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The influence of eXtended reality 3D visualization knowledge on future engineers' technical competencies

Rafał Kaźmierczak[1]✉, Tomasz Templin[2] & Agnieszka Szczepańska[3]

The rapid expansion of new technologies necessitates the adaptation of educational programs to meet the evolving demands of the labor market. This study focuses on students in technical fields, investigating their understanding of XR 3D visualization and proposing a unified training approach to improve both theoretical knowledge and practical skills. The research also evaluates how this training influences students' attitudes towards XR technologies in various applications. Key findings reveal significant improvements in technical competencies and a more positive perception of XR technologies after the training. These results suggest that targeted XR education can better prepare students for the technological challenges in their respective industries.

Keywords eXtended reality, Augmented and virtual reality, 3D visualization, 21st century abilities, Information literacy

Rapid technological progress forces the continuous adaptation of educational programs to the requirements of the labor market. The constant rollout of new technologies requires students to be up-to-date with new technologies. This poses a new requirement for higher education institutions and the necessity to adapt the graduate's profile to the ongoing changes. This trend also affects the global labor market. According to studies conducted for the European Union - "Lifelong learning has become a necessity for all citizens. We need to develop our skills and competences throughout our lives, not only for our personal fulfilment and our ability to actively engage with the society in which we live, but for our ability to be successful in a constantly changing world of work"[1].

The core scientific and IT skills are critical competencies for both technical and non-technical students. Scientific skills are sets of abilities or knowledge used to perform practical tasks in the areas of science, the arts, technology, engineering, and math. IT competencies include the ability to search for, collect, and process data and use it critically and systematically.

Modern immersive technologies such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) offer new perspectives in the design of learning environments. Milgram and Kishino[2] proposed a classification of XR systems on a continuum of 'virtuality' that links the real and virtual worlds. Their approach emphasizes the importance of integrating physical objects with virtual elements, which is very important in education, where real-world experiences can be combined with virtual enrichment.

In the context of pedagogical theories, XR technologies can be embedded within a constructivist learning framework. As a dominant learning theory, social constructivism posits that students construct knowledge through social interaction and reflection on their experiences[3]. The integration of XR technology enables the creation of authentic learning environments that simulate real professional scenarios, which is consistent with problem-based learning (PBL) and authentic learning models[4].

Within Technology-Enhanced Learning (TEL) frameworks such as SAMR and TPACK, XR technologies have the potential to transform traditional teaching methods into more interactive and engaging forms[5]. The SAMR model provides an understanding of how technology can support or completely transform educational

[1]Department of Land Management, Institute of Spatial Management and Geography, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, Prawocheńskiego 15, Olsztyn 10-724, Poland. [2]Department of Geodesy, Institute of Geodesy and Civil Engineering, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, Heweliusza 5, Olsztyn 10–719, Poland. [3]Department of Socio-Economic Geography, Institute of Spatial Management and Geography, Faculty of Geoengineering, University of Warmia and Mazury in Olsztyn, Prawocheńskiego 15, Olsztyn 10-724, Poland. ✉email: rafal.kazmierczak@uwm.edu.pl

processes. Examples of XR applications in education, such as simulations in virtual labs or interactive virtual tours, take learning to a higher level of immersion and engagement[4]. In line with this approach, XR technologies can act as catalysts for constructivist approaches to learning, supporting students to make meaningful connections between theory and practice[3].

In recent years, XR technologies such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) have emerged as key components of innovative learning environments. The development of these technologies has coincided with a renewed interest in the theories of social constructivism and constructionism, which underscore learning through interaction and hands-on experience. Contemporary research demonstrates that XR technologies can significantly bolster these theories by creating learning environments that are more interactive and engaging than traditional methods. For example Brown et al.[6] found that simulations in VR enabled students to gain a deeper understanding of difficult technical concepts, which is crucial in shaping technical knowledge. This suggests that VR technologies can effectively support learning processes based on a constructivist approach, where students construct their knowledge through experience and collaboration.

Therefore, it became necessary to explore how Technology Enhanced Learning (TEL) frameworks such as SAMR (*Substitution*, *Augmentation*, *Modification*, *Redefinition*) and TPACK (*Technological Pedagogical Content Knowledge*) could be applied to integrate XR technologies into technical education. Research by Scippo et al.[7] has shown that SAMR not only facilitates the introduction of XR into the educational process, but also leads to a profound transformation of teaching, where students can engage in tasks previously unavailable or too dangerous to complete in real-world laboratories. Introducing XR into this educational framework not only increases student motivation, but also enriches their theoretical understanding, which is consistent with findings from other studies of TEL. At the same time, the TPACK model, which combines technology, pedagogy, and subject content, has proved to be a valuable tool for preparing teachers to use XR in a way that is consistent with the curriculum. Research by[8] highlights that combining the TPACK model, which focuses on teacher knowledge in technology integration, with the SAMR model, which outlines stages from mere enhancement to profound transformation of learning, provides deeper insights into both teacher and student perspectives during the implementation of XR tools.

The use of XR technologies also has significant implications for activity theory, which underscores the importance of students' practical engagement with realistic tasks. Research by Cai and Zhang[9] shows that MR technology allows engineering students to simulate complex processes that may be too costly or risky to perform in reality. As a result, students not only learn how to perform technical tasks, but also reflect on their actions, leading to a deeper understanding of technical processes. This underscores the role of XR technologies in supporting activity theory by enabling students to simulate activities that require manual and cognitive engagement, which is crucial in technical education.

Similarly, XR is proving to be highly effective in the context of authentic learning, which involves engaging students in realistic problems and tasks. Arnab et al.[10] demonstrated that the use of VR and AR in Science, Technology, Engineering, and Mathematics (STEM) education enables students to solve real-world engineering problems, which increases their engagement and develops their technical skills. Students working in such environments are more motivated, learn the material better and develop important soft skills such as collaboration and problem-solving. In this way, XR technology not only supports the development of technical knowledge but also contributes to the holistic development of students, which is in line with authentic learning principles.

Despite the clear benefits of XR, research suggests that there are gaps that require further investigation. Chen and Konomi[11] note that while XR technology positively impacts students' short-term performance, there is still a lack of research on its long-term impact on the development of practical and interpersonal skills. Suryodiningrat et al.[12] also highlight that there is still a lack of empirical research on the impact of XR on collaboration and communication skills in technical education. In this context, the current study fills these gaps by investigating not only the impact of XR on students' technical skills, but also on their interpersonal skills, which are crucial in project-based and collaborative work environments.

Education must respond to changing demands in working life[13]. New technologies are widely adopted in many industries[14]. In particular, it concerns universal technology, which can be implemented in almost any application. EXtended Reality (XR) is considered today as an umbrella term covering a wide range of technologies, including Virtual / Augmented / Mixed Reality (VR / AR /MR)[15]. It thematically includes both the technological aspect of the presentation of virtual content itself as well as conceptual proposals for spatial interfaces and methods of human-computer interaction (HCI)[16]. To function correctly, XR requires recognizing the environment and performing spatial calculations to connect virtual representations of objects directly to real-world phenomena.

XR is now being implemented in many applications and is becoming increasingly common in education. Exemplary use cases are shown below:

- Virtual Reality (VR) in education[17–23],
- Augmented Reality (AR) in education[24–28],
- Mixed Reality (MR) in education[29–33],
- Hologram in education[34–37],
- Virtual Tour in education[38,39],
- Unmanned Aerial Vehicles (UAVs) in education[40–43].

It is estimated that in the future, these technologies will affect the teaching process and become widely used[44]. They can introduce enhanced modern educational environments[45] and overcome the boundaries of formal education[46].

Modern 3D XR visualization technologies are increasingly being introduced in geodesy, geoinformatics, and civil engineering[47–49] or non-technical sciences like land management, tourism and recreation[50–58].

Technological advances and globalization have changed these areas. It is an illustration of digital transformation, which is changing the nature of work environments[59–61]. In the same way, it forces transformations in the profile of the graduating student and the need for adaptation to the new requirements[62–64].

3D eXtended Reality visualization techniques represent a solution that brings opportunities to enhance the perception of spatial-related concepts. It is particularly relevant for students whose specialties are related to the process of obtaining, transforming, selling, and marketing products having a spatial nature.

The article presents a study aimed at evaluating the level of knowledge of XR technology and competence in the generation of 3D content for AR/MR/VR/hologram visualization techniques. The surveys were conducted with the students of the geoinformatics faculty. The faculty is a multidisciplinary institution offering educational courses for both technical and non-technical students. For technical fields of study, the students selected include:

- Geodesy and Cartography,
- Geoinformatics,
- Civil Engineering.
- Environmental Engineering.

For non-technical fields of study, they were respectively:

- Land Management,
- Tourism and Recreation,

To date, several courses realized by Faculty incorporate new technologies to improve their effectiveness.

- Geoinformatics and Geographic Information Systems will use state-of-the-art tools like GIS, which can collect, store, analyze, and visualize geographic data. With advancements in AI and data processing, GIS is becoming more sophisticated and can facilitate complex analysis and forecasting.
- Urban planning can benefit from technologies like Machine/Deep Learning and 3D visualization, which allow for more precise and effective planning. These tools can analyze massive amounts of data to understand people's needs and behavior better and simplify public consultation. New technologies also enable the creation of virtual models of cities and regions, simplifying the design of new proposals and their validation.
- Territorial marketing can use social media ads and marketing tools to reach a broader audience and promote regions and cities' attractions. Personalization of the offer can be done to adapt it to the needs and priorities of different audience groups.
- Emerging technologies like smart meters and sensors can help with ecology and environmental protection. They allow precise monitoring of the state of the environment and the deployment of more effective environmental solutions. New technologies also provide a more accurate analysis of the impact of various activities on the environment, helping to take adequate protective measures.
- Drones and satellites can provide more accurate and faster data acquisition about cities and their infrastructure for urban planning. Planners can better understand the needs of residents and plan the development of the urban structure (e.g., road network, public transportation, location of public buildings).
- Architecture/civil engineering can use 3D modeling and printing to facilitate public consultation and faster and more efficient design of buildings. Regional policy can use AI with Machine/Deep Learning to analyze data about regions and their economies. This helps understand the needs and problems of individual areas and allows better planning for infrastructure investment and economic development.
- Land management and real estate management can use new technologies like blockchain, smart contracts, and 3D modeling to improve real estate management. These technologies can reduce transaction costs and increase the efficiency of property management by tracking real estate history more efficiently.

