Demonstration of Immersive Technologies for Geospatial Learning

Dimitrios Bolkas [1] *, Matthew O’Banion [2], Erica Isabella Parisi [3], Peter Bauer [4], Ivan Detchev [5]

[1] Department of Surveying Engineering, Pennsylvania State University, Wilkes-Barre Campus, USA, - dxb80@psu.edu
[2] Department of Geography and Environmental Engineering, United States Military Academy, West Point, USA - matthew.obanion@westpoint.edu
[3] Dipartimento di Ingegneria Civile e Ambientale, Università degli Studi di Firenze, Italy - ericaisabella.parisi@unifi.it
[4] Institute of Engineering Geodesy and Measurement Systems, Graz University of Technology, Austria - peter.bauer@tugraz.at
[5] Department of Geomatics Engineering, University of Calgary, Canada - i.detchev@ucalgary.ca

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Abstract

Immersive technologies are becoming a powerful tool for educators across multiple disciplines including geospatial science. They offer new ways to engage and educate geospatial students, removing barriers that may exist in traditional teaching methods. Especially because the limitations of 2D screens are often exceeded by the complexity of modern data sets. Examples of challenges that educators often encounter are explaining theoretical concepts in the classroom, providing alternate scenarios, preparing students for physical labs, and limited / restricted access to physical sites. Immersive technologies can be a great resource to support on-site lectures and enhance remote learning, a necessity in today's educational panorama. Immersive technologies typically include virtual, augmented, and mixed reality. Each method offers different pedagogical advantages and poses different challenges. Before any implementation, these advantages and challenges must be examined and understood to maximize the benefit of immersive methods to the students and mitigate potential drawbacks that could hinder learning outcomes. This paper provides a review of the different immersive methods, presenting examples of their application in geospatial education with lessons learned and recommendations for future work. The case examples include a variety of different instruments and tasks such as the simulation of GNSS, differential leveling, total station operations, and airborne LiDAR data collection.

1. Introduction

In recent years, the geospatial field has witnessed an increased application of immersive technologies both in industry and in academia (Bolkas et al. 2021; Bolkas et al. 2022; Luhmann et al., 2022; Leica-Geosystems 2023; Trimble 2023; Laughlin et al. 2024). These technologies have experienced rapid technological development and increased level of maturity since the last decade. Under the inclusive term of “immersive technologies” we try to encompass a wide variety of different technologies including but not limited to virtual reality, augmented reality, mixed reality, and 360º videos and images. Although the concept of virtual reality is not new, and it can be traced back to the Morton Heiling’s Sensorama machine in the 1960s (Heilig 1962), its widespread accessibility is a relatively recent development thanks to the efforts of companies like HTC/Vive, Valve, Oculus/Meta, Sony, etc., who have democratized VR devices for the mass market and pushed the technology forward. For augmented reality hardware and applications, Google and Microsoft have paved the way with Google Glass and HoloLens, respectively. Although it has been adapted very fast in the scientific field, nowadays most AR applications are predominantly focusing on the usage of smartphones to attract a wider user group.

With the latest Generation of Headsets (e.g., Apple Vision Pro and Meta Quest 3), the boundaries between classic VR and AR increase in their complexity. Therefore, the term mixed reality has gained importance. However, for understanding the main properties of each method the following general descriptions remain valid:

