Modern online teaching formats for geodetic reconstruction methods in Ukraine

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Abstract

The full-scale war in Ukraine has severely disrupted engineering education, particularly in disciplines that rely on field training and access to specialized surveying equipment. This paper presents the results and educational approach of the international project Modern Online Teaching Formats for Geodetic Reconstruction Methods in Ukraine (GeoRek), which aims to develop scalable digital learning solutions capable of maintaining practical training under crisis conditions. The project combines immersive simulation technologies, modular micro-credentials, and international collaborative learning formats to support modern education in terrestrial and mobile laser scanning, photogrammetry, and 3D reconstruction.
A central component of the project is the VRscan3D simulator, which reproduces realistic laser scanning workflows within a virtual environment. The system models scanning geometry, instrument parameters and measurement noise, allowing students to practice survey planning, scanner positioning, and point-cloud generation before working with real instruments. In addition, the project develops competency-based micro-credentials aligned with European qualification frameworks and organizes international student project weeks where participants apply the learned methods to practical case studies.
The project strengthens international academic cooperation and provides a scalable framework for training specialists capable of supporting digital documentation and reconstruction of damaged infrastructure in Ukraine.

1. Introduction and Objectives

The full-scale war in Ukraine has significantly disrupted engineering education, particularly in disciplines that depend on field training and access to specialized equipment such as geodesy, surveying, and photogrammetry. According to UNESCO, more than 4400 of educational institutions in Ukraine have been damaged or destroyed since 2022, creating substantial barriers to maintaining practical components of engineering curricula (UNESCO, 2024). Many universities have experienced physical damage to laboratories, limited access to campuses due to security risks, and interruptions caused by air-raid alerts and power outages. As a result, traditional field-based training – an essential component of surveying education – has become difficult to organize or impossible in some regions.

Another major challenge is the reduced availability of professional surveying equipment. High-precision instruments such as terrestrial laser scanners, GNSS receivers, and UAV-based mapping systems are costly and often concentrated in a small number of laboratories. Wartime logistical constraints, relocation of universities, and budget limitations further restrict access to such technologies. In addition, student displacement – both internally and internationally – has changed traditional classroom and field-practice educational models. Studies on higher education during military conflict shows that engineering programs are among the most affected because they rely heavily on laboratory and field environments that are difficult to replicate in conventional online formats (Salha et al., 2024; Lampropoulos et al., 2025).

These conditions create an urgent demand for scalable digital training approaches that can partially substitute field practice while preserving essential learning outcomes. Virtual simulation environments, digital twins, and immersive learning platforms allow students to practice survey planning, instrument positioning, and data acquisition workflows in a controlled digital setting. Such tools support distributed learning, reduce dependency on expensive hardware, and enable international collaboration between universities. Digital solutions therefore play a critical role in maintaining the continuity of geospatial and engineering education during crisis conditions while preparing a new generation of specialists for post-war reconstruction (World Bank, 2024). In response to these challenges, international academic cooperation has become an important mechanism for maintaining the continuity of engineering education and supporting the modernization of teaching methods.

Micro-credentials have recently emerged as an important instrument for flexible professional education, particularly in technical fields. Unlike traditional long-term degree programs, micro-credentials focus on clearly defined competencies and learning outcomes that can be acquired within shorter training modules. This approach allows learners to quickly develop practical skills that respond to immediate labour-market needs while maintaining compatibility with existing qualification frameworks such as the European Qualifications Framework (EQF). In the context of engineering and geospatial education, micro-credentials are particularly relevant because they allow universities to update specialized technical skills – such as laser scanning, photogrammetry, and 3D data processing – without requiring full curriculum restructuring (Council of the European Union, 2022). Research on lifelong learning policies in Europe emphasizes that micro-credentials can support rapid upskilling and reskilling, making them especially suitable for sectors that

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require fast adaptation to technological change or post-disaster recovery needs (OECD, 2023).

Collaborative initiatives between Ukrainian and European universities increasingly focus on developing digital learning environments, virtual laboratories, and flexible training formats that can operate independently of physical infrastructure and field access. Such modular educational formats complement digital simulation tools and contribute to building a scalable and resilient system of engineering training under challenging conditions.

Jade University of Applied Sciences in Oldenburg, Germany, has had close ties with Ukrainian universities for many years, primarily through projects and student exchange activities since 2011 (Kravchenko et al., 2016, Luhmann, 2020, Luhmann et al., 2022). Besides academic interchange of students and teachers, the well-known virtual laser-scanner simulator VRscan3D has been developed (Chizhova et al., 2021, Popovas et al., 2021), which is now part of various teaching modules around the world. Recently, another teaching and research project has started, which is being funded by the DAAD with almost €800,000 as part of the German-Ukrainian University Network. The project is entitled “Modern Online Teaching Formats for Geodetic Reconstruction Methods in Ukraine (GeoRek)” and is being carried out in cooperation with the Kiev National University for Construction and Architecture (KNUCA) and the Dnipro University of Technology (DniproTech) together with the Chair of Digital Heritage Technologies at the University of Bamberg.