The presented list of technologies for specific topics may be incomplete, depending on the field of study. To achieve objectives, it is crucial to be aware of potential barriers to implementing new technologies in the teaching process. These can include:

- lack of specialists - the implementation of new technologies requires the knowledge and skills of experts,
- high costs for buying and maintaining equipment and training employees,
- lack of infrastructure - some new technologies require relevant infrastructure, such as high-speed Internet or well-equipped laboratories,
- lack of standards and regulations: Some new technologies may lack standards and regulations, which can obstruct their implementation and utilization in didactics,
- lack of interest - some staff or students may not be interested in learning or utilizing new technologies,
- lack of access to information,
- significant inertia in the education system adopting new technologies demands changes in curricula and the way of teaching, which can be time-consuming and require changes to the education system to work on.

When implementing new technologies into the teaching process, the focus should be on their potential application in practice rather than technology itself.

A survey of students of the multidisciplinary geoinformatics faculty was conducted to investigate the current state of knowledge in various technical and non-technical courses. The survey aimed to diagnose the state of technological awareness of 3D visualization technologies amongst students of faculties of technical sciences and social sciences and further observe changes in students' perceptions of these technologies after workshops on AR (Augmented Reality), VR (Virtual Reality), MR (Mixed Reality), hologram, Virtual Tour, UAV (Unmanned Aerial Vehicle) usage.

The survey obtained data on using new 3D visualization technologies in teaching activities, including their use in space-related applications. A 40-hour workshop was conducted afterward for a selected group of students. During the training, participants gained theoretical knowledge and performed practical tasks. After the workshop, polls were conducted to obtain information on the progress made by students in terms of their understanding of 3D visualization technology and the possibility of using it in various applications.

The survey allowed the organizers to analyze the results, conclude the effectiveness of the training, and identify areas for improvement. The Methods section explains the methodology used. Following that, the workshop curriculum is presented, along with a description of the 3D eXtended Reality visualization technologies utilized. The last section discusses the results of the initial survey and the post-training participant examination. Finally, the study concludes with a presentation of the results as well as an outline of future work.

The aim of this study is to investigate the impact of 3D XR visualization on the development of students' technical competence in engineering education. We hypothesize that targeted training using XR technology will improve students' technical skills and influence their attitudes towards these tools. The study will assess students' knowledge of XR technology and their skills in creating 3D content for AR, MR, and VR visualizations. We also assume that intensive XR training will enhance students' practical competencies in technical fields, better preparing them for today's labor market, where high-tech skills are increasingly important.

To address these assumptions, we have formulated key research questions: What difficulties do students face when learning with XR technology? How does the use of XR in technical education affect the development of their technical skills? Does XR training positively influence students' attitudes towards these technologies and their future use in professional practice? Clarifying these questions will provide a precise methodological framework for the study and a better understanding of the potential impact of XR technologies on the formation of modern technical competencies.

Methods

A survey was conducted in the first phase of the research on 207 students from the multidisciplinary geoinformatics faculty, studying various technical and social sciences programs such as Civil Engineering, Geoinformatics, Geodesy and Cartography, Environmental Engineering (technical sciences – 132 people), Land Management, Tourism and Recreation (non-technical sciences – 75 people).

The survey was conducted anonymously online, and the questionnaire comprised seven closed-ended questions. The questions focused on the students' knowledge of AR, VR, MR, hologram, Virtual Tours, UAV, and their contact with these technologies. The survey also asked for a subjective assessment of the difficulty level in using and creating a working environment with these technologies. Additionally, the survey asked whether these technologies were discussed in the courses and if they should be included in the educational program.

Each question was assigned a bivariate or trivariate response of "yes," "no," or "I have no opinion." The students were also asked to rate the relevance of these technologies to their future work on a five-point Likert response scale. Respondents, completing their answers, chose one of the ordered categories from the assigned consecutive natural numbers from 1 (least valuable) to 5 (most useful)[65].

In the next stage, a practical workshop was organized for 47 students (11 technical sciences students, 36 social sciences) from various fields of study, such as Civil Engineering, Geodesy and Cartography, Land Management, Tourism and Recreation. The workshop schedule is presented in the section Workshop Description. The students were divided into small groups (12 persons), and two instructors conducted the classes simultaneously. A panel discussion was launched after each thematic block.

At the end of the workshop, a survey was conducted to verify the changes that occurred among the students, particularly in their perception of new solutions and their ability to use them in space-related applications. The survey also asked about the students' evaluation of the need for these technologies in their discipline's educational process and their usefulness level for future employment. A five-point Likert response range scale was used for each question, with a "no opinion" answer option.

The questionnaire survey was designed to accurately assess students' knowledge of XR technologies such as AR, VR, MR, holograms, virtual tours, and UAVs, as well as their experiences with these technologies and their perception of their difficulty. Before selecting specific questions, preliminary interviews with instructors and students were conducted to identify critical areas for assessment. Questions regarding knowledge of XR technologies and evaluation of their difficulty in use were vital in understanding how these technologies are perceived and how they can be implemented in future careers.

The Likert scale was used in the questions to assess the usefulness and difficulty of technology. This scale was chosen because of its widespread acceptance in educational research and ability to accurately measure attitudes and opinions. The use of a five-point scale allowed respondents to express the degree of their attitudes towards technology, enabling a more detailed analysis of their opinions. This scale is widely used in attitude research, making it suitable for examining perceptions of XR technology.

The questions were validated through a pilot study on a small group of students to ensure that they were understandable and appropriately worded. The results of this pilot allowed for adjustments to be made, increasing the validity and reliability of the final questionnaire.

The sampling was based on the need for the survey to be representative of the geoinformatics faculty students. Of the more than 600 students eligible to participate in the survey, 207 were analyzed, representing 30.6% of the total population. The sample size was justified by aiming for a proportionate number of technical (132 students) and non-technical (75 students) students. This distribution ensured that the responses were representative of both the technical and non-technical student groups, allowing for a more precise analysis of differences in perceptions of XR technology between these groups (Fig. 1).

A preliminary survey was conducted with 207 students from the Faculty of Geoengineering, who were divided into two groups:

- Technical Sciences – 132 students from programs such as: Civil Engineering, Geoinformatics, Geodesy and Cartography, Environmental Engineering.
- Non-Technical Sciences – 75 students from programs such as: Land Management, Tourism and Recreation.

A survey was administered to assess the general level of knowledge related to XR technologies among all students prior to any interventions. From the initial group, a subgroup of 47 students was selected to form the experimental group, which underwent further examination.

An initial survey was conducted to evaluate the participants' baseline knowledge and attitudes towards XR technologies. The experimental group then participated in a 40-hour workshop focused on various XR technologies, which included: Virtual Reality (VR), 3D Glasses, Virtual Tours, Augmented Reality (AR), Unmanned Aerial Vehicles (UAVs), 3D Holograms, Preparation of environments and models. Following the completion of the workshop, a post-assessment survey was conducted to measure changes in the students' knowledge and attitudes towards XR.

The first part of the study assessed the general knowledge level of the students across technical and non-technical disciplines. The second part focused on the experimental subgroup, examining the impact of XR training on their knowledge and attitudes, measured through pre- and post-workshop surveys.

The selection process was voluntary, and the survey was conducted anonymously, which was conducive to obtaining candid responses. Students were selected based on their interest in XR technologies and participation in surveying, mapping, and land management classes. The number of 207 respondents was sufficient to obtain representative data and apply appropriate statistical tests.

Additionally, 47 participants were invited to a workshop to investigate the practical application of XR technology further. The workshop group was selected to be diverse in fields of study to obtain data on XR applications in technical and non-technical contexts.

The analysis of the collected data involved using various statistical techniques to gain detailed insights into students' knowledge and perception of XR technology. Initially, basic statistical measures such as frequencies and percentiles were calculated to identify general student attitudes and knowledge trends. These analyses helped determine how often respondents were exposed to XR technologies and how they assessed their usefulness in their future careers.

The mean, median, standard deviation, variance, and quartiles were calculated for questions based on a five-point Likert scale. The mean and median were used to assess the central tendency in the responses. At the same time, the standard deviation and variance allowed an assessment of the dispersion of the responses, helping to identify variations in perceptions of XR technology. The quartiles provided additional information about the distribution of scores within the groups, allowing a better understanding of how the students rated their experience compared to the rest of the study population.

