

# Virtual reality, augmented reality and its potential use case in space engineering

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The present article explores the potential and usefulness of virtual reality (VR) and augmented reality (AR) technologies in space engineering. VR is a realistic, interactive 3D computer-created world that you can explore as if you really are there. In this work, we explored VR technology usage in space borne systems and engineering. Usually, designers use native mechanical design software like CATIA and CREO to design and analyse various systems and subsystems. System designers must also analyse system interfaces, intricacies, and alignments from all angles in an interactive and immersive fashion to foresee and avoid potential issues. Therefore, an in-house virtual reality solution is developed to understand a complex engineering sub-system/system; its assembly, dis-assembly; sectional views and perform 360-degree analysis of system/sub-systems by direct interaction in a virtual environment. This technical paper also explores the use of AR technology for various users to understand intricate engineering models and assist the crew members remotely, even in case of unavailability of proper communication. The AR application is equipped with interactive simulations and demonstrations, enabling engineers to manipulate and investigate 3D models in a mixed-reality environment. Application is designed in a generalized way to take any complex engineering model as an input. The contribution of this work to the field of space technology lies in its innovative approach and in-house developments to visualize and interact with complex models through VR and AR-based solutions.

**Keywords:** Augmented reality, engineering 3D models, mixed reality toolkit, virtual reality.

In recent years, the engineering industry has undergone rapid and complex evolution, with 3D models and simulations being increasingly utilized to design, analyse and communicate engineering concepts. New technologies like virtual reality (VR) and augmented reality (AR) provide a novel way of interacting with system engineering models.

VR is experiencing simulations through computers, which does not exist. Head mount devices (HMD) mainly from HTC vive<sup>1</sup> and Oculus<sup>2</sup>, with headphones and hand controllers provide a fully immersive experience. There are three important I's in VR: interactivity, immersion and imagination. The key features of VR are virtual world,

immersion, sensory feedback and interaction. VR is becoming popular due to its applications in education, training, simulation, entertainment, military and engineering. Satellite payload subsystem/system designing and integration is a complex task. Mechanical teams mainly use CREO and CATIA software to design engineering systems. VR solutions shall provide them with more visual insights and help them understand internal designs better.

AR technology offers engineers an intuitive and immersive way to interact with complex engineering models in real-world environments. AR applications reading available in the market do not provide customization per the system engineer's requirements. So, there is a pressing need for the development of customized AR applications that are specifically tailored to the needs of space engineering. To address these needs, this research article also proposes the development of a customized AR-based application that utilizes Microsoft HoloLens 2 (ref. 3) devices. This application offers interactive demonstrations and simulations of complex engineering models, enabling users to better understand and engage. Through this, the application aims to improve the ability of engineers to design, analyse and communicate engineering concepts effectively.

Mechanical design teams currently use CREO and CATIA software to design engineering solutions. The challenge is to analyse system interfaces, intricacies and alignments from all angles in an interactive and immersive fashion to foresee and avoid potential issues. Therefore, there was a strong requirement to develop immersive, interactive and indigenous software applications using the latest technology to gain more insights into the engineering models. Hence, an in-house SW was developed to cater all the futuristic requirements.

## Literature survey

Many researchers have explored and implemented VR and AR technologies for different domains across the world. Wan *et al.*<sup>4</sup> developed a web application that provides an immersive experience using satellite imagery using VR. Di Giorgio *et al.*<sup>5</sup> simulated the process of satellite assembly, testing and troubleshooting without physically constructing the satellites using VR. Singla<sup>6</sup> developed a virtual reality use case in remote sensing and GIS for applications in strategy, defence and urban sectors. Lu *et al.*<sup>7</sup> explored

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the integration of remote sensing image processing technology with mobile augmented reality technology in surveying and mapping engineering. Deshmukh *et al.*<sup>8</sup> worked on a concurrent engineering approach for the early design phases of space missions. Galiè *et al.*<sup>9</sup> are working on the design of an advanced car using VR technologies. Flavie *et al.*<sup>10</sup> are studying to introduce an AR Internet of Things tool for astronauts to carry out geological activities for extra vehicle activities for missions to the Moon, Mars and beyond. Karasinski *et al.*<sup>11</sup> developed an augmented reality-assisted procedure execution for user testing for astronaut training.