- Virtual reality: in virtual reality users are fully immersed in a digital environment completely isolated from the physical world. The users virtually “exist” in the virtual environment, and they can interact with virtual objects. Navigation and control of these virtual objects takes place using a head mounted display (HMD) and handheld controllers (buttons and joysticks) or tracked hand motions. The virtual environments may range from entirely fictional realms to accurate recreations of real-world locations.
- Augmented reality: in augmented reality virtual objects are integrated into the user's physical surroundings without isolating them from reality. Instead, they use a device (e.g., tablet, smartphone, HMD) to visualize / overlay virtual objects on the physical world; therefore, achieving an integration of the physical and virtual world. Interactive sandboxes are an example of augmented reality, where topography is visualized in 3D (Reed et al. 2016 and O’Banion et al. 2022).
- Mixed reality: mixed reality is very similar to augmented reality with the main difference being that there is a level of interaction between the physical and the virtual world. Virtual objects are not simply overlaid on the physical world but are integrated into the surrounding environment blending virtual and physical environments. For example, in a mixed reality scenario, a virtual ball placed on a table, and viewed through a tablet device, would respond realistically if the table were tilted rolling off and bouncing on the ground. In contrast, a ball visualized in augmented reality would remain at the same location on the table as there is no connection and interaction between the virtual and the physical worlds.
- 360º videos and images: 360° media allows users to view 3D content using 2D devices, like smartphones, tablets, displays or HMDs. The users can pan/view around from a fixed point of view in any direction (360°) although it is not possible to freely navigate the space, but only “teleporting” between different

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acquisition points. Also, 360° content provide a heightened level of realism and sense of presence, by capturing real environments with omnidirectional cameras.

- Extended Reality (XR): extended reality is an umbrella term that is often used to refer to VR, AR, and MR. It acknowledges the spectrum of immersive technologies and their varying degrees of interaction with the physical world.

This paper will focus on the aforementioned technologies and how they are used in the geospatial discipline for educational purposes. The paper provides examples of possible solutions that immersive technologies can bring in geospatial education. Each technology will be exemplified through sample cases, discussing their advantages and disadvantages which can be a valuable guidance for geospatial educators, ending with conclusions and recommendations.

2. Immersive Technologies in Geospatial Sciences

Essential components of geospatial sciences include the collection and processing of 3D datasets (e.g., images acquired from aerial methods, point clouds, GNSS) and the production of thematic information. Training students for geospatial data collection often involves a considerable amount of hands-on learning, often in the form of outdoor laboratories. However, within geospatial education, educators often encounter challenges that are overlooked due to habitual teaching methods or the absence of alternative solutions. Yet, by taking the time to examine some of the instructional challenges that are faced daily, it’s possible to uncover opportunities where immersive technologies can make a difference.

For example, many geospatial topics have 3D characteristics. However, traditional instruction through in-class demonstration and slide decks simplify this complexity to 2D, making it difficult for students to connect theoretical concepts and practical applications and prepare for physical labs. Moreover, in scenarios where many students share the same instrument (e.g., GNSS or a total station), each student spends a limited time with the instrument, which may result in unequal skill development, with some students progressing further than others. Additionally, instructors often face time constraints when overseeing multiple student groups, striving to accomplish lab objectives within limited class periods.

Outdoor labs are typically conducted around the campus location. Over the years, students become accustomed to the terrain / survey conditions; therefore, this familiarity may diminish opportunities for students to engage in critical thinking and decision-making efforts. However, conducting field trips to actual sites, to expand student knowledge and experiences, can often be difficult or impossible due to liability, accessibility, cost and time constraints. For example, consider the case of organizing a field trip to study construction or tunnelling surveying. Finding a suitable site, coordinating with the site contractor, ensuring safety of participants, and arranging transportation can become a logistical nightmare.

Furthermore, over the years cyber-learning in geospatial sciences has increased, as a response to the need for professionals to balance work commitments with academic pursuits (e.g., Hermansen 2019). Although cyber-learning cannot entirely replace real on-site training, it is crucial to acknowledge the increasing demand for cyber-learning that geospatial programs will need to accommodate in the future. Students taking online courses require access to expensive instruments and complete tasks of comparable context and complexity as the students taking traditional courses in person. In this scenario, it can be difficult for instructors to evaluate achievement of learning outcomes when each student uses different instruments and/or completes different tasks.

Immersive technologies have the potential to address these challenges, enhancing and enriching the learning experience of students. Table 1 summarizes examples of where immersive technologies can assist in addressing instructional challenges.

