Virtual Reality and Digital Twins: A technological convergence

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Key words: immersive technologies, virtual reality, digital twins

1. SUMMARY

The commission 6 of FIG (Engineering Surveys) has established Working Group 6.3, with the objective of facilitating the exchange of knowledge among surveyors proficient in immersive technology, in addition to providing support to the community. This paper provides a synopsis of the collective's endeavours and furnishes a comprehensive survey of the current state of immersive technologies.

There is a considerable difference in the state of the art between different immersive technologies. Augmented reality (AR) has already become a part of our daily lives, as evidenced by its integration into Architecture, Engineering, and Construction (AEC), e-commerce, health, and tourism, as well as in the interfaces of total stations and geodata viewers on mobile devices. The implementation of virtual reality (VR) for practical applications is a more complex process, and is currently the subject of ongoing discussions and active research in various industries.

This phenomenon is of particular interest, as evidenced by the results of an online survey conducted by the FIG working group. The survey revealed that individuals who have engaged with immersive technologies once tend to experiment with the full range of technologies, but predominantly AR applications go beyond the experimental stage. It is evident that the advancement of VR applications is not impeded by technological limitations; rather, it is constrained by the maturity of the external environments in which these applications are utilised. Therefore, the development of geospatial VR applications on a larger scale is closely linked to the creation of digital twin (DT) applications and the future role of the surveyor within these environments. The great potential of VR is to serve as a conduit between reality and virtual worlds.

This paper provides a comprehensive overview of the applications of DTs in the context of VR as foundational digital platform, including systematic approaches to developing custom applications. In addition, it emphasises on success stories and encourages its further integration into lectures and surveying classrooms.

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2. INTRODUCTION

VR itself is not a new concept as it can be seen in figure 1. Stereoscopic devices are almost as old as photography, and although 3D perception was limited to viewing static stereoscopic images for a long time, this has fascinated people ever since. The advent of computers made it possible to visualise dynamic scenes on 2D screens, and the first experimental VR headsets were developed in the late 1960s (Sutherland, 1968). While this was a major milestone in computer graphics, limitations in computing power and screen resolution, as well as issues with field of view and wearing comfort, meant that these first applications were not at all immersive and only provided a glimpse of what would be possible in the future. Building on these early attempts, the industry has developed VR headsets for the entertainment and gaming sectors over the years.

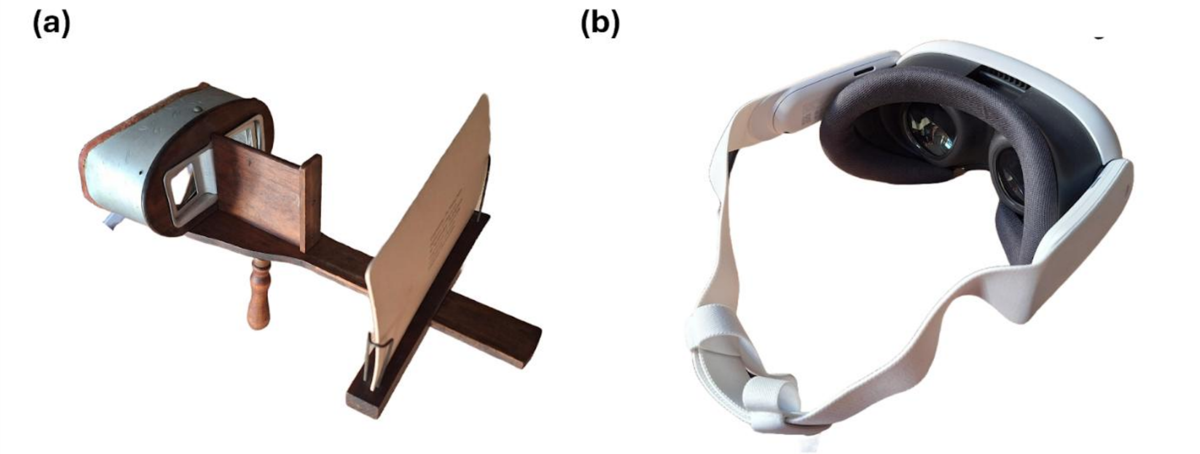

Figure 1 (a) historic stereoscope and (b) modern VR device

However, it was not until the early 2010s that major developments in computing power and rendering technologies occurred. At this time, companies such as Oculus (now Meta), Pico, Sony and Valve created sophisticated headsets for the mass market, resulting in a real boost to the industry (Dom, 2025). These rapid hardware developments continued until around 2018, when development cycles became longer and the industry experienced less dynamic development. This is also evident in the Gartner Hype Cycle, which removed the 'emerging

technologies' label and deemed VR technology well-established and highly mature in 2018 (Gartner, 2018).
Nevertheless, despite the release of several AAA games and many applications in the scientific field, there is a general feeling within the community that VR usage among the public has not met expectations. Despite tech demos and teasers in recent decades, virtual theatre visits, VR school trips to historic sites and online meetings in VR remain the exception rather than the norm.
This phenomenon is also present in the surveying industry. Although the industry is generally open to adopting new methods, most available geodetic VR applications are merely tech demos and lack real workflow integration. Consequently, the FIG has established a working group dedicated to exploring the application of immersive technologies in engineering surveys. Bringing together experts in surveying and immersive technologies, the group assesses the current state of AR/VR usage and promotes actions to encourage the community to use these technologies. The group has already published its interim results in a previous publication (Bauer et. al., 2025), which stated that the maturity of the hardware and software must be differentiated. Although most of the hardware is almost ideal for all geodetic uses, it is predominantly the software solutions that lag behind expectations. There is also a significant difference between the various types of immersive technology. While AR is already used in many fields (e.g. total station displays), the real benefits of VR applications are the most discussed issues in the community. Therefore, the group wants to encourage real content creation and workflow integration instead of the production of "cool" tech demos.
This paper sums up the final state of the group's discussions and presents a synergy between VR technology and DTs. The main thesis is that integrating humans into complex DT applications will require new visualisation and interaction concepts. Here VR will be a key-technology for visualisation in working within multidimensional datasets to enable a more human-centric and data-driven to data analysis. Therefore, the long-term success of VR applications will be tightly connected to the success of DT applications.

3. VR USAGE IN ENGINEERING GEODESY

As VR technology has matured, a whole industry has emerged, providing custom applications tailored to specific themes and reusable software solutions for the mass market. Individual applications, for instance, have become a major market in the art and cultural heritage sector. Solutions for museums and exhibitions are now standard products, predominantly provided by private software companies specialising in media production.
Advanced VR software tools for the mass market can be found in the mobility sector, where collaborative environments for 3D product and machine design and piloting have become popular tools. A prime example of the success of VR applications is Autodesk's VRED (Autodesk, 2026) software, which supports 3D design, rendering, and remote collaboration in VR. It has been part of Autodesk's portfolio since 2012, undergoing constant improvement and

updates, and it supports all major VR headsets via an OpenVR interface. It is widely used by car manufacturers.
To this day, the VR landscape in engineering geodesy remains largely academic. Although there are many VR applications with a geodetic theme, only a few have reached a level of maturity that would allow them to be exploited commercially. Many institutions have created technology demonstrators to showcase the potential of VR as a sophisticated geodetic tool. Among these is the data visualisation of the Arctic Clyde by Lütjens et al. (2019) and the data-driven tunnel monitoring simulation by Traxler et al. (2019), and the XR Building Inspector for Building Information Modeling (BIM) models by Blut et al. (2023).
However, the majority of geodetic VR applications can be found in education. As described in the ISPRS (Bolkas et. al., 2024) paper, many institutions have experimented with these applications, and there are now academic solutions for training on nearly every type of surveying instrument. Nevertheless, the VR applications are still pending to become standard teaching materials in classrooms. One of early projects, Topographic Surveying Game, was done amid to Covid19 disruption, which is developed to teach topographics surveying to students via a game environment using DT of YU Campus as survey site presented in Figure 2 (Usman et al. 2023, Bolkas et. al. 2021). Another project that stands out in this category due to its level of development is VRscan3D (2025), which provides virtual training for students using a 3D laser scanner and it is available to the general public.