There are many players in the commercial market who are working extensively in the field of VR and AR for various use cases. Techviz<sup>12</sup> and Worldviz<sup>13</sup> are companies that provide VR application SW or SW framework to develop VR solutions. Similarly, PTC<sup>14</sup> also provides Vuforia engine and other products to generate AR-based applications. Apart from these big names, many start-ups in India and abroad are picking up in the domains of VR/AR/XR, Industry 4.0 and Digital Twins. Apart from companies and their offerings, there are open-source communities such as Unity3D<sup>15</sup> and Unreal Engine<sup>16</sup>, which provide free-of-cost platforms to develop customized applications. Their freeware also contain various plugins to support growing demands from multiple disciplines. Microsoft is also providing its own library, namely MRTK2 (ref. 8), to support development on Hololens-2 devices.

This research article consists of the methodology employed to develop the customized VR and AR in-house applications using open-source frameworks, as well as the technical implementation details. The article also explores the potential benefits of VR and AR technology in the engineering industry and outlines future research directions.

## Methodology

### Virtual reality

Virtual reality has major applications in training and maintenance tasks. But, in this work, we have explored its application in engineering design, review and analysis

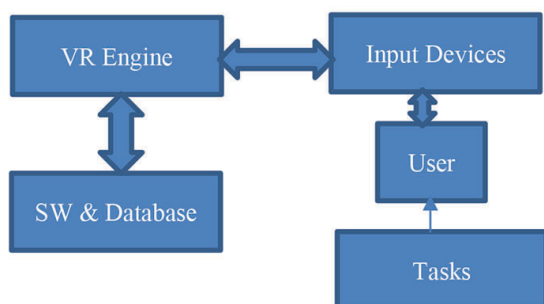


Figure 1. Virtual reality (VR) system architecture.

tasks too. Virtual reality environment takes user inputs for execution of some tasks. Based on the input given by the user, VR engine, through SW processing chain, performs the task in real-time and updates the rendered scenario. On the basis of the rendered output, user can start execution of newer tasks. Overall VR system architecture is shown in Figure 1.

### Working of head mount device and tracking system

Earlier contents are pushed to head mount devices using HDMI cable in case of head mount devices such as HTC's Vive and the Oculus Rift. However, due to the availability of wireless links, contents are rendered on stand-alone devices such as Oculus Quest Pro without any cables now. There are two lenses on the HMD devices, which are placed between your eyes. These lenses focus and reshape the picture for each eye and create a stereoscopic 3D image by angling the two relatively shifted 2D images to mimic how each of our two eyes views the world ever-so-slightly differently. VR headsets further offer accelerometers, gyroscopes, magnetometers and controllers.

Tracking devices are one of the important components of VR HMDs. These are used for interaction with system processing unit and relay the position and orientation of the user's point of view. These trackers help to determine the locality of the user in the physical space as well as direction and speed parameters. There are six degrees of freedom (6-DoF) in tracking and orientation of objects in roll, pitch and yaw available for tracking purposes. All the tracking systems mainly use inertial measurement unit sensors to read orientation and infrared or optical systems to track 6DoF.

### SW implementation details

Developed VR-based solution provides interactive and immersive solution for analysis. Here, a small sub-system model was used as a start for the proof of concept exercise. Engineering model in OSG/FBX format was exported from CREO software, as shown in Figure 2. Then the Blender SW tool was used to optimize exported model in order to reduce number of polygons. Further, a complete virtual reality-supported software package was developed in unity3D framework. All the actions of the controllers were mapped for carrying out various operations like teleporting, cross-sectioning, imploding and exploding view, etc.

In-house developed VR SW package has the generalization capability to carry out following important tasks:

- (i) Software package can import 3D models of rocketry, satellite and payloads and even sub-systems in various formats (obj, 3ds and fbx) as input.
- (ii) SW is written for 360-degree analysis of any 3D model in a virtual reality environment.

- (iii) Major potential application of the SW is in design, analysis and integration phases of payloads, spacecraft's and rocketry.
- (iv) SW is also very effective in training and maintaining new scientists and engineers on various aspects of space components.

In-house VR Software application has been designed and developed with following major features:

- (i) 360-degree analysis of model.
- (ii) Cross Sectional views.
- (iii) Exploded view of full model.
- (iv) Measurement of parts of model.
- (v) Resizing different parts of model.
- (vi) Teleportation to different areas inside the scene.
- (vii) Recording of full scene as a video.
- (viii) Voice commands to support assembly and disassembly of the model.
- (ix) Interpretable on Windows and Linux operating systems.

