Development of VR/AR applications to support geospatial education

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Keywords: virtual reality, augmented reality, geospatial education, teaching methods, topographic mapping, 3D models.

Abstract

Over the last few years immersive technologies have experienced rapid advancement providing several solutions in geospatial education such as improving student preparedness, enhancing student learning of theoretical concepts and practical procedures, and even supporting remote learning. However, several educators cannot utilize such immersive technologies because many of the existing applications are not suitable for geospatial learning. Use of immersive technologies in education often necessitates specialized software and application development with the total investment (in terms of cost and time) becoming a barrier. This project is spearheaded by Working Group V/1 of ISPRS, and it is also supported by the Education and Capacity Building Initiative (ECBI) 2024 grant to provide sample experiences to educators. This project developed two immersive experiences relevant to geospatial education that can be used to enhance lab delivery and learning. The first experience uses a simplified GNSS receiver for topographic mapping in virtual reality (VR). The second experience uses a tablet and an external GNSS receiver to visualize 3D objects in augmented reality (AR). To design these two applications the research team distributed a global questionnaire to professionals and educators. The questionnaire assisted in understanding the participant’s experience with immersive technologies, their attitude and beliefs towards these tools, and the potential benefits that immersive technologies can bring in education and industry. The results from the VR/AR implementation indicate that interactive environments can effectively support student preparation and reveal common misconceptions in topographic data collection, highlighting their value as both training and diagnostic tools in geospatial education.

1. Introduction

Technological advancements always shaped and continue to shape the geospatial profession. For instance, consider the changes brought by the Global Navigation Satellite System (GNSS), laser scanning technology, and uncrewed aircraft systems (UASs). Immersive technologies are another example of technology that is finding more frequent use in geospatial and surveying engineering applications in the last few years. For example, the International Federation of Surveyors (FIG), created a new working group (working group 6.3) with the name “immersive application in engineering geodesy” (Lienhart et al., 2023). Furthermore, there are several industry examples from surveying instrument manufacturers who invest in immersive technologies. For example, SiteVision by Trimble (Trimble Geospatial, 2026) and vGIS by Leica Geosystems (Leica Geosystems, 2026), which allow surveying professionals to view and interact with georeferenced models (like underground utilities, proposed buildings) at the site / field using augmented reality (AR), and also enhance data collection procedures by overlaying in the real space data and information already collected. Another example is the Emlid Reach R4 Pro, which enables stake-out with the help of AR (Emlid, 2026). Furthermore, virtual reality (VR) and AR are frequently been used in building information modeling (BIM) and digital twin applications for viewing point clouds, models, and enabling meaningful discussions among stakeholders and engineers (Sidani et al., 2021a; Sidani et al., 2021b; Safikhani et al., 2022; Yigitbas et al., 2023). While the previous examples were developed by industry and commercial software developers, there are also several examples of using immersive technologies in education. Immersive technologies have been used for training students to instruments and surveying methods, viewing content like point clouds and models, creating group lab activities, and in general to support geospatial and surveying education (Levin et al., 2020; O'Banion et al., 2020; O'Banion et al., 2023; Bolkas et al., 2021; Bolkas et al., 2022; Bolkas et al., 2024; Laughlin et al., 2024; Bolkas and Chiampi, 2025; Bauer et al., 2025). These studies demonstrate how immersive technologies can improve student preparedness, enhance student learning, and even support remote learning for distant students. However, educators still have limited access to immersive technologies because of cost and lack of applications with geospatial content. In addition, developing such applications requires specialized software and considerable computer science experience. The role of immersive technologies is continuously increasing, and both students and educators should be exposed to these technologies to gain familiarity. This project, spearheaded by Working Group 1 of Technical Commission V of ISPRS, and supported by the Education and Capacity Building Initiative (ECBI) 2024, developed two immersive experiences relevant for geospatial education that can be used by instructors to enhance lab delivery and learning. Thus, the specific goals related to this paper are: (1) engage professionals and educators to identify immersive experiences that can support surveying/ geospatial education, and (2) develop sample immersive experiences that educators can use in their classes to engage surveying / geospatial students. The first immersive experience uses a simplified GNSS receiver for topographic mapping in VR. The second experience uses a tablet and an external GNSS receiver to visualize 3D objects in augmented reality AR.