The Student's t-test and analysis of variance (ANOVA) were used to analyze the relationship between the different variables in depth. The Student's t-test allowed us to test whether there were statistically significant differences between the responses of technical and non-technical students regarding their perceptions of the difficulty and usefulness of XR technology. ANOVA was used to compare responses between several groups, which provided information on differences in the evaluation of XR technologies according to the level of

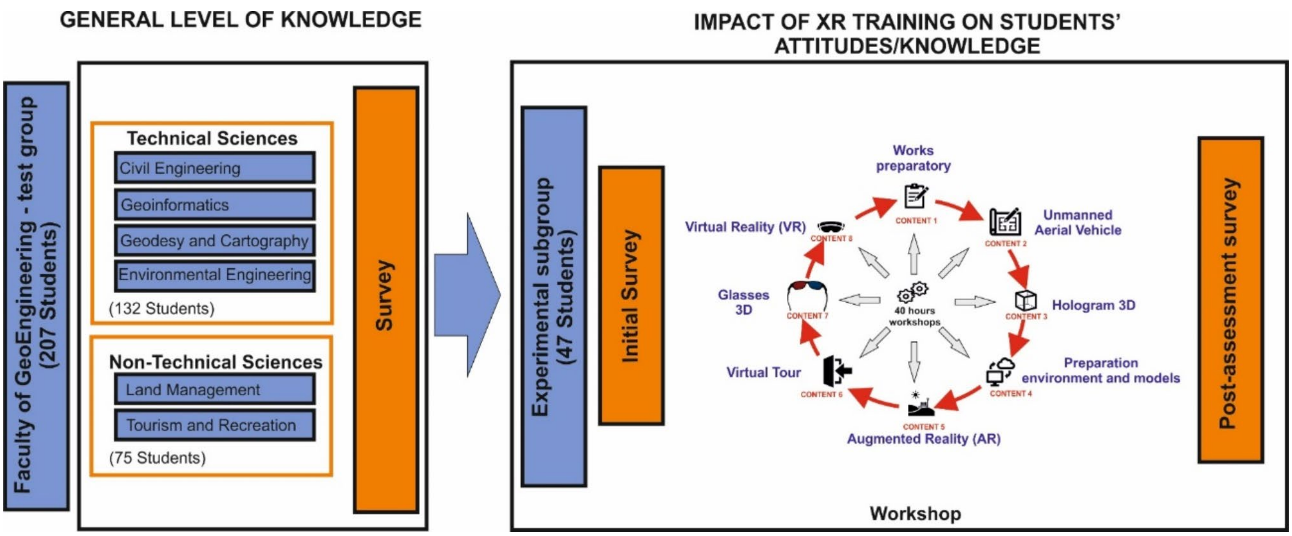

Fig. 1. Conceptual framework illustrating the assessment of students' general knowledge and the impact of XR training on their attitudes and knowledge levels.

sophistication and contact with the technologies. These statistical methods were justified by the need to accurately compare different groups of respondents and identify relationships between variables that were key to drawing reliable conclusions.

By using these analytical techniques, it was possible to obtain detailed results that provided valuable information on the level of knowledge, experience, and perception of XR technologies among students. This analysis was crucial in assessing students' difficulties and identifying opportunities for further implementation of these technologies in technical and non-technical education.

The challenges of implementing these technologies can be overcome by organizing workshops and training sessions. Such activities allow users to understand the new technology, learn how to use it, and integrate it into their daily work. It is important to remember that technology is a tool, not a goal. Understanding its benefits, implementation, and potential obstacles is crucial.

Table 1 presents the rationale for each research hypothesis, using data from surveys, observations, and interviews with workshop participants. Its goal was to identify the main challenges faced by respondents and evaluate the effectiveness of XR technology training.

The initial online survey results were analyzed in detail to form the main hypotheses for evaluating 3D eXtended Reality technology in various applications. The detailed analysis results by field of study and gender of respondents are presented in the appendices. The survey results from the workshop were enhanced with notes from direct observations of participants' behavior and reactions.

The workshop utilized various techniques to enhance students' learning and motivation. These methods were based on a constructivist teaching approach, which encourages active student participation. According to the theory of social constructivism[66] this form of activation promotes a better understanding of the material and the development of group cooperation skills. Additionally, Piaget's constructivism[67] emphasizes the role of active knowledge construction by students, which was implemented in the workshop through practical 3D visualization tasks.

The activation techniques used were supported by educational literature. For instance, the problem-based learning (PBL) project method was backed by research on technical education using XR[68], showing that this approach developed practical skills as well as theoretical knowledge. The workshop also involved group work, in line with collaborative learning theory[69] which emphasizes the importance of interaction between participants. Furthermore, the use of XR technologies enables students to learn new technologies and develop creativity and analytical thinking[70].

The challenge in implementing these technologies was to provide adequate training to enable participants to better understand the XR tools and integrate them into their daily work. According to the literature[71], technology should be seen as a tool to support the educational process rather than an end in itself. The XR workshops significantly changed students' attitudes towards these technologies and positively influenced the development of their practical skills, preparing them for the challenges of today's labor market.

The surveys conducted during the workshop have been analyzed in detail about individual questions. The results of the questionnaires were supplemented by notes from direct observations of the behavior and reactions of the participants. The study used methods that were carried out in accordance with relevant guidelines and ethical regulations for scientific research. All experimental protocols received the necessary approvals from the Research Ethics Committee of the University of Warmia and Mazury in Olsztyn, in accordance with Decision No. 2/2023. Participation in the study was fully voluntary. All participants in the study were adults and gave informed consent to participate in the study after being fully informed of its objectives, scope and potential consequences. Ensuring the confidentiality and anonymity of information obtained from participants was a priority throughout the research process. These measures were taken to ensure that the study was conducted in an ethical manner and in accordance with the highest standards of scientific accountability.

Workshop description

The workshop was conducted from December to March 2023 for students of multidisciplinary geoinformatics faculty. The workshop concerned the use of eXtended Reality-based visualization technology. A diagram of the workshop program is presented in Fig. 2.

During the course, participants gained theoretical knowledge and practical skills using modern technologies. The workshop program consisted of eight subjects, which are listed in detail in Table 2.

The exercises taught students how to create 3D models from various data sources, which is highly relevant today as we have an increasing amount of spatial data in digital form. Figure 3 shows a complete list of devices, sensors, and tools used at each stage of the workshop.

Assumption	Rationale
A significant number of respondents find the creation and use of work environments utilizing AR, VR, MR, holograms, Virtual Tour, and UAVs complicated.	The numerous individuals face challenges when using and implementing these technologies in their work environment. These obstacles may arise due to a lack of necessary skills, experience, tools, or resources, as well as the intricate nature of the technology.
Education and training can help individuals become more comfortable with using and deploying these technologies in work environments.	Education and training can be helpful for individuals who find it difficult to use complex technologies. Appropriation training can boost users' confidence, enhance their proficiency with these technologies, and enable them to apply them in practical settings.
Hologram technology and Virtual Tour are perceived as less complicated to use and integrate into work environments than AR, VR, MR, and UAV technologies.	According to a survey, hologram and Virtual Tour technologies are less problematic to use than other technologies mentioned, possibly because they are perceived as being less intricate and more user-friendly, making them more suitable for work environments.

Table 1. Rationale of the assumptions presented in the paper.

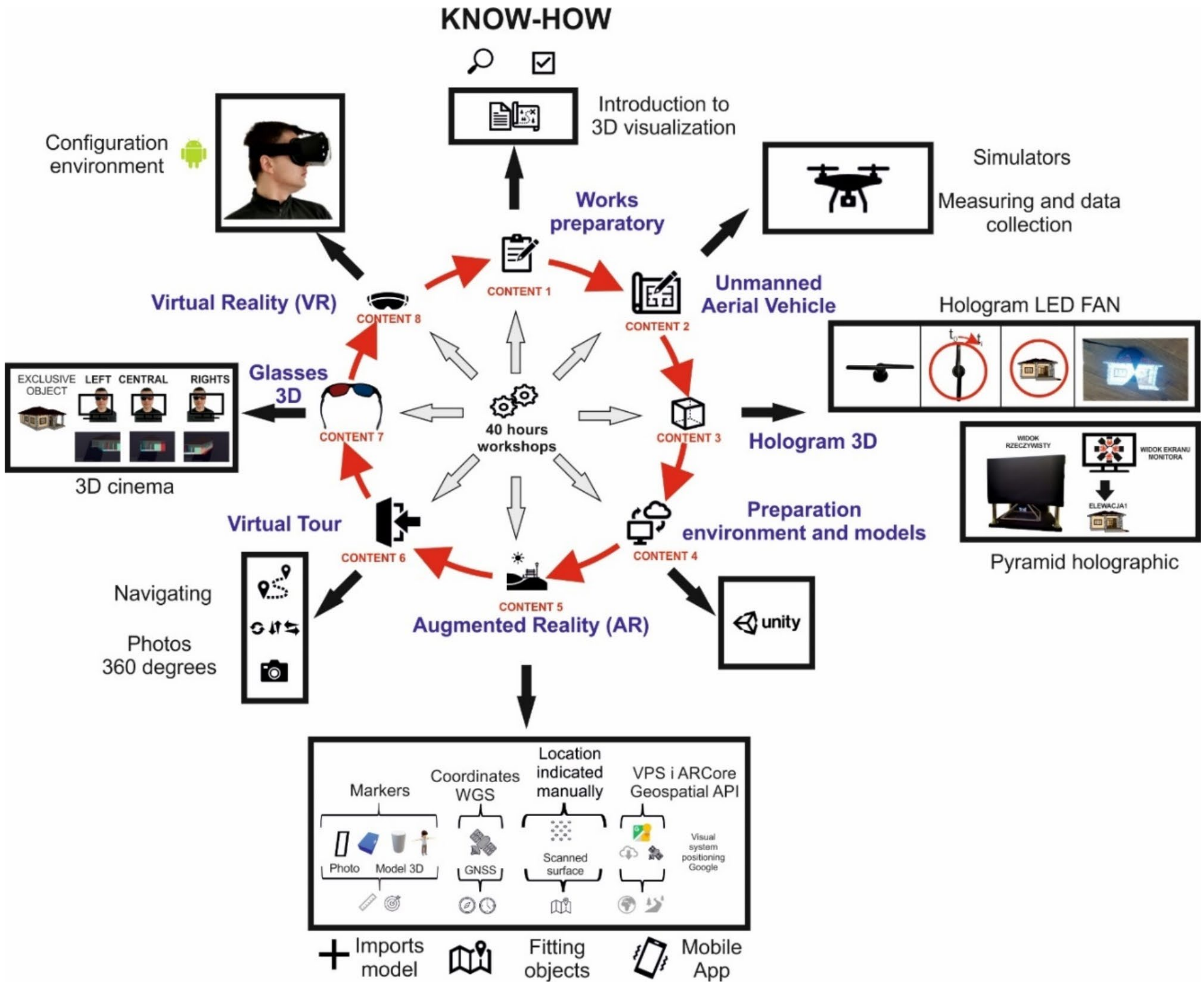

Fig. 2. Program of 3D eXtended Reality visualization workshop.