For complete workflow of the space engineering systems, a clean room environment was designed in the SW, C# scripts were developed for exploded and assembly views of the model. Customized modules were developed to facilitate assembly of every component, measurement of system parts, and resize different parts for analysis. Users are able to see cross-sectional view and inside-out view of the

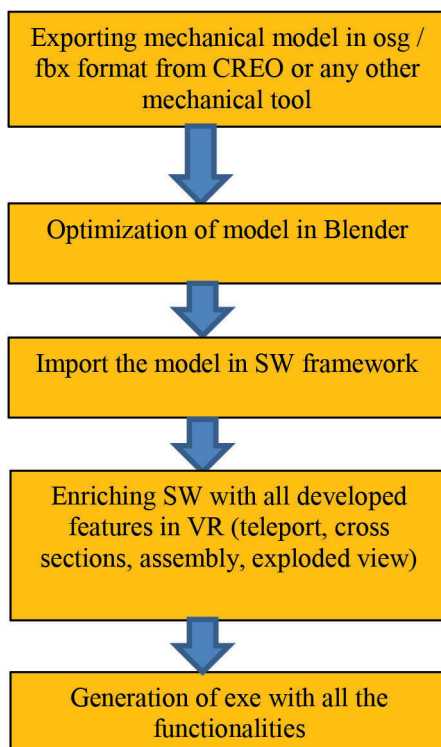


Figure 2. SW workflow.

model in VR and are also able to interact with all the parts of given model while using the developed SW.

### Augmented reality application development

To achieve the development of the customized AR-based application that utilizes HoloLens 2 devices to enable users to better understand and interact with complex engineering models, we used Unreal Engine platform and the Mixed Reality Toolkit. The Unreal Engine was selected as the primary development platform for its powerful and flexible tools for creating interactive 3D environments. The engine's Blueprint visual scripting system allowed for rapid prototyping and iteration of various features and functionalities of the application, while its robust rendering capabilities enabled the creation of high-quality visuals and realistic simulations of complex engineering models. Figure 3 depicts glimpses of unreal engine editor.

Unreal Engine supports cross-platform development for a variety of platforms, including PC, console, mobile, VR, and AR. This allows developers to create applications that can be deployed across multiple devices, making it easier to reach a wider audience. Unreal Engine is known for its advanced rendering capabilities, including dynamic lighting, particle systems and post-processing effects. This allows developers to create immersive and visually stunning environments, which is particularly important for AR applications that rely on blending virtual and real-world elements. Unreal Engine can be integrated with a variety of other tools and technologies, including AR platforms like ARKit and ARCore. This allows developers to develop AR applications that take advantage of the unique capabilities of these platforms.

We also used the Mixed Reality Toolkit, a collection of tools and resources designed to help developers generate AR and VR applications for various devices, including HoloLens 2. The toolkit provided a comprehensive set of APIs, prefabs, and components that facilitated the integration of HoloLens 2 device functionalities into the application, such as hand tracking, voice recognition and spatial



Figure 3. Unreal engine editor.

mapping. It provides a set of APIs, tools, and components for building immersive experiences that run on various mixed-reality platforms, including Windows Mixed Reality, HoloLens and Oculus.

The development process followed an iterative approach, with frequent testing and feedback sessions from engineering professionals and potential end-users to ensure the application met their specific needs and requirements. Usability testing was conducted using a combination of qualitative and quantitative methods, including user observation, feedback surveys and performance metrics analysis.

The application has three main levels: Level 1, Level 2, and Level 3. The development of each level involved the creation of GameMode and PlayerController, which were responsible for controlling the gameplay in that particular level. Level Blueprint (Figure 4) was used to create the working space in each level. The levels comprised a collection of static meshes, lights, actors, blueprints, and more, all working together to provide the desired experience to

the user. Each level had a different GameMode and PlayerController for that particular level to run. The GameMode was the setting that decided to run the application. In the GameMode, the PlayerController, Maps n Mode and Actors were selected to run. The PlayerController was a kind of actor responsible for controlling the pawn used on the level.

The authors used Actor Blueprints, Pawn Blueprints and Static Meshes to develop this application. Actor Blueprints were used to create any object that could be placed into the level, such as a camera, static mesh or player start location. Pawn Blueprints were used to control the Actors that could be controlled by the end-user. Static Meshes were used as the basic unit to create world geometry for the levels created in Unreal. These 3D models were imported into Unreal through the Content Browser and then rendered with the requirements of the user. The application has been developed using Blueprint programming, and the development of each level has been described in detail.