Issue / Challenge	**Immersive solution**	**Applicable technology**
Instructors spend a considerable amount of time for a given lab providing instrument guidance and instructions.	Lab preparation exercises can be provided via a self-paced tutorial, so that students can become familiar with the menus and required instrument(s) in advance.	VR, AR, MR, 360
Due to the nature of tasks, it is often difficult for students to visualize the necessary steps for an exercise in an adequate spatial context	The instructions are given in the same spatial environment they will be working in with additional aid from immersive technologies.	AR, MR, 360
Some real-world environments are too complicated and/or unsafe for a whole class to experience (e.g., tunnel sites, post-disaster situations, or inspection of critical infrastructure) due to liability and accessibility concerns	Students can be provided with a more comprehensive exposure to the broad spectrum of applications for geodetic projects; these sample cases can be prepared as virtual field excursions.	VR, 360
It can be difficult for an instructor to assist all students in a timely manner during a lab exercise due to the physical distances between individuals or groups. This is very apparent during outdoor surveying exercises.	Students can watch 360-videos online and reference instructions in AR/ MR.	AR, MR, 360
Students are often required to take turns using any necessary instruments or tools, which limits their hands-on experience with the equipment.	Students can experience the entire process for a given exercise (e.g., differential leveling) on their own using self-paced tutorials.	VR, 360
Cyber-learning needs access to expensive instruments and completion of similar tasks for all students to achieve the same learning outcomes	Students can complete the same tasks virtually and can therefore be evaluated based on the goals and learning outcomes for the traditional in-person course.	VR

Table 1. Contribution of immersive technologies for a selection of instructional challenges

3. Sample Cases

3.1 Virtual Reality

VR for topographic contours: At Penn State Wilkes-Barre students use VR for several surveying tasks using the Surveying Reality (SurReal) software (Bolkas et al. 2021; Bolkas et al.

2022). Tasks include differential leveling, setting up total station instruments, and collecting topographic data using GNSS (Bolkas et al. 2021; Bolkas et al. 2022). The SurReal software has also a collaborative surveying capability, where multiple students can co-exist in the same virtual environment and work together as a group, much like with surveying labs in the physical world (Bolkas et al. 2023). In this paper, we provide a sample case of using GNSS to collect ground shots for contour mapping. The VR lab aimed at preparing students for the physical lab. The virtual environment is a digital copy of the space where students conduct their physical labs (Bolkas et al. 2020). In the VR lab, students physically carry a GNSS unit mounted on a pole. At every point they have to level the GNSS unit, enter the code / description of the point, and capture the information (Figure 1). The GNSS unit is simplified at this stage and no errors are simulated. This means that captured coordinates are derived directly from the terrain. Therefore, the focus is placed on decision making. By conducting the virtual lab first, students can exercise their skills in reading the topography and optimizing their critical point data collection. For a trial group of 7 students, Figure 2 shows a plot of the reference contour lines for the area and the contour lines generated by each student. By examining the way students collect data, we can discuss with them their data collection approach and find ways for improvement. Overall, the students provided positive feedback. With an average score of 4.5 / 5, students indicated that VR improved their learning experience. Similarly, with an average score of 4.4 / 5, students indicated that VR helped them prepare for the physical labs. Instructor feedback suggested that students were more prepared for the physical lab, being able to “read” the terrain faster and reducing the level of assistance required during the physical lab.

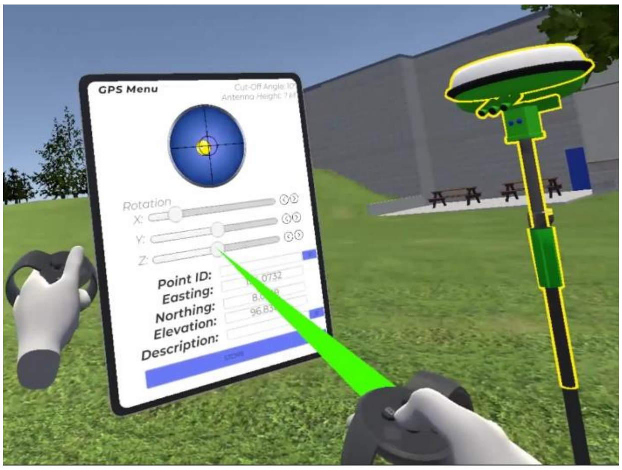

Figure 1. Measurement recording using a virtual GNSS unit.

