects of the application should be tested including the software and the user interface. Finally a user acceptance test should be undertaken.
5- Deployment: training of end-user, integration
Changing the way that people work is probably the hardest step. The integration of the application must be simple. Spending time to train users and allow them to build confidence in the application will help ensure a successful implementation.

"A VISUALISATION APPLICATION MUST HELP THE WORKFORCE, NOT HINDER THEM"

Skanska VR Case Study

New Papworth Hospital VR Implementation

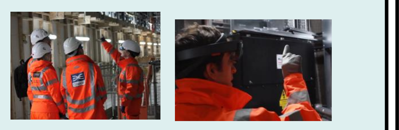
- Skanska began work on the construction of the New Papworth Hospital in 2015.
- Clients, healthcare and facilities management teams were involved in the creation of clinical drawings and room data sheets.
- With a large number of rooms and consultants involved, it would have been an extremely time-consuming task to design each room from scratch.
- To combat this, the design consultations were conducted with 3D models, allowing clinicians to use an interactive touch screen to rearrange the equipment.
- The VR technology allowed Skanksa to map out a room from every angle, including all its medical equipment. This facilitated the gathering of constructive feedback in a much shorter time period.
- Using this collaborative approach to digital engineering, Skanska has been able to engage more stakeholders in the design solution process.

https://www.skanska.co.uk/about-skanska/innovation-and-digital-engineering/innovation/smart-wearables/

Crossrail AR Case Study

Sublime AR Implementation

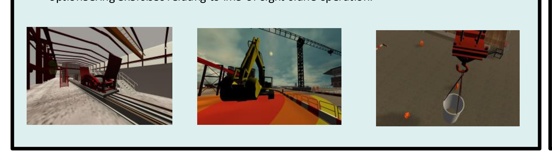
- Sublime won the bid to implement MR wearables into Crossrail's Liverpool Street station.
- The developed application had three functions: 1) Identify an asset, 2) Pull information from the cloud about the asset, 3) Push information about the asset back to the cloud.
- Functionality was identified that could be applied across a range of opportunities in the Crossrail development. However, the focus of this project were the Commissioning and Handover stages.
- The application supported enhanced efficiency when logging and reporting on installed assets. This could be carried out more quickly, safely and reliably than before as the operator could perform their tasks hands-free and head up.
- When trialled in Liverpool Street Station, the application, named 'In-Site' showed that with further development it could deliver exceptional benefits in efficiency and safety.
- The final prototype of In-Site was delivered in late 2016 and since then Sublime have partnered with Crossrail to demonstrate the feasibility of incorporating augmented reality solutions into construction.
- "It has been incredible to see a proof of concept with this technology and the solution working on a live construction site. We are incredibly proud to have worked on this programme, and the innovation will drive new levels of efficiency, safety and capability on sites like Liverpool Street Station." - William Reddaway, Innovation Programme Manager at Crossrail.



On-going : EDF Energy Case Study

VR implementation – Hinckley Point C, Avonmouth.

- The EDF team is developing the use of VR to support the site induction process in communicating site specific hazards, and awareness of the real operational environment.
- The VR environment simulates lifting operations, plant operations (including red zones) and the concrete tunnel segment production factory.
- VR will assist in the familiarisation of new site personnel to the environment they will be working in. It will give the end user a unique experience that will ultimately promote an enhanced level of engagement and awareness.
- The application provides a realistic perspective of the site from ground level that simulates the viewpoint of site operatives throughout standard operations. The simulation offers a unique perspective that could not normally be experienced. The different viewpoints will provide a better appreciation and understanding of the overall site layout.
- Further developments will include VR in undertaking buildability studies for various aspects of the project, including simulated reinforcement fixing and water jet scouring, in addition to optioneering exercises relating to line-of-sight crane operation.



Advanced Visualisation Hardware

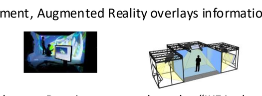
Virtual Reality
Virtual Reality removes the user from the real-life environment around them and immerses them into an entirely computer generated environment.