The paper first discusses the results of the online survey that was distributed to understand the role of immersive technologies in the geospatial profession and education. It continues by presenting the VR experience and its implementation in an actual surveying course, with discussion on the pedagogical assessment for this implementation. Next, the AR experience is presented, and finally the paper provides concluding and future work remarks. Thus, the specific contributions of this paper are: (1) assessing the needs and perceptions of professionals and educators through an international survey; (2) developing two immersive applications tailored to geospatial education; and (3) evaluating the pedagogical impact of a VR-based topographic mapping exercise in a real course setting.

2. Questionnaires

To design the two immersive applications the research team distributed a global questionnaire to professionals and educators. The questionnaire consisted of a combination of multiple-choice and Likert-scale questions and was distributed online through professional networks and international working groups. In addition, the questionnaire provided insights about the participant's experience with immersive technologies, their attitude and beliefs towards these tools, how they use immersive technologies for professional activities, and their opinion regarding the role of immersive technologies in the geospatial profession and education. The survey was distributed in collaboration with FIG working group 6.3: Applications of immersive technologies in Engineering Geodesy and ISPRS working group V/1: Education and Training through Curricula Development and Enhanced Learning Practices (see Bauer et al., 2025 for partial results). The questionnaire had a secondary goal to understand the participant's experience with immersive technologies, their attitude and beliefs towards these tools, and to understand the potential benefits that immersive technologies can bring in education and industry. The following sections provide detailed information related to the questionnaire findings, and the VR and AR applications.

A total of 45 individuals completed the survey from N. America (12), Africa (10), Europe (10), Asia (8), Australia (1), and 4 respondents did not disclose their location. The participants represent universities, industry, and government agencies. Specifically: 19 respondents were faculty from academia, 4 were students, 5 respondents were employees in government agencies, and 10 professionals working in the industry, with 4 respondents not disclosing their employment type. Based on the survey results, 58% have used immersive technologies and 42% have not. The majority of the respondents using immersive technologies, 54%, have indicated that they use immersive technologies for work related tasks, and another 42% uses immersive technologies for both work and entertainment, and only 4% indicated that they use immersive technologies for entertainment only.

The survey asked participants about the frequency of using immersive technologies. The most frequent response is monthly use, with a significant number of participants using immersive technologies every week. Specifically: 19% responded that they use immersive technologies once per year, 46% once per month, 23% every week, and 12% every day.

Survey participants showed higher familiarity with 360° content (91%), followed by virtual reality (74%), augmented and mixed reality (both at 61%) (Figure 1). The majority of the respondents, 90%, are using immersive technologies for viewing 3D content, and 55% are using immersive technologies for education, and another 55% using immersive technologies for data interaction and analysis (Figure 2). A 25% indicated that they are using immersive technologies for data collection in the field. The latter percentage is likely to increase in future years as more instrument manufacturers develop AR tools for surveying applications. The survey indicates that employers have a positive attitude towards adopting immersive technologies with scores that ranged from 3.12 to 3.38 (max is 5) for the various technologies.

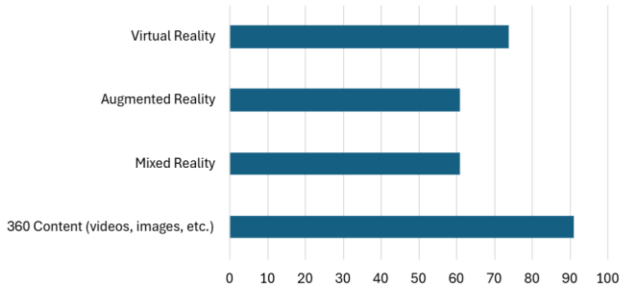

Figure 1. Answers to question: What immersive technologies have you used?

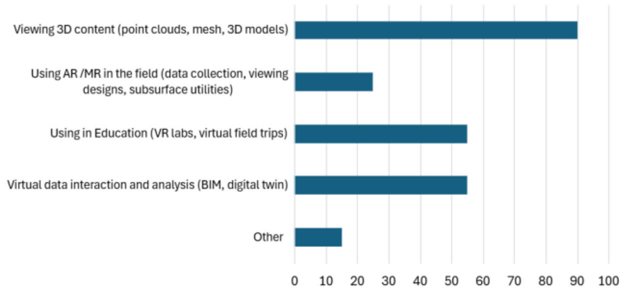

Figure 2. How does your employer / company / university use immersive technology?