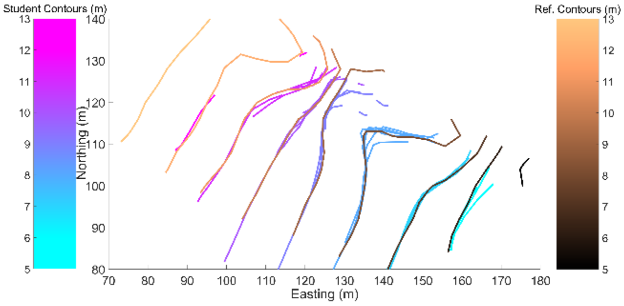

Figure 2. Reference and student contours collected in virtual reality.

VR for the education of total station monitoring: At the Institute of Engineering Geodesy and Measurement Systems at Graz University of Technology (IGMS) research is carried out on the adequate simulation and error prediction of total station monitoring in virtual 3D environments (Bauer and Lienhart 2022). VR was chosen for both the holographic visualization of thecomplex 3D environments and data interaction. The user can choose from a virtual surveying catalogue and place the objects with a virtual laser pointer directly into the scene. Upon setup, the placed objects automatically interact with the virtual environment and evaluate the quality of the virtual total stations set-up (see Figure 3). Collision control of the line of sight, evaluation of the prism orientation and distractions of the automatic aiming technology are implemented features. Furthermore, the stochastic behavior of the network configuration can be automatically simulated and visualized for the user in 3D.

Figure 3. Simulation of a total station in a tunneling scenario.

Although it has originally been created for technical applications (design of monitoring installations in complex 3D environments), it has also become a tool for the teaching of geodetic students at the IGMS. For courses in Engineering geodesy, students are given the opportunity to “play” with this virtual environment and learn about systematic effects and monitoring design interactively.

Currently, the VRsurv software is only experimental. Due to this fact, a large-scale application is not possible yet. The use of VRsurv in the classroom has been tested for select courses and the students have received it very well and with great interest.

3.2 Augmented and Mixed Reality

The AR/MR sandbox currently operated in the Geospatial Visualization Laboratory at the Unites States Military Academy – West Point was developed at the U.S. Army Simulation and Training Technology Center (STTC) in Orlando, Florida (Amburn et al., 2015). The current West Point sandbox and operating software is referred to as ARES; however, the hardware configuration was heavily inspired by the AR sandbox developed by researchers at the University of California, Davis (Reed et al. 2016). ARES is comprised of a 2.4 x 1.2 m elevated sandbox combined with a Windows OS computer, mounted overhead projector, Microsoft Xbox Kinect sensor, and a 55” LED television display. ARES has two distinct operating modes, a dynamic terrain mode and a simplified projection mode. In

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dynamic terrain mode, the overhead Microsoft Kinect sensor is used to actively measure the heights of the sand surface to support real-time projection of dynamic content such as terrain shading and/or topographic contours. In simplified projection mode, the top mounted projector can be used to display custom content on the sand surface. Based on the aforementioned descriptions of AR and MR, the sandbox is considered a MR device when operating in dynamic terrain mode and an AR device when in simplified projection mode. Past studies have relied on both the AR and MR capabilities of ARES.

An example of using the sandbox in a purely AR operating mode includes the portrayal of the 2014 Oso landslide that took place in the state of Washington (O’Banion et al. 2020). For this lesson, Microsoft PowerPoint was used to project static aerial imagery, maps, DEM hillshades, and animated content on a sand surface sculpted to represent the Oso Landslide region (Figure 4). The lesson focused on how remotely sensed data was used to characterize and better understand this event and provide a general explanation of airborne lidar collection. While projecting an animated aircraft flying over the study area on the sandbox surface, actual lidar point cloud data collected for the study site was explored on the ARES mounted TV display (Figure 5).