Phone VR
Most modern mobile phones have the capability to become simple VR headsets, using an app called "Google Cardboard". To use the VR capabilities, these phones are placed into a special headset. These headsets can be simple, such as the cardboard example shown. Phone VR can only replicate the direction in which the user is facing. More modern phones can incorporate a controller as well. Providing the user has a VR capable phone, the cost of Phone VR is limited to the cost of the headset: **Typical costs - £5 for a simple headset, £100 for the headset with controller, when used with compatible phones.**

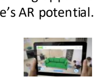
Dedicated VR headsets
As well as tracking head direction, dedicated headsets can also track a users spatial position too, by using either external sensors, or using "inside-out" tracking (using two cameras on the headset to act as eyes. These headsets are far more accurate and immersive than phone VR. However, they are more expensive and graphically demanding. Dedicated headsets require tethering to a high-spec PC running a powerful graphics card.
Cost of headset and sensors: £350-1000, Cost of PC: >£700

CAVE Systems
CAVE stands for Cave Automatic Virtual Environment. A CAVE system is a virtual environment made up of multiple 3-D projectors. These project onto several walls, and the floor. The CAVE system uses integrated tracking cameras. These cameras track the 3-D glasses, worn by the user, and also a hand-held controller. CAVE systems are less immersive that the headsets, but can accommodate multiple viewers in the system.
Cost of CAVE system: £100,000's depending on size and number of screens.

Augmented Reality
Where Virtual Reality immerses the user in a virtual environment, Augmented Reality overlays information and models in the real world.



Phone/Tablet AR
Similar to Phone VR, Phone AR can be used on most smartphones. Running apps such as the "IKEA place" app or "Pokémon Go" through googles "ARCore" can unlock the phone's AR potential.
Cost: Price of AR apps using an AR compatible phone: £0-5



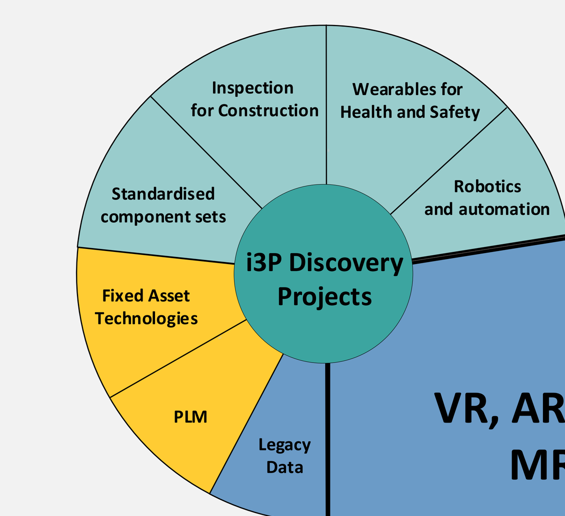
AR Headsets
AR headsets are usually designed like regular glasses with an eyepiece. The headset has a small screen within the users vision that overlays information to the user.
Many of the AR headsets have similar features to phone AR, although higher quality and are used hands free. **Cost: £1,000 - £3,000**

Mixed Reality
Mixed Reality is a mix between AR and VR. It is inputting virtual objects into the real world. The user can still see the real world, but can also place and interact with virtual objects. The headsets can map the environment in front of them using spatial cameras. Virtual objects use a 3D map created by the headset for interactions. For example, the user may choose to visualise a CAD model in a workshop, attach 3D graphical instructions to a machine to assist operators, or place a small dinosaur in their living room for fun.

Mixed Reality Headsets
Due to the relatively new technology, there are not many MR headsets on the market. The three main suppliers are Microsoft, Daqri and Meta. The Meta headsets, much like the dedicated VR headsets, need to be tethered to a high-spec PC to run. This lowers the cost. **The Meta headsets cost around £1,500.**
The headsets from the other two suppliers are less restrictive, but more expensive. **The cost of these headsets are >£3,500.**