The flowchart, as per Figure 5, for using the AR application can be summarized in the following steps:

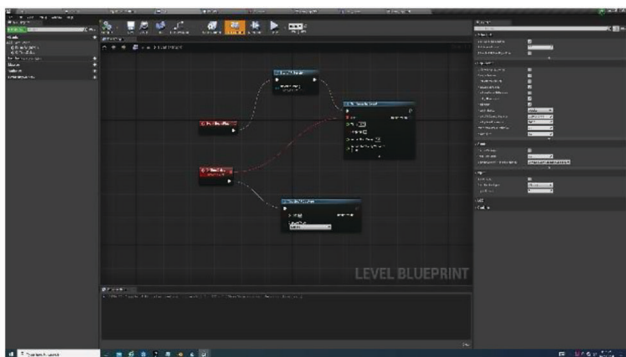


Figure 4. Screenshot – level blueprint.

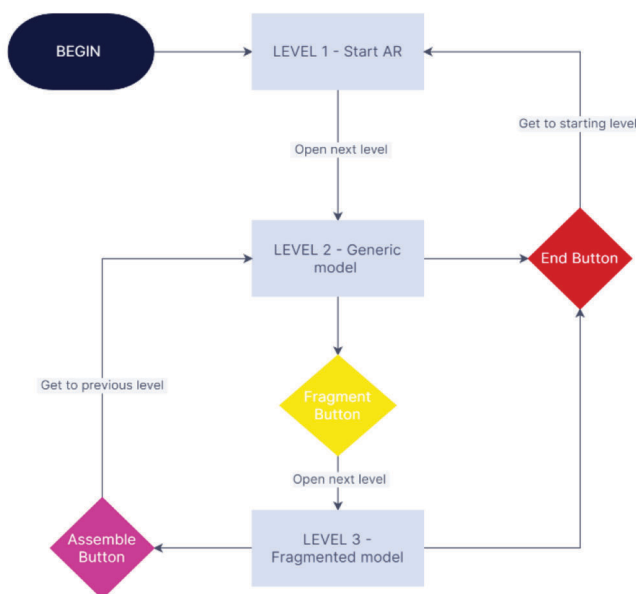


Figure 5. Application flowchart.

- (i) Begin by starting the application.
- (ii) The first level of the application will appear, which contains an interactive button labelled ‘START AR’.
- (iii) Press the ‘START AR’ button to proceed to the next level, i.e. Level 2.
- (iv) In Level 2, a generic model will appear, which can be interacted with by scaling or rotating the model. This level contains two additional buttons – ‘FRAGMENT’ and ‘END’.
- (v) Pressing the ‘END’ button in Level 2 will take the user back to the initial level, i.e. Level 1.
- (vi) Pressing the ‘FRAGMENT’ button will take the user to the next level, i.e. Level 3, where the fragmented model will appear, and each fragmented section is interactable with the user.
- (vii) Level 3 also contains two buttons – ‘ASSEMBLE’ and ‘END’.
- (viii) Pressing the ‘END’ button will take the user back to the starting level, i.e. Level 1.
- (ix) Pressing the ‘ASSEMBLE’ button will take the user back to Level 2, where the model is whole, and can be fragmented again using the ‘FRAGMENT’ button.

By following these steps, the user can easily navigate through the various levels of the AR application, interact with the model, and manipulate its various components as per their requirement.

*Packaging application for HoloLens device*

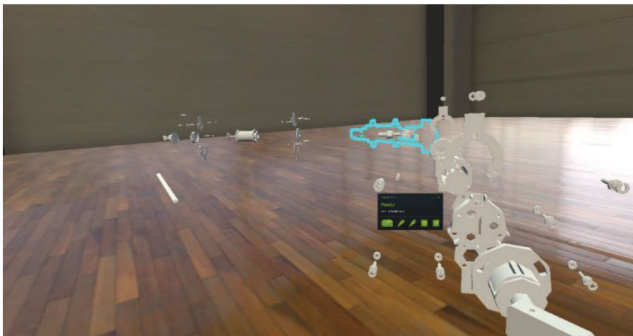
The process of developing an app for HoloLens involves selecting the C++ option and enabling three main plugins: AR, mixed reality UXTool plugin and VR. The packaging option needs to have the build configuration set to shipping, specific maps and movies that need to be packaged

should be added, and the HoloLens device needs to be selected in Platforms. The appropriate Windows SDK version should be selected, and a valid signing certificate needs to be created. The Unreal Engine provides a powerful development platform that can be used to create immersive augmented reality experiences. The C++ programming language provides developers with a powerful toolset for building complex applications. The HoloLens device offers unique features like holographic displays, gesture controls and spatial sound. The combination of these features makes it possible to create augmented reality experiences that are both engaging and immersive.