Figure 4. ARES AR sandbox with pre-landslide aerial imagery of the Oso region projected on the sculpted sand surface.

An example of using the sandbox as an MR device involves activating the Microsoft Kinect and its sand surface mapping capability to demonstrate and explain the differences between active vs. passive remote sensing (O’Banion et al. 2022). For this lesson, students are able to interact with the sand by sculpting their own terrain and observing how the “active” Kinect sensor captures the changes required for the software to recompute the displayed topographic contours (Figure 6A).

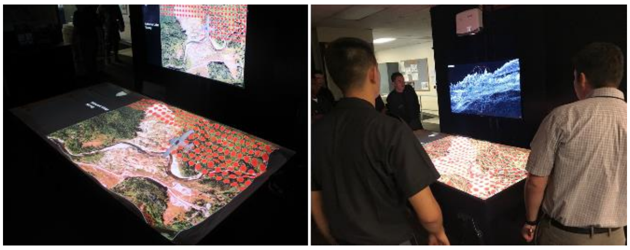

Figure 5. (Left) Airborne lidar acquisition animation displayed on sand surface and (Right) completed airborne survey with actual lidar post-landslide point cloud displayed on vertical TV display (right).

An additional experience that leverages the sandbox as an MR device was developed in partnership with the STTC to portray and explore the historic World War II D-Day battle at the Pointe du Hoc landing site on the northern coast of France. Using small Unmanned Aircraft System (sUAS) aerial imagery of current day Pointe du Hoc collected by CyArk, West Point faculty and students generated a photogrammetric 3D model of the location. This model along with a historic battle map of the site were combined to generate an immersive MR experience using the ARES sandbox and additional hardware. To seamlessly explore the historic map projected on the sand surface in relation to the 3D model presented on the TV display, the motion tracking system and hand controllers provided by an HTC Vive VR headset were utilized. By identifying the corners of the physical sandbox within the HTC Vive tracking reference frame, one of the HTC hand controllers is able to determine the location and orientation of a virtual camera that controls the view of the co-registered 3D model on the TV display (Figure 6B). It is important to note that for this example, the actual Vive VR headset was not used and all visualization was accomplished with the ARES sandbox. This specific Pointe du Hoc experience was also developed to run on a mobile device by pointing the device’s camera at a printed copy of the historic battle map and using the computed location and orientation of the device to display the relevant perspectives of the 3D model.

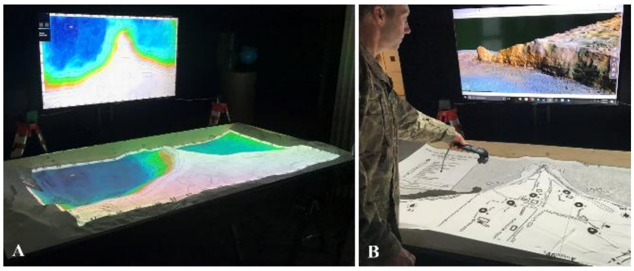

Figure 6. (A) Elevation-based color and contours displayed on the sand surface based on real-time measurement of the sand surface geometry with the Microsoft Kinect sensor. (B) Using the tracked HTC Vive hand controller as a virtual camera to display the 3D photogrammetric model of Pointe du Hoc that is co-registered to the historic battle map displayed on the sand surface.

3.3 360º contents

The Geomatics for Environment and Conservation of Cultural Heritage Laboratory of the University of Florence has been developing 360º content for Geospatial education in recent years (Ranieri et al., 2023). The positive outcomes from previous experiences in ISPRS Education and Capacity Building Initiatives (Tucci et al., 2018; Tucci et al., 2019; Tucci et al., 2020; Ortiz-Sans et al., 2020; Tucci et al. 2022), where multimedia tools were effectively used to facilitate education by conveying theoretical and practical Geospatial concepts, have inspired the exploration of 360° videos. Also, participation in the Erasmus+ SEPA - Supporting Educators’ Pedagogical Activities with 360° video project provided the necessary technical skills to produce interactive 360° videographic content (Parisi et al., 2022).