Human Factors and Usability – VR/AR/MR

- What percentage of your workforce wear glasses? Some headsets can be uncomfortable or difficult to wear with glasses.
- Do any of your workforce suffer from any other vision conditions? E.g. Colour blindness – this can impact on the experience that the user has within the headset.
- Do any of your workforce suffer from epilepsy? Exposure to screens may trigger a seizure.
- How long are you planning on using the hardware in one sitting? Microsoft suggest using the HoloLens for no more than 20 minutes (taking regular breaks) at a time to reduce eye strain.
- Many people may suffer from motion sickness when experiencing virtual reality. This may limit the experience.
- Some headsets can be heavy, such as the Daqri smart helmet that includes a hard hat. These headsets may cause neck and head strain through prolonged use.
- While using an AR or MR headset, a user may find their other senses are compromised. Environmental hazards, alarms, alerts, etc. can go unnoticed. The user's situational awareness is lowered.
- When performing a high level focussed task, AR can impact the user's focus, similarly to multi-tasking. This may cause tunnel vision or cognitive loading.
- The majority of headsets are design to be comfortable to wear. However, through prolonged use, the headsets can cause pressure on the forehead, or rear of the head.
- Due to current technological limitations, the field of view of headsets is not as wide as the human eye. Depending on the size of the object being viewed, it may be difficult to show all of the object at the same time.



Description of Use-Cases

Training/Upskilling (1) – Visual Method Statement for repeat activities – intuitive "Ikea" style instruction guide for learning, lower costs, higher retention for digitally native workers.

Design Constructability (2) – Rehearsal Sequencing; providing seamless transfer from the design team to the construction team.

Operations & Maintenance/Facilities Management/Handover (3) – Visual instructions for maintenance. Asset management tool for facilities.

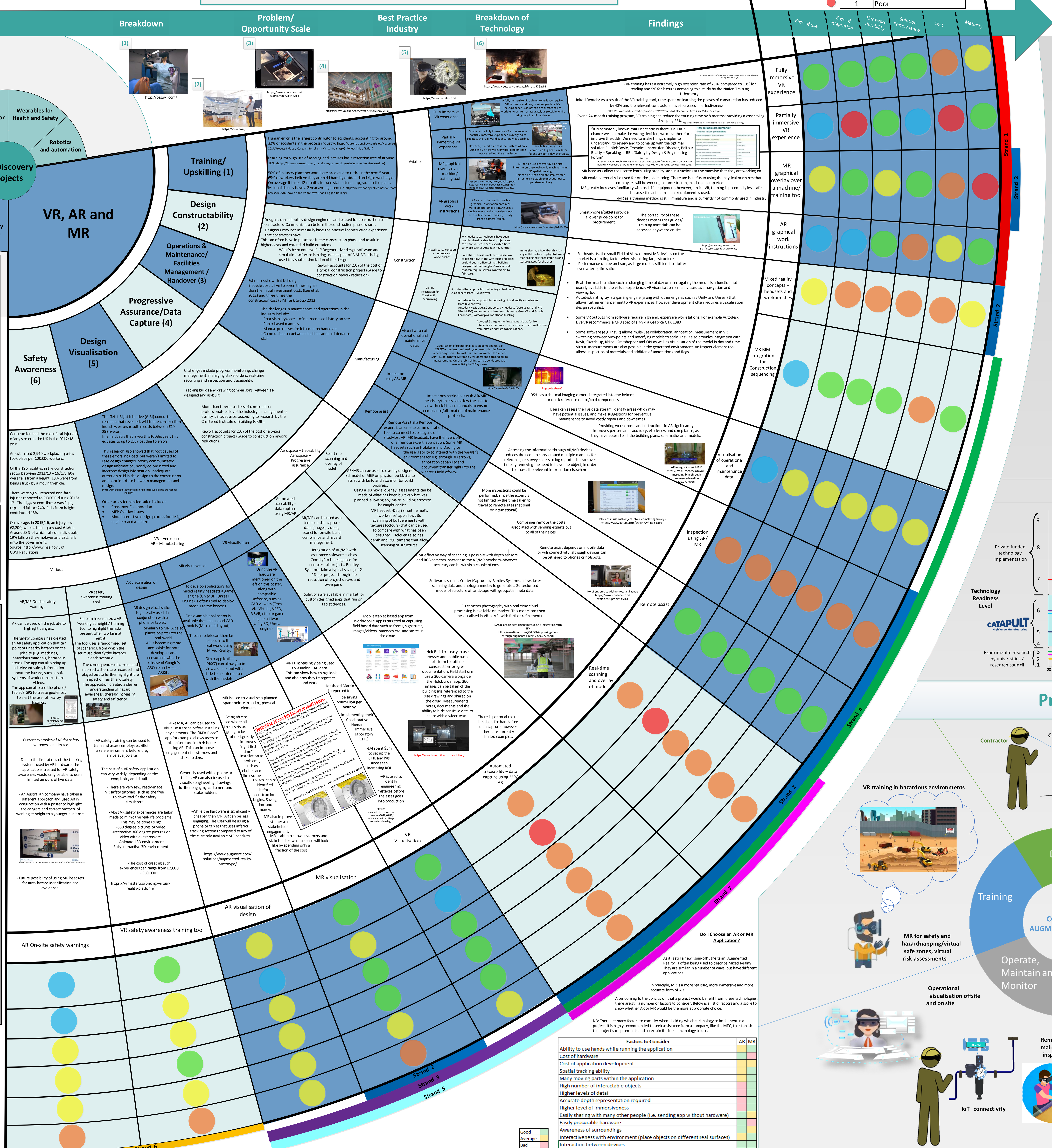
Progressive Assurance/Data capture (4) – Real-time data capture of process/progress. Validation of 'as built' to design. Remote monitoring capability for 3rd party collaboration.