1.1 Introduction to the 3D eXtended Reality visualization.
• Theoretical foundations and principles of new technologies.
2. Augmented Reality (AR)
• Development of a marker-based mobile AR application to visualize the landscaping of a single-family building
1.3 Virtual Reality (VR)
• Types of VR solutions and glasses. Principles of setting up the environment, pros and cons of selected VR display tools.
4. Mixed reality (MR)
• The use of mixed reality using Microsoft HoloLens
5. Unmanned Aerial Vehicle (UAV)
• Legal aspects of drone flights. Field flight performance with UAV flight simulators.
1.6. Virtual Tour
• 3D cameras. Creation of a virtual tour of the building.
1.7. Holograms
• Principles of creating content for use with anaglyph glasses, 3D cinema and 3D holographic visualization.
8. 3D modelling through Reality Capture data (***laser scanning, short-range photogrammetry***).
• Creation of 3D models based on laser scanning data and \imageries. Application of Structure from Motion (SfM) algorithms.

Table 2. List of subject areas of the workshop.

Fig. 3. The complete list of devices, sensors, and tools used at each stage of the workshop.

The following activation methods were used during the workshop:

- project method instruction to complete a project concerning the chosen technologies (e.g., Virtual Tour project),
- problem-solving method presenting a specific problem to be solved through the interactive work of participants (e.g., optimizing a measurement method),
- discussion method engaging students in discussion (discussion panel after each thematic block),
- group work method organizing work in groups where participants divide themselves into roles and tasks (e.g., teams gathering and processing data),

- open task method giving design problems that require creativity (e.g., designing layouts for Virtual Tour),
- pairing method organizing students to work in pairs, where one participant can help the other solve a problem (e.g., monitoring the view from the VR goggles on a smartphone),
- presentation method asking students to prepare a presentation on a selected topic (e.g., presentation of 3D models in AR),
- experiment method conducting experiments (e.g., testing technical parameters when creating 3D models),
- method of using external information databases (e.g., integrating data from the University's Student Support System with the Virtual Tour).

The next section briefly characterizes each thematic block with a description of the tools used in the educational process.

Augmented reality (AR)
The AR course introduced participants to this technology and taught them how to create mobile applications using the Unity 3D development environment and the Vuforia Library. The class also discussed different methods of displaying and placing 3D objects in space, including position-based using GNSS, location-based on image recognition (marker), and location after detecting feature points and planes. Moreover, mixed methods, which combine several location methods, were discussed.

Students had the opportunity to learn about the advantages and disadvantages of each location method and how to develop AR applications and solve challenges. The tools used to complete the task were Vuforia Engine and Unity engine, which provide technical documentation and features for creating AR applications.

Vuforia Engine is a platform for developing AR apps, offering advanced computer vision functionality on Android, iOS, and UWP operating systems. The platform provides several tools, such as the Vuforia Engine library, which includes technical documentation for creating AR applications using the Vuforia Engine SDK. The Vuforia Engine platform also offers many features that enable tracking various objects and spaces, such as images, objects, and environments.

The Unity engine is an advanced engine for creating 2D and 3D games and interactive visualizations or animations. It works on various platforms, including Windows, macOS, Linux operating systems, web browsers, PCs, video game consoles, and mobile devices. The engine also offers an Asset Store, which allows users to take advantage of paid or free resources such as textures and scripts.

Virtual reality (AR)
In the workshop, Virtual Reality (VR) and its hardware requirements were delivered. The VR display using a smartphone and VR adapters was tested, as well as the creation of Virtual Tour or Unity-based solutions. The configuration and maintenance of VR environments using devices such as the Oculus Rift and HTC VR VIVE Pro Eye, where content generation is done using a personal computer, were explained. Students learned the difference between environment configuration on devices like Oculus Quest 2 and standalone HTC VIVE Pro Eye.

Throughout the course, different solutions for displaying content, ranging from 3D models to animations and photos/movies captured using 360-degree cameras, were discussed. Participants could compare the immersion level and verify their perceptions, cognitions, and emotions. The workshop helped participants understand the practical aspects of using VR in space-related industry applications.

The following devices were used to complete this part of the workshop:

- Mobile VR headsets allow for an affordable VR experience but with lower quality and immersion compared to advanced VR solutions. They usually combine two flat images each eye perceives. These stereoscopic images, generated by the smartphone, are projected onto two lenses in front of each eye.
- Oculus Rift provides high-quality displays and 6DoF controllers for a high-immersive experience but requires a powerful GPU.
- The Oculus Quest 2 is a standalone VR headset that's more portable but with slightly less comfortable controllers.
- The HTC VR VIVE Pro Eye is a professional VR goggle designed primarily for architecture, industry, education, etc. They have very high image quality and high-quality controllers. It has very high image quality and controllers and an eye-tracking system that precisely tracks the user's eye movements.

Hologram
During the workshop, students were introduced to various technologies that can be used to display three-dimensional images. The first technology they learned about was anaglyph glasses, which use a filter in one lens to block out red and a filter in the other lens to block out blue. When the brain processes the two images together, a 3D world is created. The workshop also covered the use of separate images for each eye in 3D cinema.

The following technology discussed was the holographic pyramid, which is a conical plastic piece that can display 3D images without the need for glasses. This method relies on light diffraction and requires proper lighting and source material for the best results. The workshop also demonstrated how to display models in an LED holographic projector. This device uses rotating blades to create the impression of a 3D image suspended in the air. The workshop participants were able to learn about the device's construction and operation principles, and they were shown how to achieve a spatial effect by rotating and moving a prepared 3D model.

All of these technologies for displaying 3D images have applications in various disciplines, including science, medicine, architecture, and entertainment.

Virtual Tour
Virtual Tour is an interactive way of exploring and learning about places, objects, or buildings. With a web browser Virtual Tour, users can experience a three-dimensional environment using a computer or mobile device. This technology is widely used in the tourism, retail, and real estate industries, allowing visitors to enjoy a graphical display of a location from the comfort of their homes. Virtual tours are based on Augmented Reality (AR) and Virtual Reality (VR) and are accessible on a computer, tablet, or smartphone.

During a workshop, students created a Virtual Tour of the Faculty building using the Ricoh Theta Z1 51GB and Virtual Tour software. In addition to learning how to create virtual walkthroughs, participants also learned how to use the technology to develop educational materials, knowledge tests, and simple games.

The process of creating a virtual walkthrough involves several stages, including gathering photos and resources about the space being showcased, creating panoramas of each room or area, inserting walk-through points, adding interactive elements, integrating with a platform, testing, and publishing.

This part of the activity was carried out using:

- RICOH THETA Z1: a dedicated spherical camera that can capture 360-degree images and videos in 4 K resolution. The camera captures the entire space, making it possible to create realistic virtual tours.
- VIRTUAL TOUR PRO software is an advanced tool that enables the creation of interactive virtual tours. The program has many features and tools that allow the personalization of virtual tours, such as adding interactive elements, sound, or text.

Unmanned aerial vehicle (UAV)
In the UAV-related classes, participants were taught about the requirements and authorizations for using drones in Poland. The Civil Aviation Authority provided information and an overview of the authorizations needed. In the practical part of the class, participants used flight simulators to test their skills. They were able to customize weather conditions and choose the type of drone to practice basic maneuvers and control of the UAV.

The next step involved field flights using the DJI Mavic 2 Pro and DJI Phantom 4 Pro v2 drones. During the flights, participants learned about measurement methodology and the characteristics of conducting flights. The class also discussed various areas where data obtained from a UAV could be helpful, such as in spatial-related applications. The final exam for the open category UAV operator was also included.

To complete this part of the course, the following equipment was used:

- DJI Mavic 2 Pro: a popular drone choice among professionals and hobbyists for photography, filming, terrain mapping, building inspection, and more. It has advanced features and a high-quality camera.
- DJI Phantom 4 Pro V2: a professional drone with a 20-megapixel camera and obstacle detection system. It can record videos in 4 K quality and maintain a stable position in difficult weather conditions.
- Aerosim RC model flight simulator software: a tool that simulates the flight of remote-controlled models. It allows virtual control of the model and offers flight simulations of different types of RC models, weather conditions, and terrains, allowing modelers to improve their flying skills without the expense of purchasing and repairing actual RC models.

3D modelling
In the workshop's 3D modeling section, participants were taught how to create a 3D model of an object using various software, both free and commercial. Agisoft Metashape, one of the software programs introduced, allowed for the creation of 3D models through photo captures. The process involved planning the data collection, taking photographs or scanning the object with a mobile device, and importing the data into the software to generate the final 3D model. The participants also learned about the various settings that affect the model's quality, such as the number of points generated and the texture and color settings. They were then able to use the 3D model in virtual environments, such as video games or virtual tours of museums and buildings.

To create a 3D model, students need to acquire the appropriate data. The use of 3D scanners is one approach that captures data using laser technology or photometric methods. Photogrammetry involves creating a 3D model from photos, which requires taking images from various angles to ensure the software has enough data. Once the data is collected, specialized software like Agisoft Metashape can process the data and create a virtual 3D model. The model must then be edited to remove errors and optimized for XR before being used in various applications. The course used two software programs for the 3D modeling section:

- Agisoft Metashape is a paid program that can process data from aerial photos, drone images, or camera photos to create 3D models. It can generate models in multiple formats, including VRML, for use in virtual environments.
- Regard3D is a free and open-source program that works on Windows, Linux, and Mac OS X and can create 3D models from digital images. The program offers tools for acquiring images, combining them into sequences, and processing them into a 3D model. It also allows for editing and modification of the resulting model.

Baseline of students' knowledge
A preliminary survey was conducted among 207 students from the multidisciplinary geoinformatics faculty. The respondents represented six different fields of study (Fig. 4). The largest groups were students of Geodesy and Cartography (78 people) and Land Management (52 people). The other fields of study were Civil Engineering (29 people), Tourism and Recreation (23 people), Environmental Engineering (13 people), and Geoinformatics (12 people). As for gender, 110 women (53%) and 97 men (47%) participated in the survey.