As main barriers, the survey participants have identified the lack of knowledge to develop immersive tools or lack of commercial tools to use immersive tools (63.2%), with other significant barriers being the cost of hardware and software (31.6%), and the lack of IT support (15.8%). Despite these barriers, the majority of the participants believe that immersive technologies are going to become an important component of the geospatial industry (83% agreed, 17% said maybe, and 0% disagreed with this statement). Similarly, the majority of the participants believe that immersive technologies will become an important component of geospatial education (87% agreed, 13% said maybe, and 0% disagreed with this statement). These results indicate a growing familiarity with immersive technologies, but also highlight significant barriers that directly informed the design priorities of the developed applications.

One of the survey's goals was to seek feedback related to the immersive applications that the group should develop as part of the ECBI project. For the virtual reality experience suggestions included leveling, construction, topographic mapping, and more advanced environment and point cloud simulations. For the augmented reality experience suggestions were narrower and mainly included field visualization and overlays of models in real time. Based on this information, the group decided to build the following immersive experiences:

1. Virtual reality: a topographic data collection simulation (GNSS instrument)
2. Augmented reality: Projecting geospatial points, lines, and objects, on the real word using a mobile tablet device interface.

These two experiences are presented and discussed in the following paragraphs.

3. VR application

The VR application is based on the topographic mapping application of the Surveying Reality (SurReal) presented in Bolkas and Chiampi (2025), with several updates and new developments. This experience was selected based on the questionnaire responses, and because of the existing knowledge and software to implement this experience. In addition, the experience uses a simple GNSS instrument, which is more straightforward to use and easier for novice users of VR, compared to other surveying instruments like total stations and leveling.

This VR application uses a rover GNSS instrument, simulating network solution GNSS. Currently there are no quality factors, thus coordinates are recorded without error. Users can navigate freely in the environment. To record points they have to place and level the instrument, and then hit a record button to record points as needed. The environment is based on the Penn State Wilkes-Barre campus, which is the main environment in the SurReal software. The following updates were implemented to improve usability and learning effectiveness:

- <u>Update to newer Unity Engine version to improve performance and compatibility:</u> The GNSS instrument has been optimized for the newer Unity Engine version making it compatible with newer developments of the Unity Engine software.
- <u>Selecting controls to enhance interaction:</u> The handling buttons were changed allowing more intuitive interactions with the virtual instrument and tablet (e.g., using the trigger for most meaningful interactions).
- <u>Environment navigation to enhance movement in the virtual world:</u> The ability to freely rotate the view was removed, because we found in previous studies that it would make users feel dizzy (see Bolkas et al. 2022; Bolkas and Chiampi 2025). For this version, the rotation left and right takes place in increments, which we found to provide a more stable navigation in the virtual environment.
- <u>Terrain-instrument interaction:</u> The interaction of the instrument with the terrain when the user drops the GNSS instrument was upgraded to use the built-in Unity functions, allowing for faster and more efficient interaction of the instrument with the terrain.
- <u>Manual instrument leveling for faster leveling:</u> The instrument leveling tools were changed as well, with the sliders providing more dynamic changes to the instrument's position and allowing for faster leveling of the instrument (Figure 3b).
- <u>Auto instrument leveling to streamline data collection:</u> An automatic leveling option was added (Figure 3a). In previous implementations we found that students complained that manual leveling was taking time. Students now have an option for automatic leveling of the instrument to save them time.
- <u>Description improvements:</u> A new point description menu was created. There are preloaded description codes that the user can select (Figure 4a). In addition, the user has the ability to add a custom description code.
- <u>Fieldbook updates:</u> A new fieldbook was added; therefore, the user has access to two fieldbooks. The first fieldbook generic allows users to record generic notes. The second fieldbook records all the GNSS measurements and point descriptions (Figure 4b). In addition, users have the ability to scroll up and down similar to an excel spreadsheet.
- <u>Map view for data collection:</u> We developed a map that shows the location of the points in the virtual environment as they are recorded to help students understand what features have been collected and what features still need to be collected.
- <u>Using application in headset to increase accessibility:</u> The application was optimized and users can launch the application in the headset without needing a tethered connection to a computer. This considerably enhances the ability of users to use the developed application, it increases accessibility and dissemination.