Design Visualisation (5) – Intuitive design visualisation, collaborative design and build reviews. Stakeholders and non-engineering staff are able to easily visualise the concept.

Safety Awareness (6) – Worker on-site safety including cues to encourage safer work, and alerts to surrounding hazards and hazardous areas.

Scoring Criteria

	5	Excellent
	4	Above average
	3	Average
	2	Below average
	1	Poor



Do I Choose an AR or MR Application?

As it is still a new "spin-off", the term 'Augmented Reality' is often being used to describe Mixed Reality. They are similar in a number of ways, but have different applications.

In principle, MR is a more realistic, more immersive and more accurate form of AR.

After coming to the conclusion that a project would benefit from these technologies, there are still a number of factors to consider. Below is a list of factors and a score to show whether AR or MR would be the more appropriate choice.

NB: There are many factors to consider when deciding which technology to implement in a project. It is highly recommended to seek assistance from a company, like the MTC, to establish the project's requirements and ascertain the ideal technology to use.

Factors to Consider	AR	MR
Ability to use hands while running the application	Average	Good
Cost of hardware	Good	Bad
Cost of application development	Average	Average
Spatial tracking ability	Average	Good
Many moving parts within the application	Average	Good
High number of interactable objects	Bad	Good
Higher levels of detail	Bad	Good
Accurate depth representation required	Bad	Good
Higher level of immersiveness	Bad	Good
Easily sharing with many other people (i.e. sending app without hardware)	Good	Average
Easily procurable hardware	Good	Bad
Awareness of surroundings	Good	Average
Interactiveness with environment (place objects on different real surfaces)	Average	Good
Interaction between devices	Good	Good

Good	green
Average	yellow
Bad	pink

Development Strategy

Strand 1
The use of VR in training is well founded within the i3P consortium. However, sharing this information can improve the training of the next generation of the industry's workforce.
1.1 i3p members to share VR best practices and use-cases for training
1.2 i3P members and research base to research and share ROI models for training applications – TRL 8 (6months)

Strand 2
Although there are prototypes for MR uses, MR (Headset) technology is not yet advanced enough to roll out into industry.
2.1 Research base to complete a technology watch activity to advise i3p when technology appears that would address the limitations identified in this research.
2.2 Research base to work with i3p to address potential applications and complete demonstrator projects to gain an understanding of user acceptance in an industrial application.