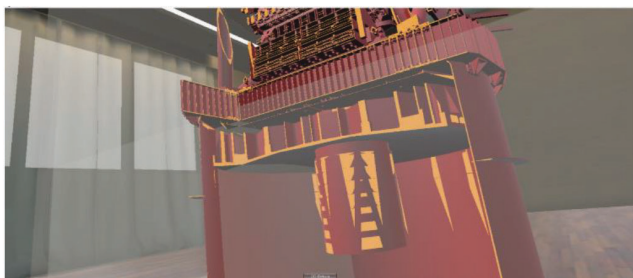
## Results

Initially, we started with small subsystem and developed limited VR features in SW framework. By gaining experience from initial exercise, we enriched VR software with more features and made the SW rugged enough to handle a bigger (size and volume) and more complex system. In this section, we are presenting results on initial subsystem assembly followed by full payload system. Figures 6–8 contain a few results captured using indigenous VR application.

Augmented reality application was successfully developed on HoloLens-2 device using the Unreal Engine with Blueprint programming. The application consists of three main levels. In Level 1 (Figure 9), a Pressable Button was created to enable the AR Session for the application.



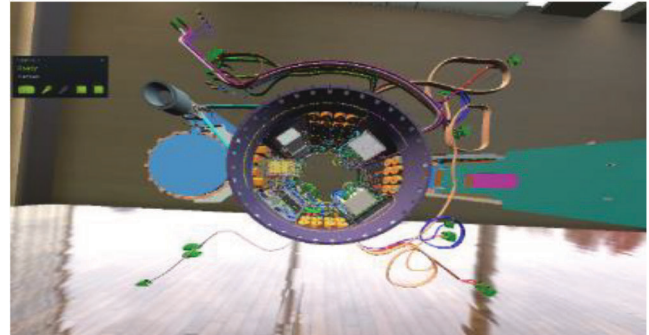
**Figure 6.** Exploded sub-system view.



**Figure 7.** Cross section view of the payload model.

Three additional Pressable Buttons were created for fragment, assemble and end functionalities. These buttons were associated with Actor blueprints that were programmed using Blueprints to take the user to the next level upon pressing.

In Level 2 (Figure 10), a desired 3D model of Gaganyaan crew module was imported into the scene using the Content browser and the .fbx file format. The imported model was placed in the scene along with the Fragment and End



**Figure 8.** Payload model in VR.



**Figure 9.** Level 1 (Start).



**Figure 10.** Level 2 (model in AR mode).



**Figure 11.** Level 3 (Internal view of the model).

buttons. The UXTool component was added to the viewport of the Actor blueprint of the model, which allowed the user to manipulate the model in various ways.

In Level 3 (Figure 11), the model was separately fragmented into different components using the Modelling tool in the Unreal Engine. These fragmented components were placed in the scene along with the Assemble and End buttons.

Users can further experience related video instruction while holding any part of the module. It can help crew module to perform its tasks optimally even in case of loss of ground communication.

The application provided an intuitive, node-based interface for creating new actors and script events. The functionalities of the application, such as Fragment, Assemble, and End, were programmed using Blueprints and were easy to use for the end user.

### *Evaluation and performance metrics*

Virtual reality and augmented reality SW evaluation metrics are categorized under three major categories such as independent variables (IVs), dependent variables (DVs) and questionnaire metrics (QMs)<sup>17</sup>. We have showcased our developed applications to scientists, engineers of respective fields, top management level people in the organization. For our work, we have considered all major evaluation and performance metrics. We used IV levels of transformations, translation in  $x$ ,  $y$ ,  $z$  direction, 180-degree rotation of the targeted model and 6 degrees of freedom (DoF) in our VR app, whereas IV variables of translation, scaling, rotation and 3 DoF were used in AR application.

Dependent variable metrics of task completion time were used in our study. All our users were able to complete all the given tasks in VR and AR applications with ease. Users are free to use the applications at their convenience and for operational purposes.

We also took subjective feedback from our users through oral questionnaires consisting of ease of use, fatigue experience, level of detail and overall experience with the applications. All type of users appreciated the in-house designed applications which more visual insights and analysis.