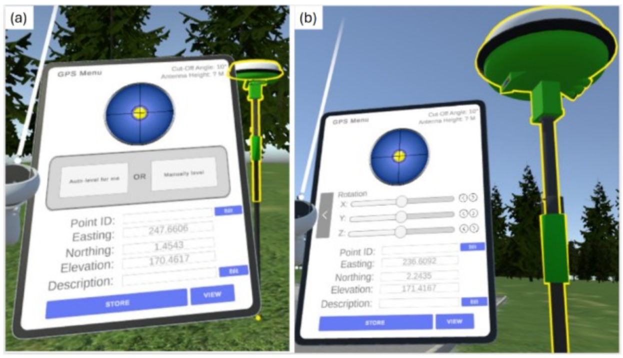

Figure 3. GNSS Auto level and Manual level (a) main menu option, (b) manual leveling menu

Figure 4. Descriptions and fieldbook. (a) User can select an existing point description or enter a custom description, (b) fieldbook showing a test point being recorded; the option of a generic or GPS fieldbook is also shown.

These design choices were aimed at improving usability, reducing user discomfort, and enhancing the effectiveness of the learning experience. The ability to launch and use the application in the headset was a major improvement, because it removes important hardware constraints. It increases accessibility and dissemination of the VR application and facilitates implementation in larger student groups.

The VR application was tested in Fall of 2025 in a mapping course of the Surveying Engineering program at Penn State Wilkes-Barre with seven students participating. The students completed the VR lab using Meta Quest 3 headsets connected to desktop computers. The VR lab took about 40 minutes to an hour to complete. This time includes the time needed to connect the headsets, explaining to students about the scope of the lab, and showing them the main software controls and instrument interactions, as well as the actual VR lab implementation.

Prior to the virtual reality lab, students attended lectures on topographic mapping as part of their normal course plan. The lectures covered topics related to collecting planimetric features and ground shots for contours using various instruments such as total stations and GNSS. Without any prior formal lab demonstration, the students were asked to collect topographic data in the areas shown in Figure 5. During the VR lab implementation, the students were given a demonstration of the VR application and the main software controls. Students spent about 10 minutes familiarizing themselves with the software. Under instructor supervision, they were asked to level the GNSS instrument and record a point to verify readiness to complete the VR lab. Then, the students were asked to collect the features shown in Figure 5. These are typical topographic features that surveyors collect in topographic surveys. Similar features exist in the virtual environment of this lab, which is used to prepare students for physical labs. Most of those points are single shot features. Ground shots are multiple shots spaces appropriately to map the terrain. Breaklines were also required by students, as it is an important element for correct terrain modeling. Priority area 1 was given to the students, which includes trees and high slopes.

The instructor and the research team observed and marked if points were collected in a correct or incorrect way. The correct way for collecting these features is shown on the second column ('requirement') of the evaluation table in Figure 5. The team also evaluated if they used the correct field code / description.

Student sample information: Seven out of the eight students opted to participate in this study. All seven students have previously worked for a surveying firm through an internship. Three students indicated that they are very familiar with the lab in question, one moderate familiar, two slightly familiar, and one student indicated that they are not familiar at all. In addition, six out of eight students indicated that they have used VR before, mostly for gaming and recreation. One student had a Quest headset at home, and that student was the best performer in the group. Six out seven students said they have collected topographic data with GNSS, mostly through work. Compared to our previous implementations, this cohort is considerably more experienced both in terms of surveying and mapping, and in terms of virtual reality. In previous studies only 10% - 20% of students had used VR, and most students were mostly inexperienced. The lack of VR experience created challenges in previous years, as students spent considerable time to become familiar with VR controls. This sometimes made the overall experience less enjoyable. Instead, this cohort, being more experienced with immersive technologies, needed only few minutes to become familiar with the VR software and was able to complete the required tasks with limited assistance from the instructor and the research team.