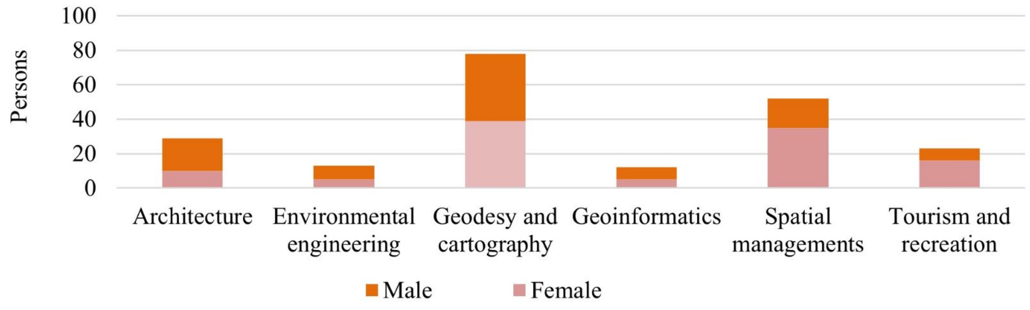

Fig. 4. The characteristics of the persons evaluated by educational field and gender.

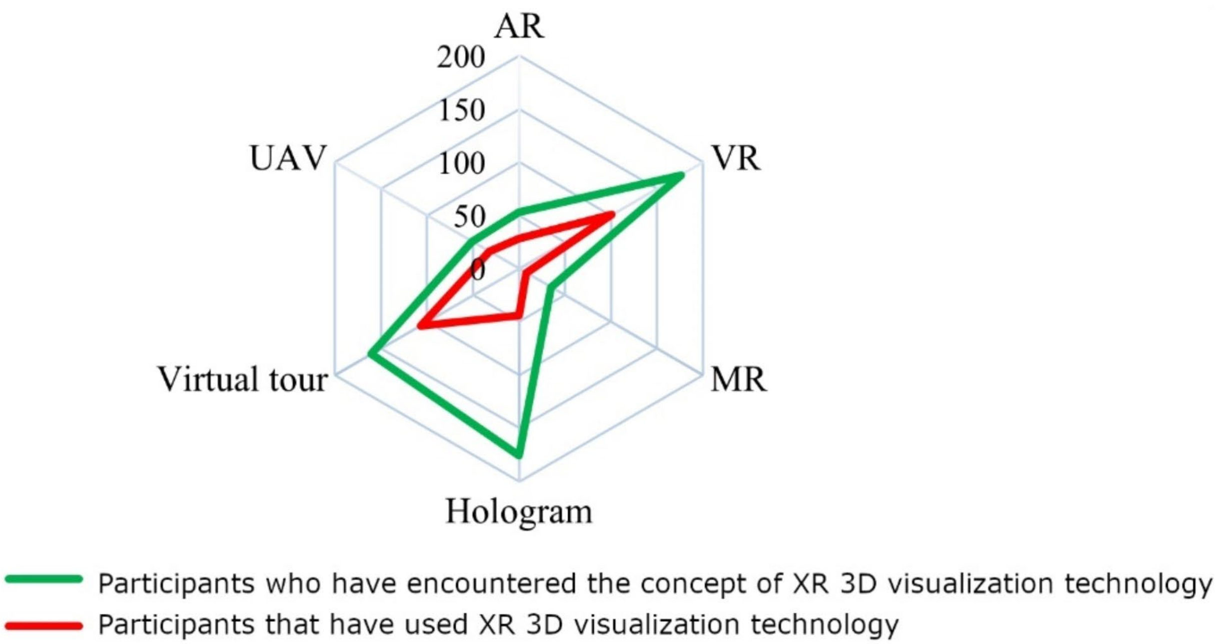

Fig. 5. Technological awareness of respondents' eXtended Reality 3D visualization.

Knowledge of the technologies studied, and the ability to distinguish between them among students varied. While almost 85% of respondents were familiar with VR and Holograms, only about 26% and 17% were aware of AR and MR technologies, respectively. VR and Virtual Tour were the most frequently used technologies (49% and 52%, respectively), while MR technology was the least popular (only 4%). The aggregated responses of survey participants are presented in Fig. 5, while a detailed analysis of the responses can be found in Table A1.

The survey also asked about the difficulties of using 3D visualization technologies. Many respondents had no opinion, likely due to a lack of experience with the technologies (AR 65%, MR 71%, UAV 63%). This is a direct consequence of the previous question, showing that only a few respondents used these technologies. On the other hand, according to respondents, using technologies such as VR and Virtual Tour is relatively easy (65% and 63%) (Fig. 6).

Regarding the complexity of utilizing and constructing solutions with these technologies, it appears that many students are uncertain. A large number of them believe that developing their solutions using these technologies is challenging, indicating that education and training in this area can be highly beneficial. Since only a few respondents used 3D visualization technologies, most of them chose "I have no opinion" when asked about the difficulty of creating their own solutions using the technologies mentioned above (ranging from 38% of respondents for VR to 57% of respondents for MR) (Fig. 7). According to 25% of respondents, designing custom solutions using Virtual Tour technology is relatively simple.

The survey asked participants if certain technologies were covered in their classes and if they believed they should be included in the curriculum for their respective fields of study (Fig. 8). The majority of respondents stated that these technologies were not frequently discussed in their classes and that they learned about them elsewhere. Among the technologies mentioned, virtual touring received the most responses (34%), while AR and MR had the lowest (12% each). Table 1 (a-e) provides a thorough examination of the survey results.

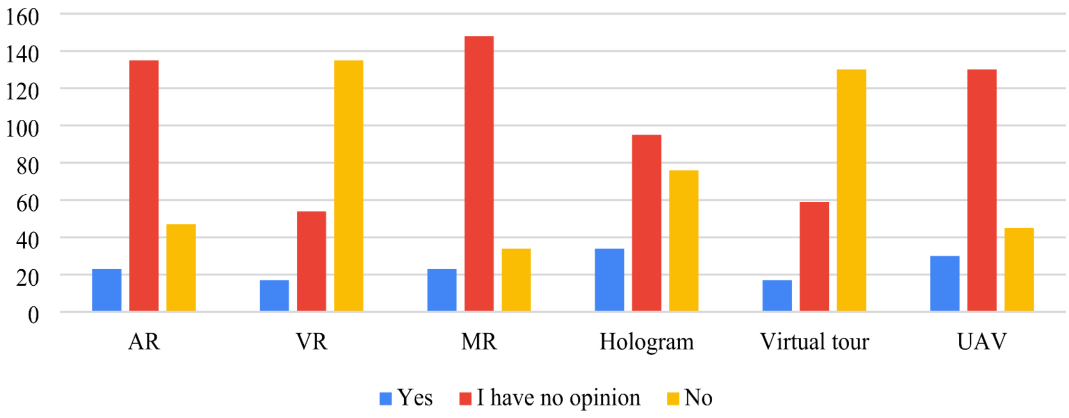

Fig. 6. The level of difficulties of using eXtended Reality visualization technology.

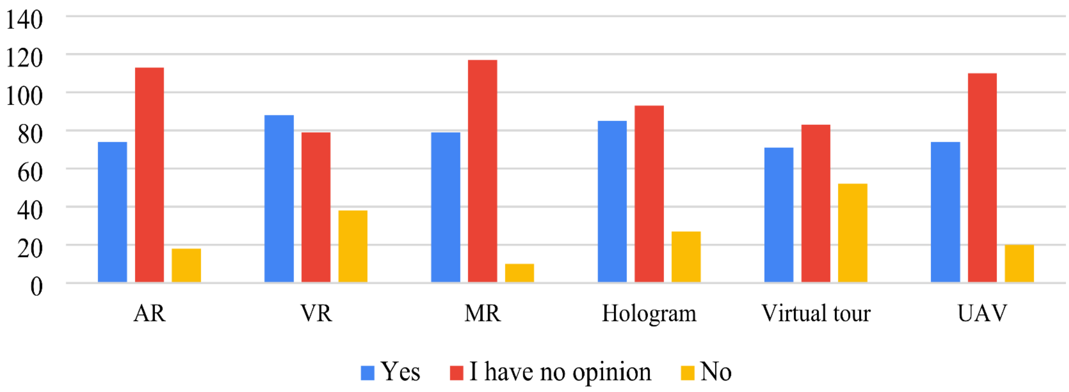

Fig. 7. The level of difficulty of creating a working environment with eXtended Reality 3D visualization technologies.

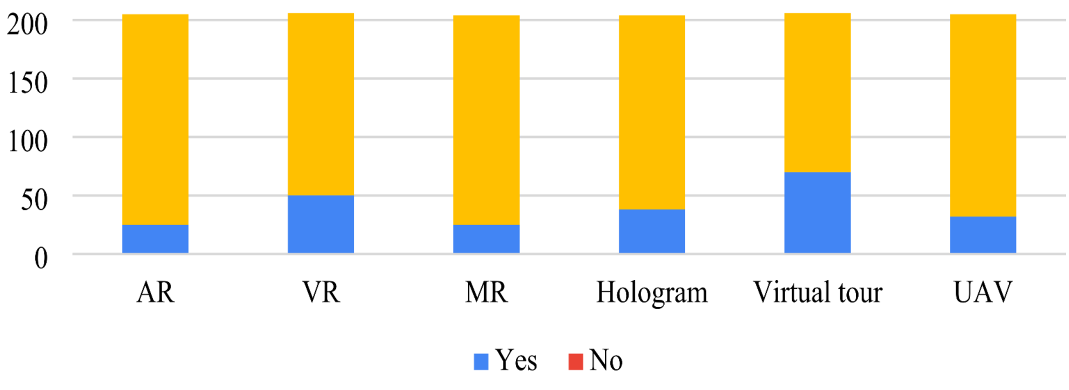

Fig. 8. Status of using eXtended Reality 3D visualization technologies in the teaching process.

Even though these technologies were seldom mentioned in educational courses, indicating a lack of comprehension and practice, many individuals believed that they should be included in their field of study. Among the top choices were VR (62%), Virtual Tour (59%), and Holograms (55%). Figure 9 shows an overall summary of the responses concerning whether or not these technologies should be taught in classes. At the same time, a more comprehensive examination of the feedback can be located in Table A1.