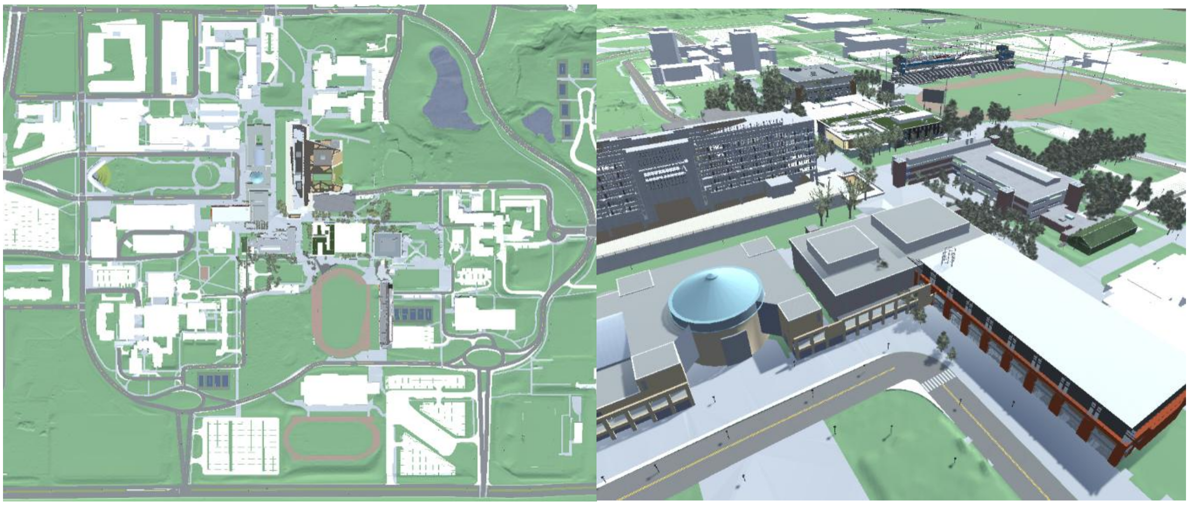

Figure 2 The top-down (Left) and the perspective (Right) view of the digital twin of the campus buildings in the game environment extracted from (Usman et. al., 2023)

In the commercial sector, only Leica Geosystems and Faro support the use of VR in their software solutions. Faro started supporting VR headsets in their point cloud software, Faro Scene, in 2017 (Faro, 2017). This tool supports all interactions from the conventional 3D viewer and is compatible with the Oculus Rift and HTC Vive series.
In 2018, Leica launched Leica Cyclone VR (Leica, 2018) for viewing and annotating 3D meshes. However, with the company shifting its focus to the Leica Register360 and Leica 3DR

pipeline, the Cyclone VR viewer was discontinued and integrated in 2022 into the Leica True View software (Leica 2022). This software now also supports the visualisation of point clouds. However, these applications have never matched the maturity of applications like the Autodesk VRED software. Also, due to the limited support for VR headsets and data formats, their long-term impact on the community is questionable compared to available solutions from the entertainment sector. Furthermore, most geodetic applications neglect the central collaborative aspect of VR integration.

In complex system and data landscapes, where very different types of data have to be processed, combined and analysed, the versatility and adaptability of the tools used are of central importance. Companies and scientific institutions such as forensic departments define domain-specific workflows for their purposes and adapt their VR working environments specifically to these requirements (Staiger, 2022).

4. 3D PERCEPTION OF DIGITAL TWINS (DT) IN VR

DT (Sacks et. al., 2011) and VR present a paradigm shift moving beyond traditional data collection and processing towards highly interactive, comprehensive, and immersive spatial analysis and visualisation. For surveyors, this synergy provides unprecedented complementary capabilities for collaborative visualization of complex physical environments. The DT provides a high-fidelity, virtual representation of the real world, such as physical infrastructure, land area, or the built environment. VR serves as the visualization and interaction interface for the complex, multi-modal DT. With VR headsets, users are immersed in the DT, allowing them to see objects and environments in their actual size as if they were on-site in the real world. This is demonstrated in figure 3, which shows a virtual total station in a LOD2 city model for planning purposes.