Evaluation

Feature	Requirement	Correct Code	Correct Placement	Incorrect Placement
Edge of Pavement	Single Shot			
Face of Curb	Single Shot			
Back of Curb	Single Shot			
Curb Curves	Three Shots (Min)			
Utility Poles	Single Shot (any side)			
Trees	Single Shot (any side)			
Signs	Single Shot			
Sanitary Manhole	Single Shot in Center			
Storm Inlet	Shot on (3) Corners			
Stone Wall	Face of Stone Wall			
Parking Paint Stripes	One Shot at Each End (Centered)			
Ground Shots	Spaced and Positioned Appropriately			
Breakline(s)	Clear Change in Topography			

Figure 5. Assessment tool for the VR topographic lab.

Table 1 provides the student assessment of the VR topographic mapping lab. Student performance was evaluated based on predefined criteria for feature identification, point placement, and use of correct field codes. Although the sample size is limited, this study is intended as a pilot evaluation to explore the potential of VR-based training in geospatial education. The table lists the feature students had to collect, the field requirement, and their scores. In some cases, students needed to create their own code to properly describe the feature being surveyed. All students identified and used the correct field codes for all collected features. As shown in Figure 4a every code has a description when selected; therefore, students can validate their selections before recording a point. In contrast, some students had difficulties when placing the GNSS pole in proper location for field data collection. Specifically, students made mistakes when recording the face and back of curb. Students placed the GNSS pole at the side of the curb instead of on top of the curb face and curb back. Furthermore, from the perspective of the instructor and research team, ground data collection revealed the greatest discrepancy between expectations of consistency and students' actual performance. Ground shot placement and point density varied substantially among students, particularly in their identification of breaklines and their overall approach to topographic data collection. Four students spaced ground shots too far apart, and five failed to correctly identify breaklines. In several cases, students collected breaklines only at either the top or the bottom of a slope, rather than at both locations, resulting in incomplete terrain representation. Additionally, an important observation was that no students captured soft breaklines associated with anthropogenic features, such as pavement edges at the top of the slope. Instead, they focused exclusively on hard breaklines strictly related to the terrain. These issues were discussed with students following the VR lab and in preparation for the subsequent physical lab. Field observations during the physical lab indicated marked improvement in students' ability to "read" the terrain. Students demonstrated a more nuanced understanding of topographic data collection and a clearer distinction between topographic and planimetric features. In this case, VR not only served as a valuable tool for enhancing student learning outcomes, but also provides instructors with meaningful insight into areas requiring additional emphasis and instructional support.

Overall, students performed well in identifying features and using correct codes, while the main challenges were related to spatial judgment, particularly in point placement and breakline identification.

Table 1. Assessment results of the VR topographic mapping experience.

Feature	Requirement	Correct / incorrect code	Correct / incorrect placement	Notes
Edge of pavement	Single shot	7 / 0	7 / 0	
Face of curb	Single shot	7 / 0	4 / 3	Placement not on top of curb face
Back of curb	Single shot	7 / 0	4 / 3	Placement not on top of curb back
Curb curves	Three shots (min)	7 / 0	6 / 1	Did not use three points
Utility poles	Single shot (any side)	7 / 0	6 / 1	Placement beside pole
Trees	Single shot (any side)	7 / 0	7 / 0	
Signs	Single shot	7 / 0	7 / 0	
Sanitary Manhole	Single shot in Center	7 / 0	7 / 0	
Stone Wall	Face of stone wall	7 / 0	7 / 0	
Parking paint stripes	One shot at each end (centered)	7 / 0	7 / 0	
Ground shots	Spaced and positioned appropriately	7 / 0	3 / 4	Spaced too far apart
Breaklines	Clear change in topography	7 / 0	2 / 5	Did not identify breaklines as expected; shots were placed either at only the top or bottom of slope instead of collecting both top and bottom.

The following tables (Tables 2, 3, and 4) provide the anonymous student feedback received for this VR lab. Minimum score is one and maximum score is five. In terms of general pedagogical feedback, students report that they liked the VR labs and added to the fun of learning, allowing us to engage students in a different but meaningful way. Students also report the benefits of VR labs to help them learn how to collect field data for topographic mapping, help them prepare for real labs, and that VR is a useful training tool for surveying education. In general, the pedagogical feedback we received in this study is comparable with scores received in previous tests conducted using similar VR labs, validating the benefits of VR labs and establishing its importance in surveying education. The feedback received in this study is uniquely important because the student sample was somewhat experience with VR, and therefore, students did not focus on the “wow” effect of VR for novice users, instead they were able to engage meaningfully with the learning experience right away.