Strand 3
VR is currently well established as navigational tool for building and site modelling. However, there is currently limited collaborative use and model manipulation capability due to computational and graphical power limitations. This technology is evolving constantly and development to improve the hardware is expected.
3.1 Research base to investigate new methods for enabling increased collaborative working and manipulation of CI design models through testing of new collaborative software/applications.
3.2 Demonstration of collaborative VR capabilities on an i3p project

Strand 4
Having the ability to integrate BIM models, with the BMS through an IoT network would be an immensely powerful tool. Understanding all that data is not easy, being able to visualise it, especially on-site, would make the tool invaluable
4.1 Research base to investigate existing examples of integration with BMS applications to improve understanding of technology capabilities
4.2 Research base to develop demonstrator of BIM-BMS-Visualisation

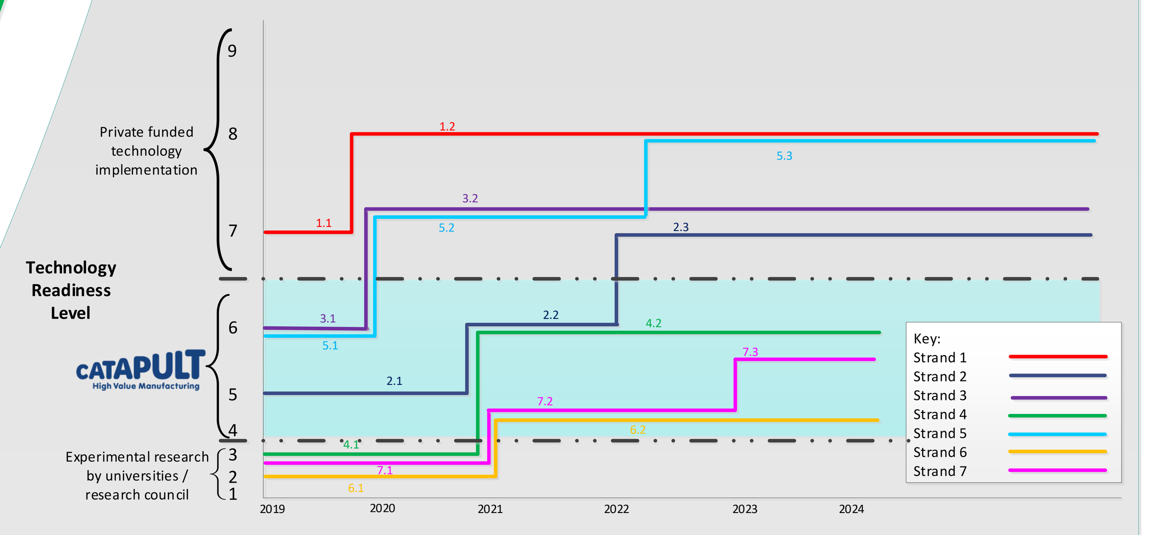
Strand 5
Model optimization is crucial for allowing visualisation hardware to run smoothly. Therefore, developing best practice for optimising models based on model size, file type, device and environment of use-cases is essential
5.1 Technology watch until agnostic software is available
5.2 Research base to conduct tests to determine software's suitability VR/AR/MR use
5.3 Research base to develop and share best practice for model optimisation and deployment into VR/AR/MR

Strand 6
Being able to detect a hazard before it becomes dangerous would be an invaluable tool and limit the number of workplace accidents massively. Using MR headsets is one possible way that this could be accomplished. Connecting the device to other systems and integrating machine learning and AI would give the headset the ability to see potential dangers, particularly useful in safety critical environments.
6.1 Research base could undertake a feasibility project to explore the concept of MR on-site risk assessment
6.2 Research base could investigate use of AI with MR for auto-hazard detection

Strand 7
Reporting on build progress is crucial for managing projects and hitting targets. MR headsets scan the environment to orient themselves while in use. If the scanning on the MR headset can be utilised for build reporting, this would cut down on surveying time and give a much more accurate and up-to-date picture of the progress being made during a build.
7.1 Research base to identify scanning maturity of headsets
7.2 Identify use-cases for scanning technology
7.3 Back-end integration with current software

CP. Authoring tool (platform) – TRL 3 (STAGED)

Project Plan



Production Concept