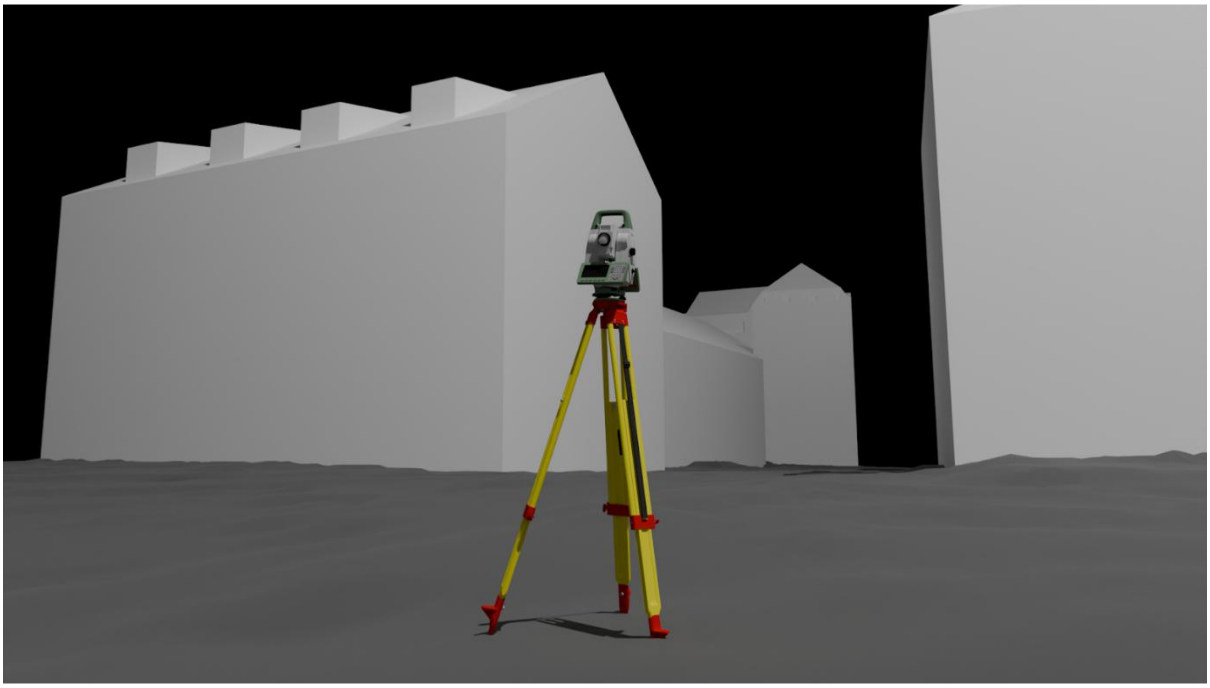

Figure 3 Virtual surveying instrument within a digital city model

In comparison to the abstract visualization on a 2D screen, this offers a true sense of scale and depth and reduces cognitive load and enhances understanding. Additionally, users can virtually walk through and interact with the objects and environments, for example enabling surveyors to visit a site virtually, regardless of physical access or environmental conditions. Surveyors can for example identify spatial conflicts, assess line-of-sight, and plan field missions with a level of detail impossible with traditional viewing methods (Bauer and Lienhart, 2022). Instead of multiple field visits, a surveyor can perform preliminary inspections, determine optimal equipment placement (e.g., control points, laser scanner locations), and identify potential safety hazards before stepping onto the site. This drastically reduces fieldwork time and risk. Also, visualizations can extend beyond the visible spectrum, for example to underground utilities, hidden structural elements, or historical deformation data mapped directly onto the geometry. Using the immersive capabilities of VR, complex spatial relationships can be comprehended more easily, accelerating decision-making and quality control processes.

5. HUMAN-CENTERED SIMULATIONS WITH DIGITAL TWINS

Although 3D perception is an advantage of immersive technologies for some applications, VR applications offer a real benefit in the form of complex content that can easily be transferred to humans. This makes VR the ideal tool for connecting humans and digital information systems. A DT is therefore the ideal counterpart to VR, since a DT is more than just a static 3D model

— it is continuously updated in exchange with the physical world. Figure 4 shows that the amount of information accessible through a VR application depends heavily on the underlying model. While simple 3D viewers only allow geometry to be analysed visually, 3D BIMs and fully digital models enable sophisticated analysis involving various objects, topology, attributes and even real-world data.

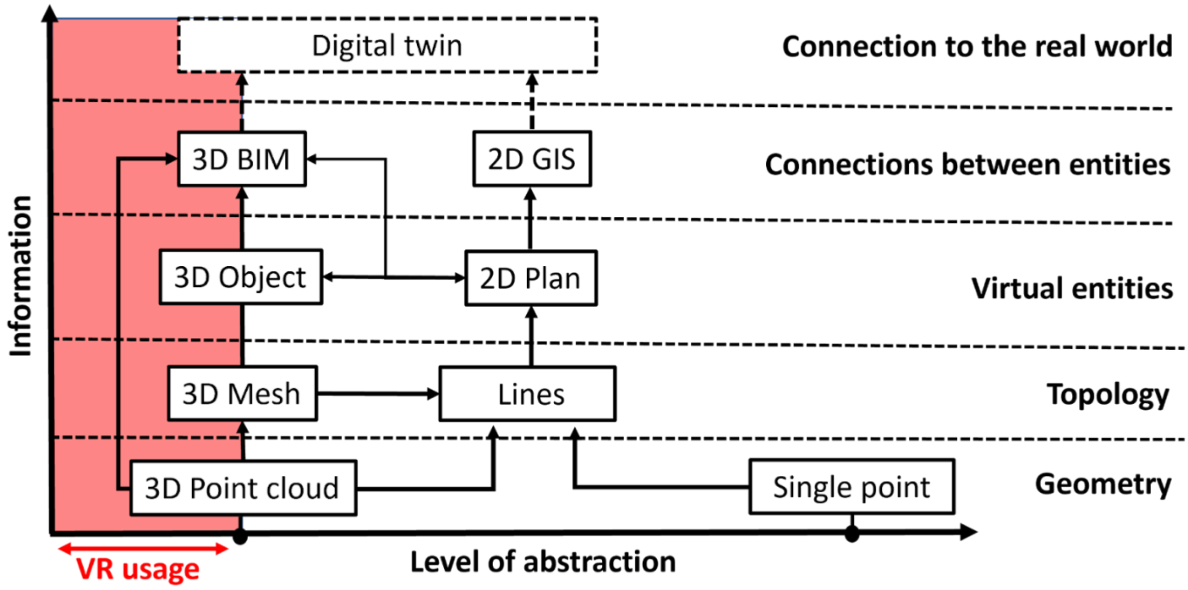

Figure 4 Levels of data abstraction

For instance, a continuous data stream from the physical world into the DT can instantaneously be rendered in VR, offering the surveyor unique diagnostic capabilities. For example, the surveyor could stand virtually on a bridge or a construction site, and real-time data from structural health sensors (e.g., strain gauges, accelerometers) could be directly overlayed onto the geometry. The surveyor could then use the VR controller to "teleport" to the anomalous element, inspect its immediate surroundings, and pull up a virtual data panel displaying the raw time-series movement graphs. This would allow an assisted inspection by a remote expert.
Furthermore, a key advantage of VR applications is their collaborative and decision-making capabilities.

A suitable use case would be in the construction industry. where during the construction phase, the DT is continuously updated with new point cloud scans and design models, enabling a real-time and automatic comparison of the 'as-built' geometry against the 'as-designed' BIM. However, it is ultimately a human decision how to handle collisions and resolve conflict issues. A VR interface could highlight spatial clashes (e.g. a newly installed pipe intersecting a planned ventilation duct) and provide immediate, quantified feedback to the construction manager and all stakeholders. It could also provide the capability for collaborative virtual on-site inspections. It can facilitate discussions based on a uniform and understandable database by visualising legal aspects, structural simulations and alternative building versions. In a similar scenario a surveyor could place virtual replicas of surveying instruments (e.g. total stations) in VR by selecting locations for control points interactively, assessing line-of-sight clearance and simulating geodetic network design. Once the optimal setup is established, the precise 3D coordinates, station setup parameters, and observation list can be exported directly to the total station, enabling real world execution and clearer communication of on-site issues to all stakeholders.

Another use case of digital twins and VR is the simulation of lifecycle effects based on the information of the digital twin. Here not only maintenance is an issue but also emergency response and public safety. This is where crowd simulation becomes a critical layer of the human-centered DT. By integrating agent-based modeling with the precise 'as-built' geometry of the DT, stakeholders can simulation complex evacuation scenarios that account for dynamic variables, such as varying occupancy levels (Luo et al., 2017), reduced visibility from smoke (Tan et al., 2015), or blocked access routes (Liu et al., 2025) (Liu et al., 2024). In this context, the role of VR expands from a passive visualization tool to an active 'human-in-the loop' validation environment. While mathematical algorithms can predict general crowd flow, they often dail to capture nuanced human reactions to danger, such as hesitation or irrational pathfinding. By conducting human-subject experiments in VR, empirical behavioural data, such as gaze tracking, decision latency, and exit route preference, can be captured under controlled and reproducible conditions. This real-world data is then used to calibrate the simulation agents, ensuring that the DT reflects realistic human psychology rather than just theoretical physics. In addition, VR also serves as a powerful emergency training tool for both civilians (Liu, Becerik-Gerber, et al., 2025) (Liu et al., 2023) and first responders (Partarakis et al., 2025) (Narciso et al., 2020). Once the crowd model is validated, the DT functions as a realistic 'serious game' environment where response protocols can be practiced without disrupting physical operations, allowing them to develop decision-making skills and spatial familiarity with the facility in a risk-free environment.