The technical feedback is also very positive. Students comment positively on the interaction with the VR software, movement in VR, handling of the GNSS instrument, and the created functions in the virtual tablet. This feedback is critically important because of the new features and developments we have implemented in this VR lab, which seem that they were received well by students.

Table 2. Student general pedagogical feedback.

Questions	Score (max 5)
Gave me more incentive to learn	4.1
Added to the fun of learning	4.6
Improved overall learning experience	3.7
I liked the VR lab overall	4.7

Table 3. Student surveying pedagogical feedback.

Questions	Score (max 5)
Helped me learn how to collect ground shots and topographic features	4.0
Helped understand surveying methods and techniques	3.8
Helped understand how to operate surveying instruments	3.7
Can help me prepare for real labs	4.0
Is a useful training tool	4.3

Table 4. Student technical feedback.

Questions	Score (max 5)
Interacted in a clear and concise manner	4.7
Movement in VR	4.1
Quality of virtual environment	4.1
Handling of the GNSS instrument	4.4
Functions in the virtual tablet	4.3

In terms of symptoms, four students indicated that they felt nauseous, with two students saying a moderate amount and two little. Two students indicated they experienced a headache and two an eyestrain. The students said that these symptoms went away about 30 minutes after they finished the VR experience. All students indicated that they enjoyed the VR experience, despite these symptoms, which they described as minor overall. These observations suggest that the VR environment not only supports skill development but also acts as a diagnostic tool to reveal student misconceptions in terrain interpretation and data collection strategies.

4. AR Application

The AR application represents a preliminary development aimed at supporting real-world visualization of geospatial data. It is based on Android tablets, and it leverages real-time positional data obtained either from the device’s internal GPS or, for improved accuracy, through connection to an external GNSS receiver. The use of an external receiver significantly enhances positional precision, which is essential for accurate spatial alignment of virtual content. During development, an Emlid Reach RS2+ was utilized via Wi-Fi. For example, Figure 6 shows how the AR application successfully connected to Emlid GNSS unit. However, we anticipate expanding support for additional GNSS units. The application interface includes a navigation menu that provides access to core functionality such as coordinate management, model selection, and system settings (see Figure 7 and Figure 8).

The application allows users to load 3D models in the .glb format, which was selected due to its ability to encapsulate geometry, textures, and associated assets within a single file. File access is managed through the Android Storage Access Framework, which provides a unified interface to local and cloud-based storage providers such as OneDrive and Google Drive. This integration simplifies the import and export of both

3D models and coordinate data, supporting efficient data sharing and storage across multiple devices. A dedicated model manager allows users to view, add, and manage available 3D models within the application (Figure 9).

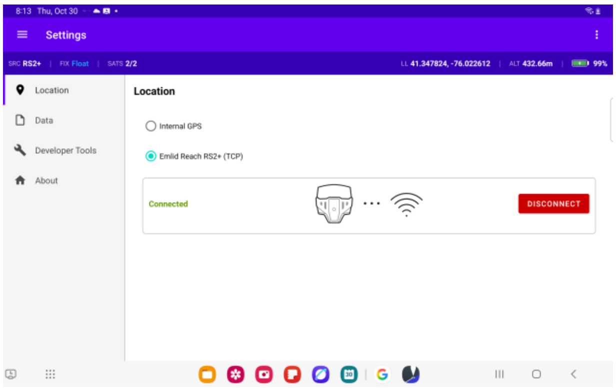

Figure 6. Connection of AR application with the Emlid GNSS receiver.