In the final question, students were asked to assess how relevant the analyzed technologies would be in their future work. Due to the lack of knowledge and class discussion, many students opted to choose the "I have no opinion" answer. However, Virtual Tour (27% of responses) and VR (20% of responses) received the highest number of "5" ratings (very useful), indicating that they are considered highly valuable technologies (as shown in Fig. 10).

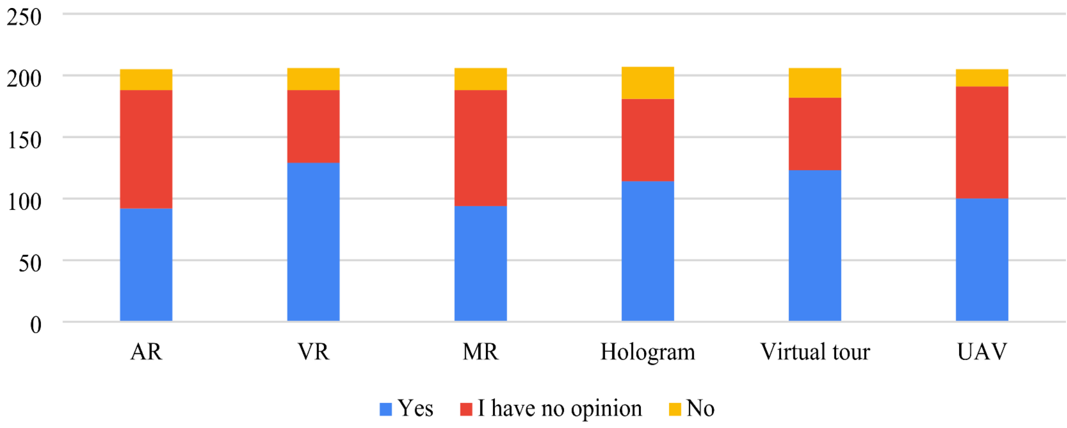

Fig. 9. The need for the realization of didactic courses with the use of eXtended Reality 3D visualization technology.

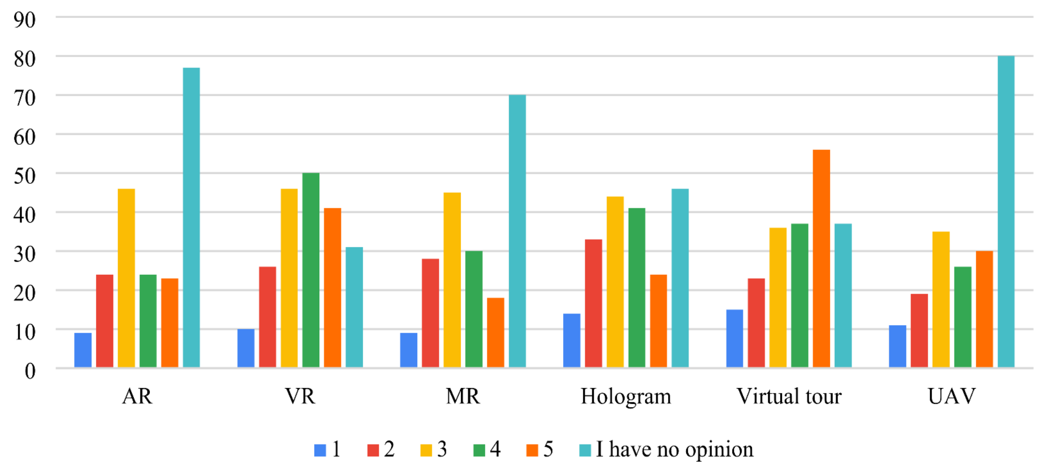

Fig. 10. The suitability of eXtended Reality 3D visualization technology for future work.

These technologies are also the ones that students are most likely to encounter outside of class. Nevertheless, other less familiar technologies, such as MR, showed potential and could be beneficial with further education in this area. A detailed distribution of the responses by field of study is shown in Table A2.

The study conducted a t-test to determine if there was a significant difference in how men and women assessed the usefulness of specific technologies for future work. The results showed that Virtual Tour had a significant difference in ratings, with women giving it a higher average rating of 3.82 ($n=90$) compared to men's 3.28 ($n=77$). The standard deviation for the women's group was 1.22, and for the men's group was 1.37. The t-statistic value was 2. 67, indicating a statistically significant difference between the groups with a significance level of $p=0.008391$, lower than the standard significance level of 0.05. This suggests that the difference in the ratings is statistically significant, so women and men differ in their perception of the usefulness of virtual tours in future work. The F-value for the variance was 1.26, and the p-value was 0.286873. This indicates that the variances between the groups are not statistically different. Overall, the study found that women rated Virtual Tour as more useful for future work than men. For the other technologies, there are no such differences.

The Descriptive Statistics Cross-Sectional Table (Table A3 and Table A4) showed that AR received an average rating of slightly more than 3 out of 5, with men rating it slightly higher. VR was more popular, with an average rating half a point higher than AR. Women expressed slightly more interest in VR than men. MR scored just over three and was more appealing to women. Holograms received an average rating of 3.18, with women expressing slightly more interest. UAV was the least popular technology, with an average score of 3.37, slightly more appreciated by women.

The study observed that the variation in ratings may depend on several factors, such as gender, area of specialization, interests, and experiences. However, both men and women rated all technologies as potentially valuable for future work. Virtual tours were the highest-rated technology, especially among women.

Table 3 provides more detailed conclusions for each technology.

In summary, based on the responses, it can be concluded that:

Technologies	Findings
AR	- the average rating of AR technology across all respondents was 3.22, with a standard deviation of 1.17, which means that answers were pretty diverse, - in each field of study, both men and women assessed AR technology at a similar level, - women studying geoinformatics rated AR technology the highest of all groups (mean 4.33), but this group was also the most minor (only three responses), raising the chances of fluctuation, - for Civil Engineering students, men and women rated AR technology almost the same (mean 3.30 and 3.00, respectively), - confidence intervals for the averages indicate the diversity of responses within each group, - within each field of study, the lowest and highest ratings tended to be identical for men and women.
VR	- The average rating of VR technology among all respondents was 3.50, with a standard deviation of 1.17, which means that the answers varied. - male and female students in each field of study rated VR technology at a similar level, with some differences, - male students studying geoinformatics rated VR technology the highest of all groups (mean 4.00), - women studying environmental engineering gave the lowest average rating (2.67), but this group was one of the most minor (only three responses), which may affect the fluctuation of results, - for civil engineering students, men rated VR technology slightly higher than women (mean 3.38 and 3.63, respectively), - confidence intervals for the averages indicate the variation in responses within each group, - within each field of study, the lowest and highest ratings tended to be identical for men and women.
MR	- the average rating of the relevance of MR technology was 3.17 for all respondents, with a standard deviation of 1.13, indicating some variation in responses, - men and women from each field of study rated MR technology at a similar level, with some differences, - women studying geoinformatics rated MR technology the highest of all groups (mean 4.00), - one female environmental engineering student rated 1.00, the lowest possible rating. - for civil engineering students, men rated MR technology slightly lower on average than women (3.18 vs. 3.43, respectively), - the confidence intervals for the mean scores indicate the diversity of responses within each group, - within each field of study, the lowest and highest scores were generally identical for men and women.
Hologram	- The average rating of the usefulness of hologram technology was 3.18 for all respondents, with a standard deviation of 1.19, indicating some variation in responses, - men studying environmental engineering rated hologram technology highest among all groups (mean 4.17), - for civil engineering students, men rated hologram technology slightly lower on average than women (2.91 vs. 3.63, respectively), - women studying surveying cartography and civil engineering rated hologram technology higher than men in the same fields of study, - The confidence intervals for the mean scores indicate the diversity of responses within each group, - in most fields of study, the lowest and highest scores tended to be identical for men and women, except in civil engineering, where men rated hologram technology between 2.00 and 4.00. In contrast, women rated it between 2.00 and 5.00.
Virtual Tour	- The average rating of the relevance of Virtual Tour technology was 3.57 for all respondents, with a standard deviation of 1.32, indicating some variation in responses, - women studying land management, surveying and cartography, and civil engineering rated Virtual Tour technology very high, with average ratings of 4.03, 3.94, and 4.00, respectively, - for men, the highest ratings for Virtual Tour technology came from geoinformatics and environmental engineering students, with respective average ratings of 3.71 and 3.67, - all groups, except women studying environmental engineering, rated the Virtual Tour technology from 1 to 5. women studying environmental engineering gave the technology a consistent score of 2.00, but these values came from only two female respondents, which may not be representative of the entire group, - confidence intervals for mean scores indicate the diversity of responses within each group.
UAV	- the average rating of the relevance of UAV technology was 3.37 for all respondents, with a standard deviation of 1.27, indicating some variation in responses, - women studying Geodesy and Cartography, and Geoinformatics rated UAV technology very highly, with average ratings of 3.89 and 4.33, respectively, - for men, the highest ratings for UAV technology came from students of land management and tourism and recreation, with respective average ratings of 3.58 and 3.40, - all groups, except women studying environmental engineering, rated UAV technology from 1 to 5. A woman studying environmental engineering gave the technology a consistent score of 3.00, but these values came from only one respondent, which may not be representative of the entire group, - confidence intervals for mean scores indicate the diversity of responses within each group.

Table 3. Findings of statistical analysis of responses on the usefulness of eXtended reality 3D visualization technology in student future work.

- no significant differences can be seen in the responses between students representing technical and social sciences,
- all technologies were known to at least a few respondents, but most of them did not have experience in using them; VR, hologram, and UAV technologies are the most popular - most respondents have encountered VR and hologram technology and used these technologies,
- more women than men have met the terms AR, VR, MR, and UAV; more men have met the terms Virtual Tour and hologram; also more women than men have used AR, VR, MR, and UAV technologies,
- majority of respondents have not used any of the technologies mentioned, which may indicate that they are still not widely available or too complex to use,
- majority of respondents find AR, VR, and MR technologies challenging to use, which may suggest that there is still a need for more intuitive interfaces and more straightforward ways to enjoy these technologies,
- respondents who had experienced AR, VR, and MR technologies evaluated them positively, which may suggest that despite the difficulties in use, these technologies have potential and are worthy of future development,
- it is notable that participants interviewed were mainly students, which may affect their perception and utilization of the technologies, as they may have more interest in and ability to use these technologies compared to the general population,
- further research should be conducted to understand barriers to using 3D visualization technologies.