Also, DT for natural disasters like flood and water resource management can be provided in gaming environment, see Figure 5. An example of such system is the York University Virtual Sandbox, which is an accessible, immersive digital-twin platform of the York University Keele Campus that unifies a WebGL game-based client and a VR client (Meta Quest 2) to teach hydrology (heavy rain, surface runoff, flooding), resilience, Low Impact Development (LID) and surveying through authentic campus contexts. This system is developed in Unity, the experience layer renders BIM-derived buildings and a performance-optimized terrain mesh (heightmap-based, partitioned colliders, baked lighting, worldspace-height shaders) with drone-style overhead and first-person/VR camera controllers. Students interact with hydrology tools leveraging GPU-accelerated, particle-based fluid simulation for real-time feedback in both web and XR modes. Overall, York University Virtual Sandbox operationalizes the school wide extended reality Sandbox vision extending its AR/VR hydrology demonstrations into a campus-scale, browser-and-headset ecosystem that is inclusive, affordable, and optimized for experiential learning at scale. LID/green infrastructure, and broader civil/geomatics topics, see the video of https://youtu.be/kMLSi0au9yA?si=bxPTonc9uxSz74Ge

Figure 5 York University Virtual Sandbox, an immersive digital-twin platform of York University's campus for teaching hydrology (flooding, heavy rain, surface runoff), resilience

6. ONLINE SURVEY ON IMMERSIVE TECHNOLOGIES: COMMUNITY FEEDBACK

To gain further insight into how the surveying community is adapting to immersive technologies, the FIG working group 6.3 in collaboration with ISPRS Working Group V/1 has conducted an online survey. A total of 45 professionals completed the survey. Respondents were from N. America (12), Africa (10), Europe (10), Asia (8), Australia (1), and 4 were not disclosed, which can be seen in figure 6a. 19 respondents were faculty from academia, another 4 were students, 5 from government agencies, 10 from the industry, and 4 selected to not disclose their employment status.

The survey shows that more than half of the respondents have used immersive technologies (58%), with the majority of them (54%) saying that they used immersive technologies for work-related tasks.

Regarding the usage-intensity, 19% (of those who use immersive technologies) said that they use immersive technologies every year, 46% of them every month, 23% every week, and only

12% every day. Thus, the most typical frequency encountered today is monthly use of immersive technologies.

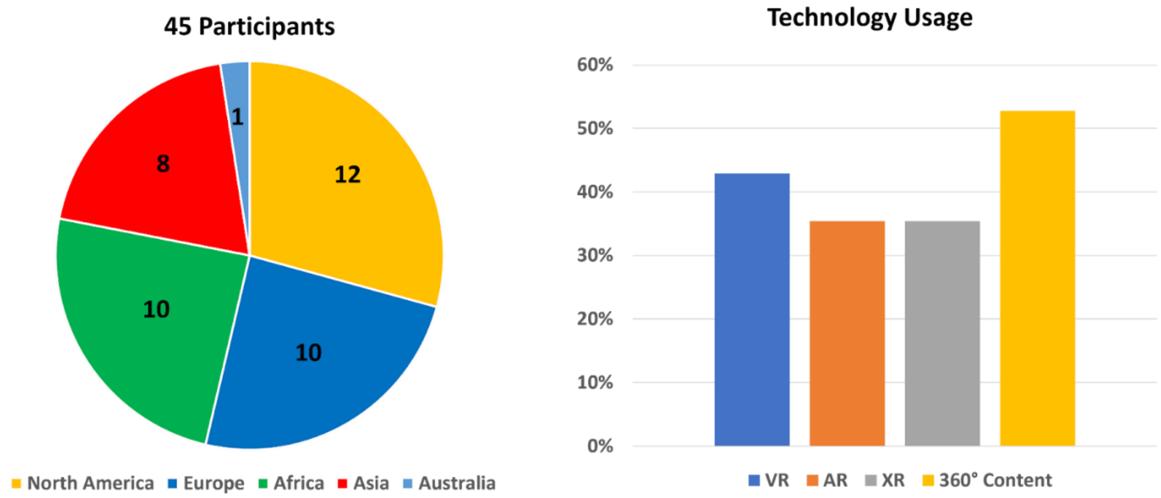

Figure 6 (a) origin of the responses and (b) used technology

In general, those working with immersive technologies will tend to use more than one technology. 43% of all responses stated they have used VR, 35% used mixed reality (MR) or AR, and 53% used 360º content.

In our survey we find that 52% of the respondents have used immersive technologies for viewing 3D content, which clearly marks that viewing 3D content with VR is also a standard process and many people make use of the available options in the entertainment sector or the limited commercial options in surveying software. Furthermore 32% used VR for education and training, 55% for data interaction and analysis (BIM and digital twins), and 15% for field data collection.

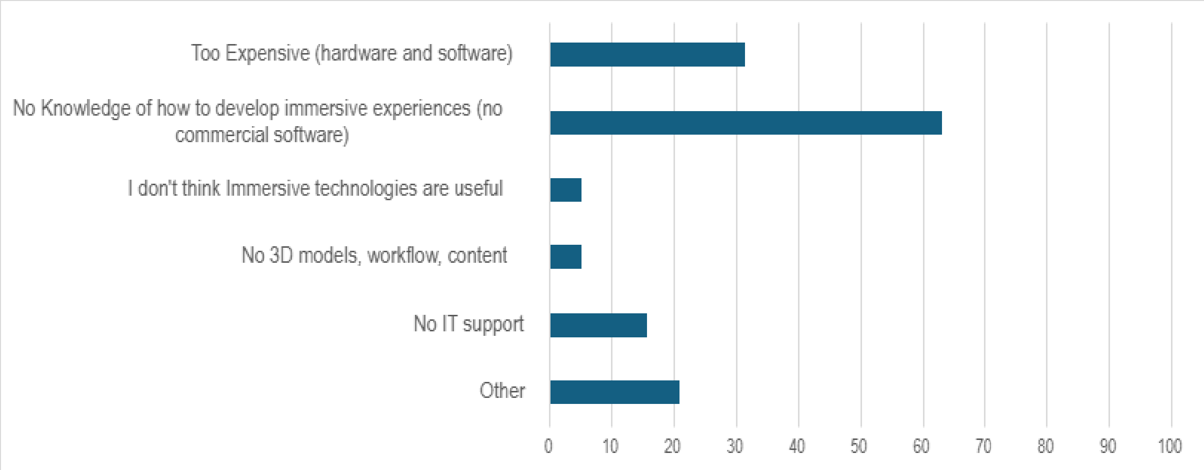

Figure 7 Responses why participants have not used immersive technologies

Despite the maturity of VR, survey results indicate the barriers to using immersive technologies are still the lack of knowledge to develop immersive experiences, the high cost of hardware and software/experiences, and no IT support to develop and support immersive technologies, as seen in Figure 7.
However, the vast majority of the participants agree that immersive technologies will continue to increase their footprint and importance in geospatial industry and education, with percentages of 83% and 87%, respectively.