In Geosciences education, one of the primary objectives of employing 360° videos is to digitally replicate hands-on field activities and experiences by providing a high level of realism and sense of presence. In this context, a simulated experience by using specifically produced 360-based multimedia educational tools have been developed for topographic surveying and laser scanning field activities(1) focused on recording and documenting built heritage sites (Tucci et al. 2022).

The produced 360° videos fulfill various functions: serving as a replacement or supplement to practical activities, aiding in preparatory study, furthering understanding of theoretical elements, and facilitating the review of field activities when back in the office. The main educational objectives of this project had the user in mind with an aim to make the educational content captivating and visually appealing, as well as informative (Tucci et al. 2022). In this example, we developed two videos using the same footage. The first one focuses on the theoretical concepts (see Figure 7) and the second one contains interactive content for self-assessment (Figure 8) (Tucci et al. 2022). The interactive content included texts, graphics, tables, images, videos, quiz question, which were developed using Vivista (Vivista PXL Hasselt, 2022)

Figure 7. A scene from the non-interactive 360° video shared on the GeCo Lab’s YouTube channel. The video can be viewed online or downloaded as a local file by students for playback on their personal computers (e.g., using the VLC media player by VideoLAN). Additional multimedia materials were incorporated using an editing software (Adobe Premiere Pro 2022) to support the instructor's explanations. (Tucci et al. 2022).

Figure 8. A scene from the interactive video produced by using the Vivista software. The interactions are categorized as optional or mandatory, depending on the context, to enhance students' self-assessment of their knowledge on specific topics. This approach encourages students to look around in the 360° space and make decisions, similar to fieldwork, or to answer questions based on the instructor's comments. (Tucci et al. 2022).

The production of 360° content provides flexibility in user experience, as it can be accessed on various devices, including PC screens, mobile devices, and VR/AR/MR headsets. Non-interactive content can be viewed on personal computer displays using a standard media player, while interactive videos in this case require downloading the Vivista Player. Both types of content can also be experienced in an immersive environment using a VR headset for 360° viewing and interactions.

3.4 Uses of immersive technologies in the industry

Immersive technologies are also advancing in the private sector. VR and AR are popular technologies in 3D modeling and building information modeling (BIM) (Alizadehsalehi et al. 2020; Zhang et al. 2020; Safikhani et al. 2022). Their use in the BIM industry is mainly focused towards visualizing engineering designs and allowing for more interactive and user-centered communication between professionals and clients, facilitating design operations and decision making. Of the three immersive technologies (VR, AR, and MR), AR is probably the technology that has found the most use in the geospatial profession. Several geospatial instrument manufacturers are investing in AR technologies to assist surveying field operations and data collections (Trimble 2023; Leica-Geosystems 2023) and address several of the existing challenges. For instance, AR tools are used to show building and construction designs on the physical environment allowing for improved communication and decision making between stakeholders. Quality control and quality assurance operations are enhanced with AR tools, which provide a simpler and more natural way for identifying errors and mistakes in construction, increasing efficiency and reducing costly changes. Using AR, surveyors can see the location, shape, and measurements of subsurface utilities, allowing them to verify information and understand the site. This way a field crew could either avoid damaging existing infrastructure or they could get to specific infrastructure of interest without relying on time consuming and brute force trial and error methods. They can also view the data as they collect them, allowing them to visualize points, lines, and surfaces and verifying them for their correctness while in the field. Hence, data collectors are transitioning from the conventional 2D depiction of datasets to a more natural 3D depiction of information.