The results of a survey indicate that although various technologies are becoming more known and accessible, improvements are still needed to ensure their practical application and integration into existing work environments. Women tend to be more familiar with these technologies, but there is little gender difference in evaluating their level of difficulty. To address these issues, training courses and workshops, like the one organized, could help individuals understand and learn how to use these technologies in their daily work. It is important to note that technology is a tool that can aid in achieving specific goals, and an overall understanding of its benefits and potential difficulties is necessary.

The survey also highlights a significant need for education in 3D technologies related to surveying, cartography, and land management. Many of these technologies have yet to be discussed in courses, but students express interest and see their potential benefits for future work. Therefore, educational institutions should pay more attention to this area.

Based on this research, the following assumptions were established and verified through workshops:

• **Assumption 1:** A significant number of respondents find the creation and use of work environments utilizing AR, VR, MR, holograms, Virtual Tour, and UAVs complicated.

• **Assumption 2:** Education and training can help individuals become more comfortable with using and deploying these technologies in work environments.

• **Assumption 3:** Hologram technology and Virtual Tour are perceived as less complicated to use and integrate into work environments than AR, VR, MR, and UAV technologies.

Evaluation diagnosis

In the next phase of our research on eXtended Reality 3D visualization, we conducted training workshops to increase knowledge and assess changes in attitudes. A total of 47 individuals participated in the questionnaire, consisting of 27 women (57%) and 20 men (43%). Among the participants, nine were studying Geodesy and Cartography, two were studying Civil Engineering, 33 were studying Land Management, and three were studying Tourism and Recreation. We analyzed the responses to questions similar to those in the initial survey, and our conclusions are presented below. The analysis was evaluative because it was conducted after the workshop.

A) do you think it is challenging to use the technologies you have learned?

Analyzing the results of the survey, it can be seen that the difficulty level for the use of various technologies as perceived by respondents varies quite a bit (Fig. 11):

- AR was rated the most accessible technology to use, with most ratings being 1 or 2, suggesting that users find it easy or moderately complex to use.
- VR was also rated as relatively easy to use, with some ratings being higher than AR, indicating some level of uncertainty among respondents.
- MR received mixed opinions as the votes were evenly distributed. Some respondents found it easy to use, while others rated it as more complex.
- Holograms were rated as moderately complex to difficult, with scores ranging from 1 to 5, indicating potential technical challenges or a need for more understanding of the technology.
- Virtual Tour received positive ratings, with most respondents finding them easy or moderately complex to use.
- The use of drones or UAVs was rated the most difficult among all the discussed technologies, with many scores being three or higher, indicating a higher level of difficulty.
- All technologies, except UAVs (2.56), were perceived as relatively easy to use, with average ratings below 2.5. This suggests that the current technological development reveals the potential of the technology. However, the complexity may be a barrier to its expansion, which demands the expertise to deploy XR-based solutions (refer to Table A6).

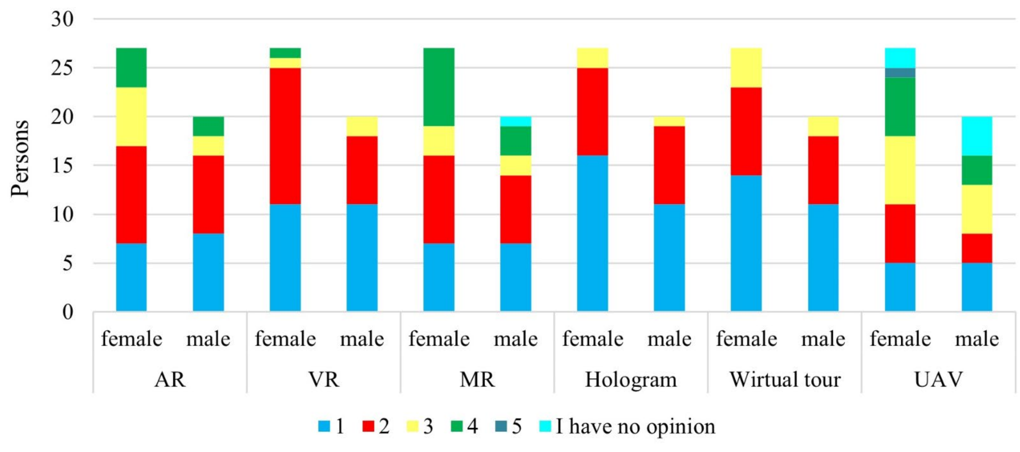

Fig. 11. Level of difficulty of using eXtended Reality 3D visualization technology (1-very easy, 5-very difficult).

Respondents found AR and Virtual Tour the easiest to use, while UAVs were perceived as the most complicated technology. Other technologies like VR, MR, and holograms received mixed opinions, which is understandable as different technologies may require different skills and resources to be effectively used. Generally, students are comfortable using the technologies they have learned, with technical students (GP, GiK, Bud) appearing more confident than TiR students. The year of study does not significantly impact the comfort level in using technology, although students in older years appear somewhat more self-confident.

B) do you find it challenging to create a working environment with the technologies you have learned?
After analyzing the survey results about the difficulty of creating a working environment with various technologies, we observed the following (Fig. 12):

- Most respondents rated creating a work environment in AR as moderately tricky, with marks mostly ranging from 2 to 3.
- Creating a work environment in VR was assessed as easy to moderately complex, with most ratings falling in the 1–3 range.
- MR received similar ratings to VR, indicating that creating a work environment with this technology is perceived as moderately complex.
- Holograms received a wider range of ratings, but many of them were 2 or 3, suggesting moderate difficulty.
- Virtual tours are the most accessible technology to integrate into a work environment, with most ratings at 1 or 2.
- UAVs, like holograms, received a broad range of scores, but most marks were in the 2–3 range, indicating moderate difficulty.
- Creating a working environment using previously learned technologies is rated as slightly more complex than exploiting them, particularly for AR (2.68), MR (2.72), and holograms (2.22). This suggests that while these technologies are easy to use individually, creating a work environment with them may present some challenges (Table A6).

When it comes to creating work environments, students tend to feel confident using the technologies they have learned. However, those in technical fields are more comfortable with the technologies than those in the TiR fields. Virtual Tour is the easiest technology to implement, while AR, VR, MR, and UAV are deemed moderately complex. Respondents found holograms to be challenging, indicating a need for further training or experience.

C) does using the technologies you have learned need to be applied to the educational process in your field of study?
After analyzing the results, it is clear that introducing eXtended Reality 3D visualization techniques in the education process is highly needed (Fig. 13).

- Most respondents rated the need to use AR and VR at 5, indicating a high need for both technologies in their education.
- MR is also considered highly necessary, although some ratings were slightly lower.
- Holograms received slightly more varied assessments, but most still rated them as necessary or reasonably necessary.
- Virtual Tour technology is highly desirable in education, with most ratings at 5.
- UAVs also received high ratings, although some respondents rated them slightly lower.

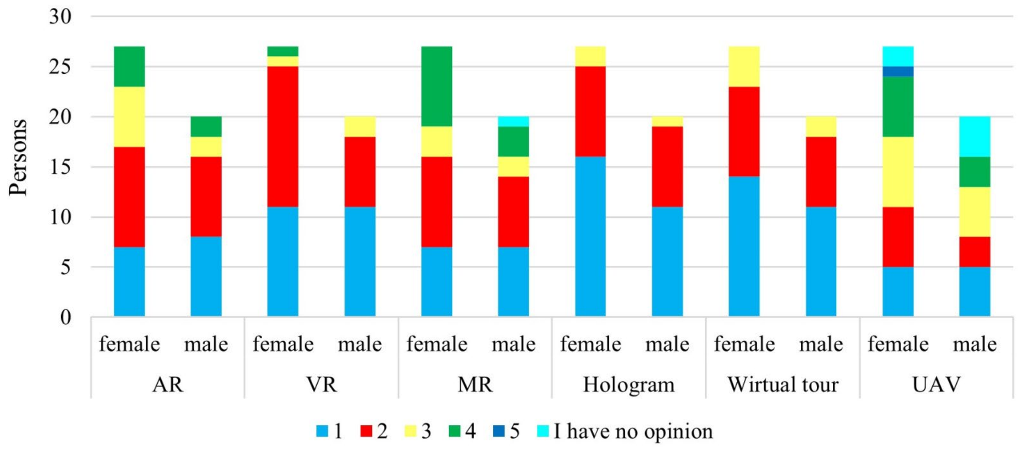

Fig. 12. Degree of complexity in creating a working environment with eXtended Reality 3D visualization technologies (1-very easy, 5-very difficult).

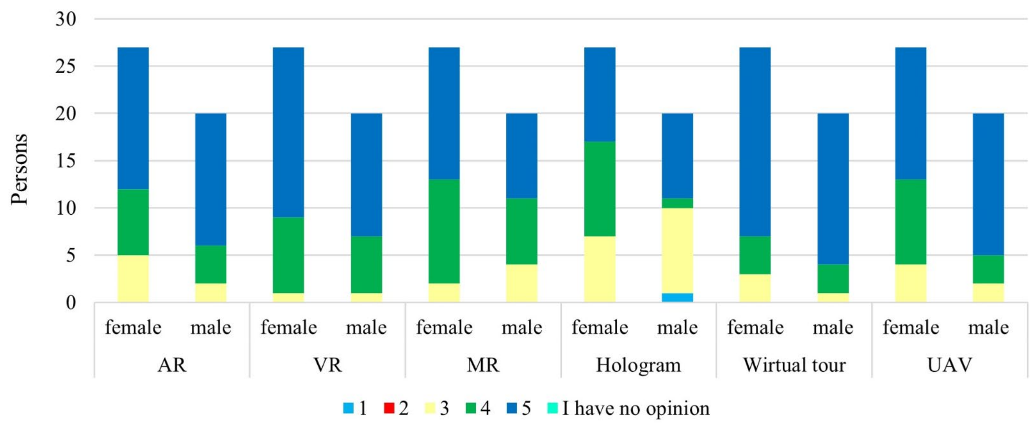

Fig. 13. Potential need to integrate eXtended Reality visualization technology into the educational process (1 - completely unnecessary, 5 - very necessary).