### **Conclusion**

This work comprised exploring of virtual reality and augmented reality technology for space engineering and developing in-house solutions. The outcome of the VR work is that we have successfully established and implemented this technology at the Space Applications Centre and developed potential in-house use cases and applications for space engineering.

Apart from development of zero cost solution in VR, we have also done in-house development of an AR-based application for space engineering. Our goal was to develop an interactive experience that would enable users to quickly explore and understand complex 3D models without having any prior knowledge or expertise about the subject matter. We used various features such as hand tracking gestures and voice commands to interact with the virtual objects naturally, which further enhanced the user experience. We also incorporated advanced techniques such as occlusion mapping, spatial sound effects, and other features that helped create a truly immersive experience.

Our work concluded that VR and AR-based applications could be highly beneficial when it comes to understanding complex concepts or remote assistance by providing an immersive experience where information can be explored more intuitively than traditional methods like text-based documents or videos. VR and AR have the potential to revolutionize many industries, including space engineering, navigation, education, and healthcare, where conveying complicated ideas quickly is essential but often difficult due to their complexity.

There are many other potential use cases for virtual reality in the future, like terrain visualization of large scale data, planetary data visualization as a first-person, water level assessment and visualization of the risk of inundation for urban cities, virtual 3d city modelling and interactions with 3D objects, etc. AR also has the potential to revolutionize many industries, including space technology, navigation, education, and healthcare, where conveying complicated ideas quickly is essential but often difficult due to their complexity. We are working on an AR and deep learning project for navigational usage too. In the future, we will explore more cases of VR/AR/XR and digital twins in linkage to space engineering and applications.

1. <https://www.vive.com>
2. <https://www.oculus.com>
3. <https://microsoft.com/>

4. Wan, W., Yang, Z., Du, X. and Zhao, X., Space make the virtual a reality: a web-based platform for visualization and analysis with earth observation satellite data. In IEEE 7th International Conference on Virtual Reality (ICVR), Foshan, China, 2021, pp. 279–285; doi:10.1109/ICVR51878.2021.9483848.
5. Di Giorgio, F., Tosoratto, L., Poletti, M., Martinelli, E. and Barilla, N., Virtual reality in satellite integration and testing. In IEEE International Symposium on Systems Engineering (ISSE), Edinburgh, UK, 2016, pp. 1–7; doi:10.1109/SysEng.2016.7753136.
6. Singla, J. G., Virtual reality based novel use case in remote sensing and GIS. *Curr. Sci.*, 2021, **121**(7), 958–961.
7. Lu, W., Zhao, L. and Xu, R., Remote sensing image processing technology based on mobile augmented reality technology in surveying and mapping engineering. *Soft Comput.*, 2023, **27**, 423–433; <https://doi.org/10.1007/s00500-021-05650-3>
8. Deshmukh, M., Wolff Robin, Fischer, P., Flatken, M. and Gerndt, A., Interactive 3D visualization to support concurrent engineering in the early space mission design phase, Paper No 020, 5th Council of European Aerospace Societies Air and Space Conference, 2015.
9. Galiè, G., Guerra, F., Alessandri, G., Pignatelli, G., Donnici, G. and Frizziero, L., Study of advanced car design for vehicles of 2030 using virtual reality technologies. In Proceedings of the First Australian International Conference on Industrial Engineering and Operations Management, Sydney, Australia, 20–21 December 2022.
10. Rometsch, F. A. A. S. D. T., Casini, A. E. M., Drepper, A., Cowley, A., de Winter, J. C. F. and Guo, J., Design and evaluation of an augmented reality tool for future human space exploration aided by an internet of things architecture. *Adv. Space Res. Sci.*, 2022, **70**(8), 2145–2166; <https://doi.org/10.1016/j.asr.2022.07.045>.
11. Karasinski, J. A., Joyce, R., Carroll, C., Gale, J. and Hillenius, S., An augmented reality/internet of things prototype for just-in-time astronaut training. NASA Ames Research Center, May 2017; doi:[https://10.1007/978-3-319-57987-0\\_20](https://10.1007/978-3-319-57987-0_20).
12. <https://techviz.net>
13. <https://worldviz.com>
14. <https://www.ptc.com>
15. <https://unity.com>
16. [www.unrealengine.com](http://www.unrealengine.com)
17. Ali Samini and Palmerius, K. L., Popular performance metrics for evaluation of interaction in virtual and augmented reality. International Conference on Cyber Worlds, 2007.

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