7. GETTING STARTED WITH VIRTUAL REALITY - HOW TO VISUALISE MY DATA?

In order to support the community and help to overcome the mentioned limitations in the previous sections this paper also illustrates a (free) workflow pipeline towards using VR, that can be reproduced by anyone. The following section presents a simple example using a basic workflow. It demonstrates how a 3D data set can be transferred into a VR environment and being explored, providing an accessible entry point for first-time VR users.

7.1. CHOOSE THE VR SYSTEM

The application of VR software systems differs fundamentally not only in terms of the data formats supported, but also in terms of the design of user and system interfaces and the respective application purpose. Game engines such as Unity and Unreal Engine are primarily designed for real-time rendering, interaction and visual quality as well as rapid content creation. They provide excellent support for model generation and scene design, and can be quickly learnt by beginners in the VR world. Such systems are particularly well suited for applications where high visual quality and a high degree of interactivity are paramount. They enable the development of appealing, immersive scenarios in which content is not only displayed but can

also be actively experienced and influenced. Typical areas of application include training and education software, interactive demonstrators and presentations, where complex content needs to be conveyed in a comprehensible, intuitive and impressive manner. Real-time graphics and support for modern interaction concepts effectively support learning and decision-making processes. Software systems such as TechViz, ParaView or COVISE/OpenCOVER, on the other hand, take a more technical and scientific approach and are typically embedded in complex industrial or research-related work processes. The initial learning curve is comparatively flat, but opens up extensive possibilities for visualising and analysing large and heterogeneous data sets as you progress. Extensibility and customisation to user-specific data and processes are enabled through module and plugin concepts.
These systems are particularly suitable for the precise, dimensionally accurate representation of large measurement, simulation and reconstruction data sets where geometric accuracy, scale fidelity and reproducibility are paramount. They are designed to process heterogeneous data sources – such as point clouds, meshes, volume data and simulation results – together and display them consistently in a common coordinate system. They also support complex VR infrastructures such as CAVE systems, multi-projection environments and fully tracked VR setups, in which user position, viewing direction and input devices are continuously recorded and incorporated into the interaction with the data. Due to their close coupling with specialised hardware, the systems mentioned are particularly suitable for scientific analysis, technical

evaluation and forensic reconstruction, where immersive visualisation is used primarily for gaining insights rather than for presentation purposes.

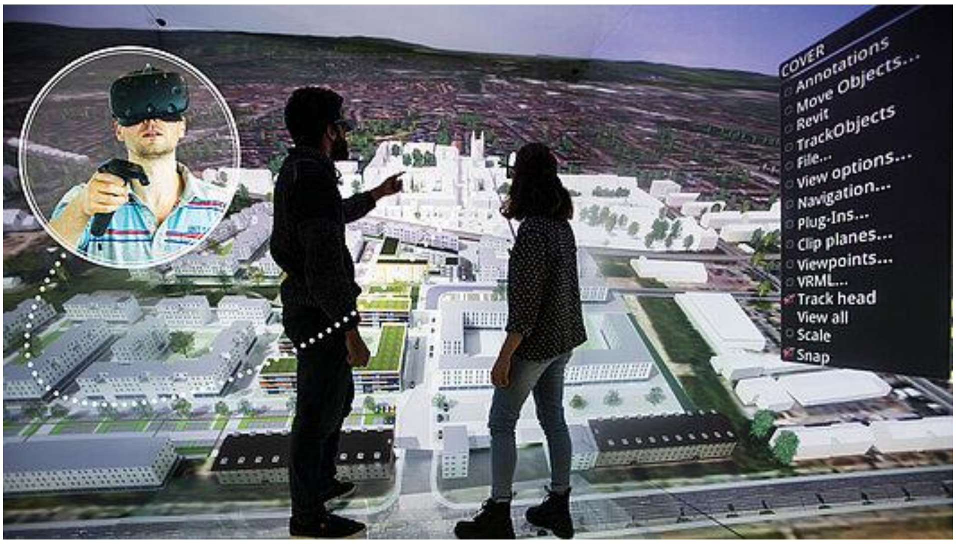

Figure 8 Multimodal and collaborative data visualisation in VR (KoLabBW, 2026)

7.2. HELLO VR

Our goal here is to first generate an initial VR representation using a simple example with a single point cloud dataset. Then use a VR setup for visualisation of the data and give an idea of a basic workflow to integrate VR into your processes.
For this example, we will be using COVISE/OpenCOVER (High-Performance Computing Center Stuttgart, 2026a). This software package focuses on the post-processing and visualisation of scientific data, particularly the results of complex numerical simulations (High-Performance Computing Center Stuttgart, 2026b). Since both COVISE/OpenCOVER (https://github.com/hlrs-vis/covise, https://fs.hlrs.de/projects/covise/support/download/) are open source projects, numerous functions and extensions have been written by various users from research and industry over the course of many years of ongoing development and improvement, meaning that the software has much to offer beyond its core task (High-Performance Computing Center Stuttgart, 2026b). As we are not processing any simulation data here, we will focus on OpenCOVER's visualisation capabilities. OpenCOVER essentially uses the OpenSceneGraph Toolkit (https://github.com/openscenegraph/OpenSceneGraph) for rendering and supports numerous options for loading and interacting with the data. It can also be easily expanded with plug-ins, for example to read your own data formats or create new interaction options. While feature-rich software can sometimes be complex to use, we will see that OpenCOVER simply opens up a wide range of possibilities.
OpenCOVER is capable of reading and simultaneously visualising a wide range of data formats. However, it can be challenging when using different tools to pre-process different kinds of data

types that need to be merged with differently oriented coordinate systems and coordinate origins.

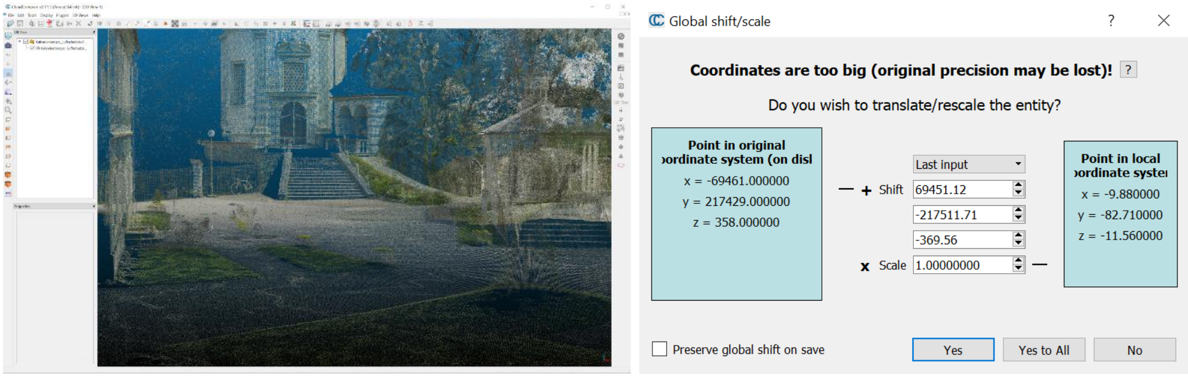

Figure 9 Reading and shifting a dataset with CloudCompare

As mentioned, we are only visualising a single point cloud here. Typically, after scanning and registration in the scanner manufacturer's proprietary software, such a point cloud is provided as exported data or as an exchange format for further processing. Software such as the open-source project CloudCompare (2026) can read these data formats and allows further post-processing if necessary, as seen in Figure 9.
The sample dataset used in this example, is available to us in LAS format and can be loaded directly into CloudCompare. Two important steps in the preparation of the data in CloudCompare are the selection of the area of the dataset to be visualised and the adjustment of the origin. Depending on the software or a specific georeferencing, the origin of the coordinate system may be far from the actual scan data. Since the initial position of the viewer in VR is at (0,0,0), it may be useful to shift (translate/update origin) the data to a region near the origin.