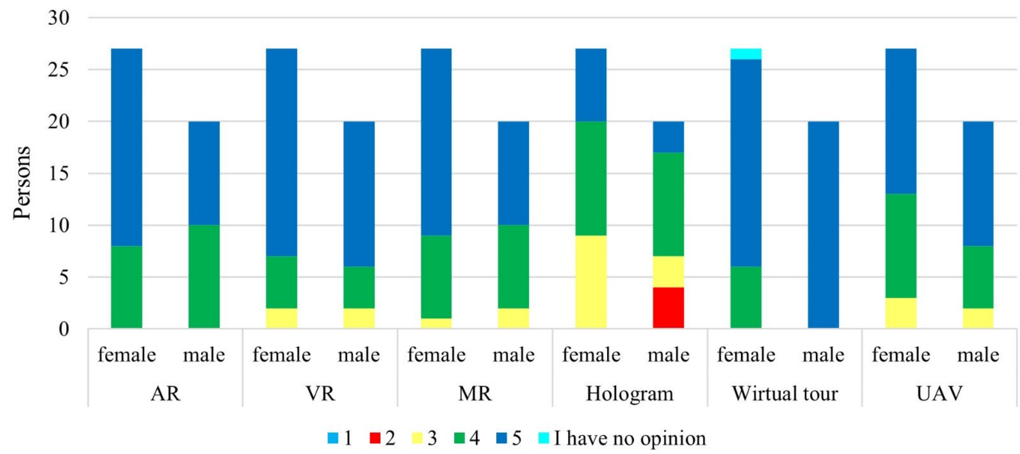

Fig. 14. The potential of eXtended Reality visualization in the respondent's future work (land management and real estate). (1 - not at all useful, 5 - very useful).

- All technologies are considered extremely necessary in education, with average ratings above 4. Virtual Tour (4.68) and VR (4.62) are considered the most necessary, while holograms (4.00) are rated as slightly less necessary (Table A6).

Based on conclusive data gathered from students across all fields of study and years, it is clear that the use of learned technologies is fundamental in the educational process. The opinion that these technologies are essential appears to be consistent regardless of gender, year of study, or field of study. In fact, modern technologies such as AR, VR, MR, holograms, Virtual Tour, and UAVs are becoming increasingly valued in educational contexts.

Regarding the usefulness of these technologies in future work, the provided data shows that respondents generally found all of the technologies helpful. However, the ratings varied somewhat by technology (Fig. 14).

- AR received all marks of four or higher, indicating that respondents found the technology to be highly beneficial. This is because AR combines the real and virtual worlds, making it applicable in various aspects of land management and real estate.
- VR also received high marks, although slightly lower than AR. This technology is the most immersive of the discussed technologies, which can be helpful in various aspects of land management, such as virtual real estate demonstrations.
- MR, which combines elements of AR and VR, was also rated positively, although some respondents gave it a rating of 3.
- The usefulness of holograms received the most varied opinions, with ratings ranging from 2 to 5. This indicates indecision about how useful this technology can be in land management and real estate.

- Respondents believe virtual tours are beneficial, the vast majority of ratings being 5. This is because a Virtual Tour allows one to visit a space without physically moving around.
- UAVs were also identified as very useful. Drones have multiple applications in land management and real estate, such as photographing properties from the air or monitoring the condition of buildings.
- Unmanned aerial vehicles (UAVs) and mixed reality (MR) are perceived as the most valuable technologies for land management and real estate, with average ratings of 2.56 and 2.28, respectively. Holograms and Virtual Tour were rated less valuable, with ratings of 1.49 and 1.60, respectively (Table A6).

An evaluation was carried out to determine whether there was a significant difference between men's and women's opinions on the usefulness of certain technologies for future work. A t-test was conducted (Table A5), and the results showed no significant differences.

The data analysis revealed that all the technologies discussed in the survey were helpful for land management. However, some (such as AR, VR, Virtual Tour, and UAVs) were rated slightly higher than others (MR and holograms).

Overall, the survey results indicated that the students found the technologies explored to be useful and important for their education.

Conclusions

The demand for education regarding 3D eXtended Reality technologies such as AR, VR, MR, Holograms, Virtual Tour, and UAVs is high, particularly in the fields of Geodesy, Cartography, and Land Management, as indicated by preliminary research. Respondents are open to the use of these technologies in the future, indicating significant potential for their application in spatial-related industry applications. Though respondents have limited knowledge and experience, many believe that these technologies can be relevant to their future work. Therefore, education in these areas is crucial.

Overall, the research shows that students have a high demand for knowledge in this area. Before the workshop, most students required assistance in identifying the AR concept, suggesting that it is not yet widely used in education or experienced in the usual student environment. In contrast, the majority of students encountered the term VR, which may be due to its increasing popularity in various areas such as gaming. Similarly, most students had not engaged in the term MR, a relatively new and developing technology. Holograms are a well-known concept due to their long history and prevalence in media and pop culture. Familiarity with Virtual Tour is also standard, as they are often used in tourism and real estate. The unfamiliarity with UAVs may be due to their specialized use in military or technical fields such as surveying, military, aerial photography, and filming.

Understanding these technologies may depend on their prevalence, applications in practice, and how common they appear in academic and non-academic contexts. Though some of the discussed technologies are familiar, most students lack direct experience, indicating a gap between theoretical knowledge and practical understanding of these new technologies.

The workshop significantly increased awareness of modern 3D visualization technologies. After the seminar, students better understood the technologies used, resulting in extended usage. The level of difficulty was reduced as participants gained practical skills and experience in areas that were previously unknown to them. This hands-on experience changed their perceptions of technology and inspired them to explore and learn more about the technologies covered in the workshop. The discussion panels also showed a remarkable stimulation of creativity among participants, leading to submissions of their research areas or projects. By investing just a few hours in a given technology, stereotypes about its level of difficulty were overcome.

The workshop instructors used various teaching techniques and tools to engage students in the learning process. These activation methods aimed to enhance the participants' skills, abilities, and motivation to learn while forming positive attitudes and values. By using these methods, educators can increase the effectiveness of the learning process and make it more enjoyable and engaging.

The benefits of these activation methods extend to the students, instructors, and the university. For students, these methods result in increased motivation to learn, better understanding and knowledge consolidation, and active class participation. As a result, students can improve their memorization skills, group work abilities, creativity, and analytical thinking. For teachers, these methods can increase teaching efficiency, improve teaching skills, and increase job satisfaction while helping them work with Generation Z. The university benefits from increased student involvement in learning, enhanced attractiveness, and the introduction of new forms of education in the form of workshops and the development of organizational culture.

In the Polish system of higher education, students are evaluated based on their knowledge, skills, and competencies. The workshop showed that by introducing a single subject into the course of study, it is possible to change students' mental attitude towards modern 3D visualization technologies.

Research has highlighted four key areas that require further investigation in the future. Firstly, there is a need to analyze the utilization and comprehension of augmented reality (AR), virtual reality (VR), and mixed reality (MR) technologies. Results indicate that many individuals require assistance in understanding and using these technologies efficiently. Therefore, further research is necessary to determine the specific areas where users struggle the most to develop effective teaching and support strategies. Secondly, the effectiveness of training and workshops needs to be examined to understand how it contributes to users' ease and confidence in AR, VR, and MR technologies. This research will help identify the most effective training methods to optimize the education process.

Thirdly, there is a need to analyze the perception of various technologies, such as holograms, Virtual Tour, and drones (UAVs). Preliminary results indicate that these technologies are perceived differently, and further research is required to understand why. This analysis will provide insight into the factors that influence users' perceived ease of use and deployment of these technologies. Lastly, understanding and addressing user assistance needs is another area that requires further investigation. Survey results show that users require additional support in using new technologies, and research can help identify the specific forms of support needed and how to deliver them effectively. These studies will offer valuable insights into how to promote and implement new technologies effectively in different work environments.

The study results confirm the hypotheses about the positive impact of training in XR technologies on the development of students' technical competence. After the workshop, students showed significant improvement in both theoretical knowledge and practical skills related to AR, VR, and MR technologies, consistent with the assumption that intensive training contributes to technical competence. A clear impact of the workshop on changing students' attitudes towards the new technologies was also observed, with initial fears and difficulties in using XR giving way to greater confidence and motivation to explore them further and apply them in future careers.

Key research questions about the difficulty of learning with XR were confirmed. Students initially found it challenging to understand and identify advanced technologies such as AR and MR, but after the training, their perception of these tools improved significantly, and their level of difficulty with their use was reduced.

The results also suggest that the training had a significant impact on students' positive attitudes toward continuing to use XR in future professional projects. The reduction of stereotypes related to the difficulty level and the increased awareness of the benefits of these technologies in engineering education confirm that targeted XR training can effectively prepare students for the challenges of today's labor market, where modern visualization tools and 3D technologies are becoming increasingly important.

The introduction of XR as an integral part of engineering curricula is recommended to educators and policymakers. It is worth investing in regular training and hands-on workshops to help students master these technologies and understand their potential applications in the workplace. Integrating XR into technical education not only supports the development of modern skills but also better prepares students for the challenges of a changing labor market.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

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Conceptualization, R.K. and T.T.; methodology, R.K and T.T.; software, R.K. and T.T.; validation, R.K., T.T. and A.S.; formal analysis, A.S.; investigation, R.K. and A.S.; resources, R.K and T.T; data R.K. and T.T.; writing—original draft preparation, R.K., T.T., A.S.; writing—review and editing, A.S.; visualization, R.K.; supervision, R.K. and T.T.; project administration, R.K.; All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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Correspondence and requests for materials should be addressed to R.K.