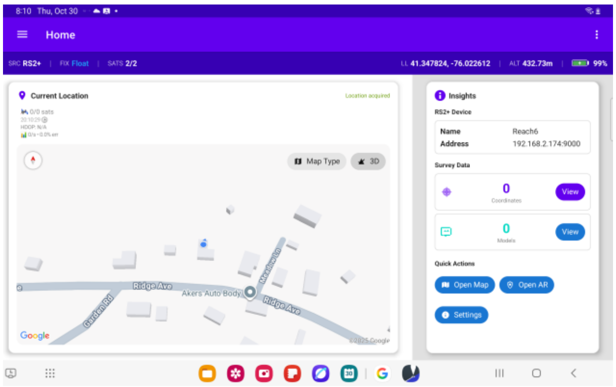

Figure 7. Home tab of the AR application showing a geolocated map view.

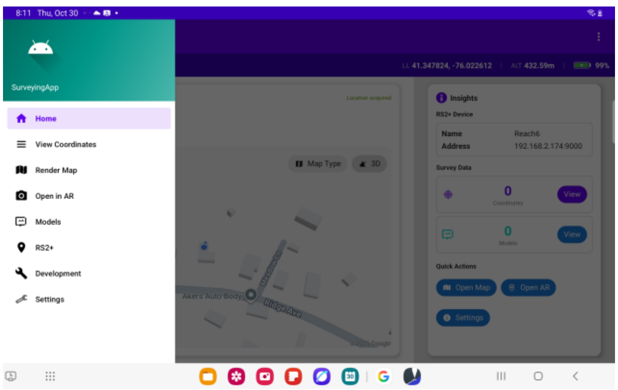

Figure 8. Menu in the AR application.

Users can collect geospatial points in the field, with the application recording key attributes including latitude, longitude, altitude, timestamp, provider, and accuracy metrics. During data collection, both the recorded coordinates and selected 3D models are visualized on a two-dimensional map interface, providing immediate spatial feedback. Users can associate specific models with collected coordinates, enabling their placement at corresponding real-world locations.

The collected points can be visualized either on the two-dimensional map or through an augmented reality interface. In AR mode, the application uses the device’s camera to display a live view of the surrounding environment, within which geospatial points are anchored to their real-world positions. This allows 3D models to be rendered in situ, creating an intuitive and immersive visualization that aligns digital content with the physical environment.

From an educational perspective, this application can support field-based learning, allowing students to better understand spatial relationships between digital models and the real environment. The application is intended to support educational activities in areas such field data collection and building information modeling. Ongoing development efforts are focused on improving spatial accuracy, with the goal of achieving centimeter-level alignment between virtual models and real-world features. This application is currently under development, and future work will focus on improving positioning accuracy and evaluating its effectiveness in educational settings.

Figure 9. Model manager in the AR application.

5. Conclusions

This work engaged the geospatial community to identify high-impact immersive learning needs and delivered two targeted applications: (1) a VR topographic mapping experience using a simplified virtual GNSS unit, and (2) an AR field-visualization prototype that anchors 3D models to GNSS positions on Android tablets. Together, these efforts lower adoption barriers for instructors by providing ready-to-use, discipline-specific experiences aligned with authentic surveying tasks.

A pilot classroom deployment of the VR lab demonstrated that immersive environments could serve as both a training and a diagnostic tool. For example, students reliably identified features and applied correct field codes but showed certain systematic misconceptions in spatial judgment (e.g., breakline identification, and ground-shot spacing). These misconceptions were identified through the VR implementation, enabling targeted feedback that translated into improved performance during the subsequent physical lab. Student perceptions were strongly positive, and reported discomfort was minor and temporary, suggesting that the developed VR lab is appropriate for instructional use.

The AR prototype application aims to provide 3D model visualizations in the field using device or external-GNSS positions on Android tablets. This application, while still under construction, can strengthen students’ spatial reasoning during outdoor labs in surveying education. When complete it will enable viewing of 3D models, support field activities such as planning and validating feature locations, and enable discussions of construction design alternatives.

Next steps focus on further development of the AR application, and packaging of the VR and AR applications for dissemination to instructors and facilitate broad classroom adoption. In addition, the working group is planning to assess both applications in larger student cohorts to quantify learning gains, and to further understand the role and importance of immersive technologies in geospatial education.

Acknowledgements

This project is funded by the ISPRS Foundation and the Education and Capacity Building Initiative (ECBI) 2024 (https://www.isprs.org/society/ecbi/default.aspx). FIG Working group 6.3 is acknowledged for their assistance in distributing the online survey.

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