Alternatively, the viewer position can also be initialised using a saved or a pre-defined viewport. CloudCompare suggests to shift the data automatically (Figure 9), as it is outside the coordinate precision range of the data fields.
Once the data has been imported and we have reviewed it, the tool offers export to the E57 data format as well as various ASCII formats such as the PTS format. For this example, we choose the E57 format.
With support of the integrated E57 library (libE57, 2010), OpenCOVER can read the E57 dataset directly. This dataset can then be dragged and dropped directly onto the OpenCOVER icon on the Windows Desktop. For optimal performance, it is recommended to start

OpenCOVER using the COVISE shell to ensure the relevant environment variables are being set and the correct configuration of the system is loaded (Fig. 10).

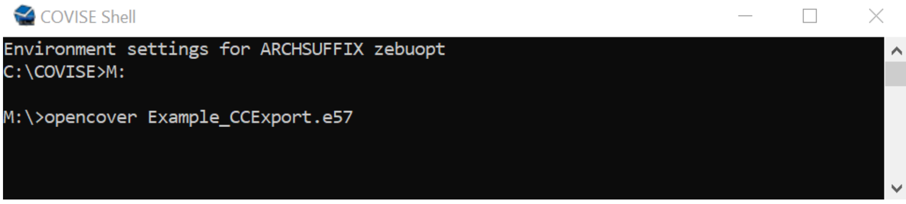

Figure 10 Start OpenCOVER and load example

The most important navigation modes can be accessed via the menu within the render window or keyboard shortcuts. Click and hold the mouse button and move it in the desired direction, which follows certain restrictions depending on the navigation mode as follows:
Navigation Mode "Move World" (t - translate): In this mode, the entire object space is translated and rotated. All movements are applied relative to the user's hand position, which serves as the center of rotation.
Navigation Mode "Drive" (d - drive): In this mode, the user moves through the object space as if driving a vehicle. The vertical axis (Z-axis) is consistently kept upright, ensuring a stable orientation during navigation.
Navigation Mode "Walk" (w - walk): In this navigation mode, the user moves through the virtual environment in a manner analogous to natural walking. When the virtual ground surface (mesh object) is sufficiently close, the system automatically pulls the user down to the floor plane. This mode also enables the user to ascend or descend stairs, thereby supporting navigation in multi-level or uneven virtual spaces.
If you are lost in object space or simply want to view the entire model, you can select *View all (v - view all)*. This function rescales the object space so that the entire scene fits within the user's field of view.
The current position and view of the viewer can be saved as a viewpoint within the viewpoint sub-menu. In principle, any number of viewpoints can be saved, but the most important one is the first one. The file containing the viewpoints is stored in the current directory as a VWP file. So that if this file is found during start up of OpenCOVER the default starting position (0,0,0) of the viewer will be replaced by the first viewpoint found in that file. This allows a start point and a series of more viewpoints to be saved and recalled during presentations, for instance. Once data can be loaded into OpenCOVER and rendered by the desktop renderer, the data can in principle be used with many other VR/AR devices. It is then simply a matter of configuring OpenCOVER to determine which perspectives should be rendered on which devices/displays. The COVISE repository provides a number of sample configurations for this purpose. For example, *config.pw.xml* can be used for powerwalls, 3D projectors or natively running HMDs, while *config.vive.xml* can be used for the HTC Vive or other similar HMDs if they can be used via SteamVR. Of course, perspectives, windows and resolutions, as well as multi-channel renderings, must be adapted to the specific devices to be used. The configuration is simply added to the Windows system environment variables with *COCONFIG=config.vive.xml*. Next

time a COVISE Shell is called, OpenCOVER will use the new configuration to start up using the new configured devices.

Figure 11 Point cloud rendering in OpenCOVER (Desktop and HMD)

7.3. DESIGN YOUR FIRST WORKFLOW AND FURTHER STEP

In many fields where similar data types and recurring tasks are handled regularly, established processes and workflows evolve over time. One of the greatest added value of VR lies in the clear and intuitive presentation of data and results, for example in professional exchanges between experts or in front of clients, decision-makers or management. Consequently, integrating VR as a complementary tool within existing workflows is especially beneficial for review processes, discussions and interactive model validation, as it allows complex relationships to be represented spatially and made tangible, supporting discussions and decision-making processes.
As mentioned, a key requirement is to prepare the different data sets, which are to be visualised simultaneously, in such a way that scaling, orientation and referenced coordinate systems are consistent with each other. While laser scan data is usually georeferenced, 3D reconstructions can sometimes be positioned and oriented in a local or even randomly defined coordinate

system, caused by the software used. Early harmonisation of these reference systems is therefore crucial to ensure correct and traceable joint visualisation in the VR environment.

Figure 12 Point cloud rendering in OpenCOVER

7.4. LOADING DATASETS INTO A VIRTUAL REALITY ENVIRONMENT

Laser scan data is usually exported in standardised exchange formats such as E57, LAS or as ASCII-formatted point clouds (e.g. pts, xyz) as shown in our example. By using software tools such as CloudCompare or Autodesk ReCap as an intermediate step, it is possible to specifically restrict those areas of the data set that are to be transferred to the VR model.