3.5 Limitations

One of the major concerns for educators are the potential side effects (such as nausea and dizziness) that students can experience while using immersive technologies. Even short exposures of less than 10 minutes can cause motion sickness (Dennison et al. 2016), which means that immersive experiences should be short. Our experience suggests that immersive experiences should be limited to about 20 minutes, as longer exposures can increase student discomfort (Bolkas et al. 2022). VR is the technology that suffers the most from such side effects. Mostly due to the virtual movement (e.g., moving forward, view rotation) of the user. Usually this has to be taken into account in the design of the application. A common approach is the use of “in-game” teleportation and the avoidance of continuous movement in all axes (e.g. fly like a bird, or roller-coasters). As part of a VR differential levelling exercise conducted by O’Banion et al. 2023, 63% of a 32-participant population stated they felt some level of nausea during the experience and 31% said

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[1] https://youtu.be/4MtcNm7KEfc?si=njiKwwClmlyf9df9

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they experienced a headache and/or eyestrain. When asked if they enjoyed the VR experience despite their symptoms, 82% of the population said yes, 14% said maybe, and 4% said it negatively affected their enjoyment. While a significant portion of the population admitted to experiencing some negative physical symptoms, the majority of participants did not feel it negatively impacted their VR experience. This is a good reminder that students will have varied reactions to VR and it is the responsibility of the instructor to have alternate non-VR educational content ready for those that have adverse reactions.

AR / MR maintain a connection with the physical world; therefore, fewer side effects should be expected. When it comes to 360° videos, we have not noted any significant physical side effects except for some eyestrain associated with prolonged viewing in a VR HMD. Newer HMD designs aim to reduce nausea symptoms for users, and there is an expectation for improvement in the future.

Other important concerns are related to the hardware and software needed to design and maintain immersive experiences. Developing stable immersive experiences for everyday usage requires considerable computer science knowledge. Often, a collaboration with developers from computer science is necessary. However, even when such a collaboration exists, maintaining the hardware and software can be troublesome and time consuming in the classroom. For instance, we need to execute frequent software updates for the HMDs, as well as keeping graphics drivers up to date. This means that instructors must check and prepare headsets and computers before each use. Also, some of the updates may interfere with the developed immersive experience and can necessitate further coding and software development. In addition, updating graphics drivers in educational institutions often requires administration rights that some faculty may not have.

Another barrier is associated with the direct cost of purchasing the HMDs and computers to run immersive experiences, as well as finding sufficient space for the users to navigate around without the risk of tripping and falling.

These are some important limitations that may intimidate instructors in embracing this new technology; however, immersive technologies already demonstrate high maturity in the gaming and e-commerce areas. Therefore, we believe that as the technology advances in the future and with increasing demand of immersive applications in the geospatial sector, many of those obstacles will be overcome and the availability of out-of-the-box solutions with geospatial content will increase. For instance, if there is sufficient demand for immersive experiences by several departments, then a shared lab space can be created with a dedicated technician to handle maintenance. There are universities that have started building labs dedicated to immersive technologies. Many times, these labs are integrated with the library services at the institution. Furthermore, additional technicians may be tasked with the role of assisting faculty in software development. Maintaining large lab spaces with sophisticated equipment and dedicated lab technicians is not uncommon for engineering departments. The difference lies in reaching a sufficient return of investment level to convince administrators to proceed in such investments.

3.6 Conclusions

Immersive technologies are experiencing rapid advancement for educational and professional applications. Each immersive technology offers different advantages and disadvantages, and they can be used to address different challenges. Even though integration and use in geospatial education is not very common, there are universities and educators who have made the first steps in adopting this new technology to address several educational challenges. This paper presented sample use cases of VR, AR, MR, and 360° videos from several geospatial educators and institutions. All cases demonstrated the ability of immersive technologies to teach complex content, and their ability to enhance and support geospatial education. Geospatial education involves the use and operation of several complex instruments. Although virtual / remote instruction can never replace actual on-site training fully, we expect to see an increased integration of immersive technologies in geospatial education. However, for this to happen, geospatial programs will have to overcome the important limitations related to hardware / software cost, and the cost of developing meaningful geospatial experiences for the students. This can happen by collaborating with other engineering programs to develop centers of immersive technology development at their institutions; therefore, sharing cost and resources and leveraging synergistic actions that make the integration of such technologies sustainable.

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