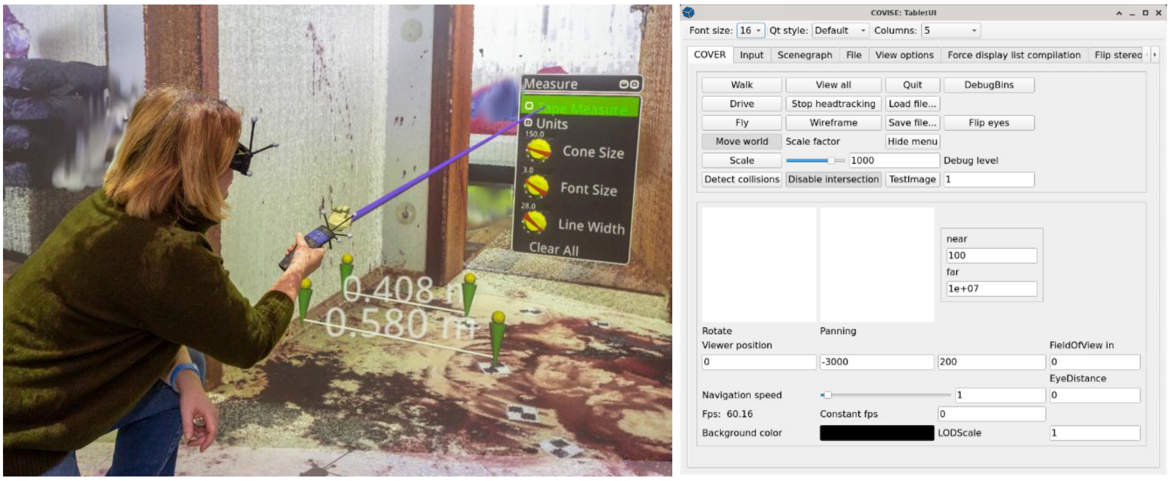

Figure 11 Working in VR & tablet UI

While correctly referenced E57 datasets can usually be loaded directly into OpenCOVER, ASCII-based point clouds require additional pre-processing. Within the OpenCOVER

toolchain, the *PointConvert* and *PointSort* tools are used in particular to convert the data into a structure suitable for visualisation.
Photogrammetrically generated data sets can often be exported in OBJ format, which is one of several easy ways to transfer the data into VR. In addition, formats such as VRML are still useful, as they offer many options for customising complex and extensive data sets.

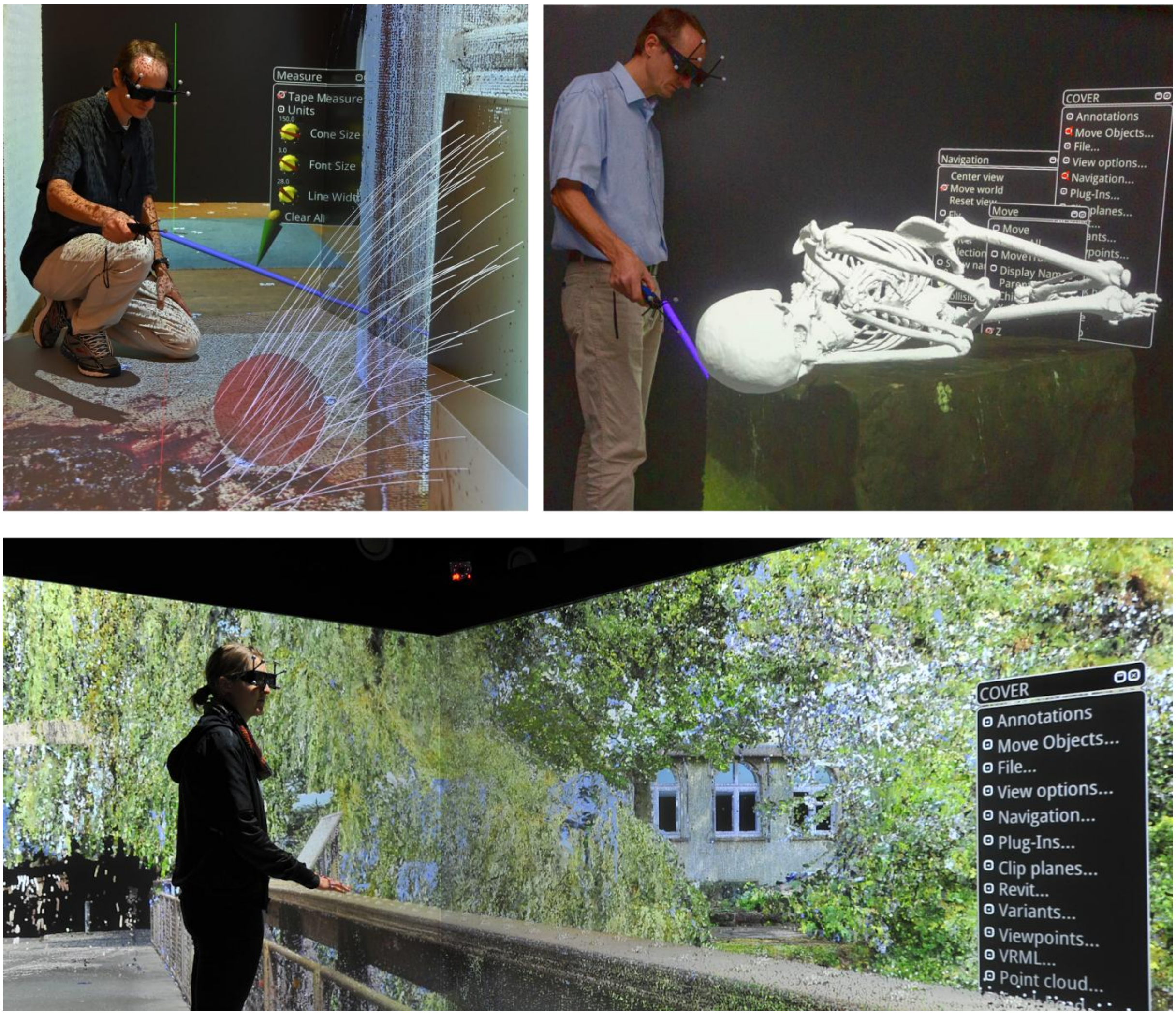

Figure 12 Forensic VR application scenes

Other data types, such as DICOM data from CT or MRI scanners, can be integrated in various ways. Either segmentation is first performed in specialised software such as *3D Slicer*, followed by import of the generated meshes, or the data is processed directly as volume data sets. In this case, the *vconv* tool from the OpenCOVER toolchain enables conversion to the *xvf* format to allow direct volume rendering.

Exchange formats such as OBJ or WRL have also proven themselves for 3D modelling tools and CAD systems, as they enable consistent transfer of geometry, structure and additional attributes into the VR environment.

Finally, it can be helpful to define a VRML file in order to link specified data sets with each other and to define or add further animations and features for presentations, for example. These and other processing steps allow numerous models from different sources, as well as abstract data sets such as movement trajectories, density distributions or heat maps, to be integrated into a common model and visualised in VR. This is one of the advantages of VR: rather than viewing individual data objects separately, it allows the complete model, with all relevant information, to be presented, examined and discussed together in its spatial and contextual context. This form of multimodal visualisation makes it possible to analyse complex issues holistically - for example, from the integrated examination of different specialist models of a building in a BIM context (Kieferle, J., Woessner, U., Seibitz, M., 2024) to the clear representation of forces acting on human bones in traffic accidents as part of an expert assessment.

Once a model has been created on desktop, OpenCOVER offers the option of using a variety of different hardware systems for immersive visualisation in VR, as described above. This opens up a wide range of possibilities for working with these models directly in an VR environment, examining them interactively, navigating through them and exploring them for analysis, review or presentation purposes.

Standard tools within OpenCOVER enable basic interactions such as moving objects, taking measurements, setting clipping planes and creating screenshots. The range of functions can be flexibly expanded with additional plug-ins to adapt specific requirements.

The application is conveniently controlled via the tabletUI, a simple but useful user interface to steer the application while standing within a CAVE for instance. This can be used to configure basic settings such as navigation modes or point cloud rendering parameters. In addition, defined layers can be shown or hidden, and additional modules can be loaded dynamically. Furthermore, the system also supports cross-location collaboration (Woessner, U. & Kieferle, J., 2016). Multiple VR systems can be connected to each other, allowing users in different locations to work with the same data or models simultaneously, review and discuss them together.

8. DT AND VR INTEGRATION INTO LECTURES

Integrating DT and VR into geodetic classrooms is a necessity for preparing students for the future of work. As industries increasingly adopt technologies that rely on real-time data, immersive visualization, and predictive analytics, academic institutions must proactively prepare students with these competencies to remain competitive and lead the future workforce.

Such labs should be part of an overall DT and reality capturing concept and the corresponding curricula should include the following key features:

- Hands-On Labs: Students capture spatial data using LiDAR or photogrammetry or other similar methods, process point clouds, build DT models and port to VR headsets
- Immersive Demonstrations: Faculty stream VR sessions during lectures and allow students to explore models in VR labs.
- Collaborative Projects: Engineering students collaborate in teams to create, optimize, and analyze DT data in VR environments. They propose solutions to specific tasks based on their findings.

To outline how such a laboratory can be considered exemplary, the California State Polytechnic University, Pomona (Cal Poly Pomona) laboratory is described in greater detail. The workflow is described in figure X and consists of point cloud processing with Trimble RealWorks, BIM Modelling in Autodesk Revit, DT management in Autodesk Tandem, and VR coding with OpenXR in Unity Game Engine, which can be seen in Figure 15.
Autodesk Tandem is a live, cloud-based service that supports the creation and management of DTs for buildings and infrastructure projects. Its primary role is to gather, organize, and visualize building data from various sources, including BIM data in a unified, live DT environment. While Tandem doesn't natively support direct live data integration with Unity, achieving this functionality involves leveraging a middleware approach or using application programming interfaces (API) to create a bridge between the two platforms.
Once the middleware is in place, Unity can be configured to interact with this service to fetch the latest data. This is accomplished through Unity's ability to make web requests, which can be programmed to query the middleware for updates. When Unity receives this data, scripts within the engine can update the game objects in real-time, modifying physical attributes, adjusting visual elements, or triggering actions based on the data received from Tandem. This allows Unity to reflect the current state of the DT, with changes in the DT immediately mirrored in the Unity application.
For continuous and real-time data synchronization, developers might choose between implementing an event-driven system or a polling system. An event-driven approach would involve setting up notifications or events in Tandem that, when triggered, prompt the middleware to push the latest data to Unity. This method ensures immediate updates in Unity but requires a more complex setup. Alternatively, a simpler polling mechanism can be employed, where Unity periodically sends requests to the middleware to check for any changes.

This method is more straightforward to implement but may introduce a delay between the actual change in Tandem and its reflection in Unity, depending on the frequency of polling.

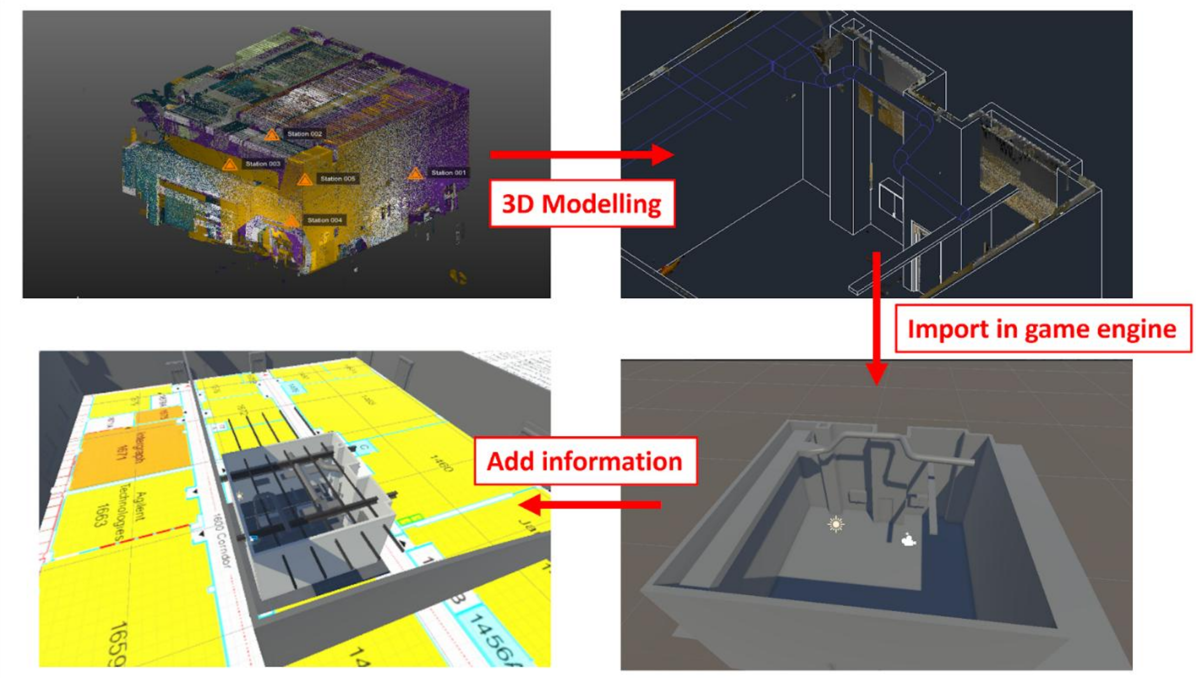

Figure 13 Conceptual workflow

The final product for this exercise is a functional demonstration that has been adapted for use on a Meta Quest 2, enabling offline demonstration. The demonstration features a scale model of a Cal Poly Pomona Engineering Lab classroom (Building 17), created to scale from the point cloud data acquired using a LiDAR scanner. The user's left controller functions as a tablet-like display, while the right controller serves as a pointer. By utilizing the pointer, the user can interact with valid objects marked as 'devices' within the Unity environment. Upon clicking, the object will transform into a green color, and its corresponding demonstration data will be displayed on the tablet.

The current proof-of-concept is limited to a single classroom. A logical expansion is to scale the DT to entire buildings or the full campus, creating a comprehensive virtual campus environment. This would enable large-scale simulations for emergency planning, space utilization, and sustainability studies. Students could collaborate on projects involving smart city concepts and urban planning within a virtual campus ecosystem.

9. SUMMARY

This paper is a result of the FIG Working Group 6.3. It proposes the use of immersive technologies, particularly VR, for visualising complex 3D data and digital twin applications in

engineering geodesy. VR can be a particularly suitable solution for integrating humans into a virtual decision-making process in the context of digital twins.
Although VR technology is highly developed, the geodetic software landscape lacks commercial software and real workflow integration. However, examples from the automotive sector clearly demonstrate the feasibility of collaborative working within VR.
Due to the lack of adequate commercial software, usage within the community is limited. An online survey showed that 'lack of knowledge' is still the main reason for not using VR. Therefore, this paper outlines a simple VR application in which the workflow relies heavily on open-source software and can be reproduced by anyone. This should encourage the community to experiment with the technology. Futhermore, immersive technologies should be incorporated into the education of future surveyors. This paper presents a best practice example on how such lecture could look like.

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