The objectives of the project include the following tasks:

- Further development of the virtual laser scanner simulator VRscan3D for e-learning purposes
- Development of micro-credentials in four different subjects
- Bilateral student project weeks
- Application of new methods to real use cases of destructed buildings in Ukraine

This flexible approach offers a scalable solution for geodetic training amid current challenges, providing an innovative framework for Ukrainian geospatial education and a collaborative approach between the countries.

2. Simulation of terrestrial and mobile laser scanning

Despite rapid progress in virtual reality and simulation technologies, the application of immersive environments in geodetic and surveying education remains relatively limited and fragmented. Most existing digital tools focus either on visualization of geospatial data or on simplified educational demonstrations, rather than on physically realistic simulation of the full surveying workflow. While VR and simulation platforms have been successfully applied in fields such as medicine, social sciences, neuroscience and psychology, their integration into engineering education – particularly for geodetic survey – remains insufficiently (Radianti et al., 2020; Jensen & Konradsen, 2018). This gap becomes especially critical in disciplines where hands-on experience with measurement instruments is essential for understanding error sources, survey planning, and data quality control.

Another limitation of existing VR approaches is that they focus mainly on visual immersion rather than measurement realism. In surveying practice, the learning process requires not only interaction with a virtual environment but also an understanding of equipment parameters, observation geometry, target placement strategies, and noise characteristics that affect the result. Current educational VR systems don’t reproduce these physical aspects of geodetic measurements, that restricts their usefulness for professional training (Radianti et al., 2020, Wang et al., 2018). As a result, students often gain conceptual familiarity with spatial data but lack opportunities to practice realistic data acquisition workflows before working with expensive field equipment. One example of applying simulation technologies for measurement training is DVocean Digital, a prototype that simulates hydrographic 3D measurements using a multibeam echo sounder in a virtual survey environment. (Deggim & Kersten, 2023). The system integrates a virtual survey environment together with a simulated multibeam echo sounder instrument, enabling users to reproduce the hydrographic measurement process within an interactive 3D simulation. Similarly, the VRscan3D platform follows the same direction by combining an immersive virtual environment with simulated surveying instruments, allowing users to reproduce realistic measurement workflows and better understand data acquisition processes.

The research gap lies in the development of immersive geodetic simulation environment that combine realistic measurement modelling with interactive training scenarios. Such systems should simulate instrument parameters, scanning geometry, and data quality characteristics while allowing users to perform complete workflows from survey planning to point-cloud generation and processing. This particularly relevant in situations where access to field equipment is limited, such as during military conflict or in resource-constrained educational environments. In this context, simulation platform like VRscan3D aim to bridge the gap between theoretical instruction and practical surveying training by providing a physically-based virtual environment for learning terrestrial and mobile laser scanning workflows.

Over the past several years, VRscan3D has evolved from a basic prototype into a comprehensive modular educational and research platform designed to simulate terrestrial laser scanning (TLS) and mobile mapping workflows within a high-fidelity virtual environment. Built using the Unreal Engine, the system leverages a high-performance gaming framework to provide immersive real-time 3D visualization and interactive navigation of complex digital twins. The technical foundation of VRscan3D is centered on a multi-stage LiDAR construction pipeline that replicates the physical process of data acquisition based on a mathematical model of 3D line intersections (ray tracing).

The process of data generation begins with the Scan Phase, during which the system projects an angular grid of rays from the virtual scanner’s center based on user-defined resolution settings. The result of this stage is an ideal point cloud, which precisely reflects the geometry of the underlying 3D model without errors. To achieve realistic surveying data, the system then implements a secondary stage: the application of noise and intensity modelling.

The simulator incorporates sophisticated stochastic noise models that include:

- gaussian noise: emulates random measurement errors in distance and angles;
- material-dependent noise: signal intensity and noise levels are calculated based on the optical reflectivity properties assigned to surfaces within BIM or 3D models;
- geometric noise: accounts for the laser beam's angle of incidence on a surface;
- temporal jitter: simulates sensor instability and random micro-deviations during the rotation of the device.

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The parameters for these noise models are derived directly from the technical specifications of real-world scanners. The platform supports a wide array of professional instruments, including the Leica RTC360, Leica BLK360, Faro Focus 3D (X330), and the Trimble TX and Trimble X9 series (Fig. 1). Access to these devices is facilitated through realistic graphical user interfaces (GUIs) that mimic the look and logic of the manufacturer's original software, allowing students to master instrument controls before fieldwork.

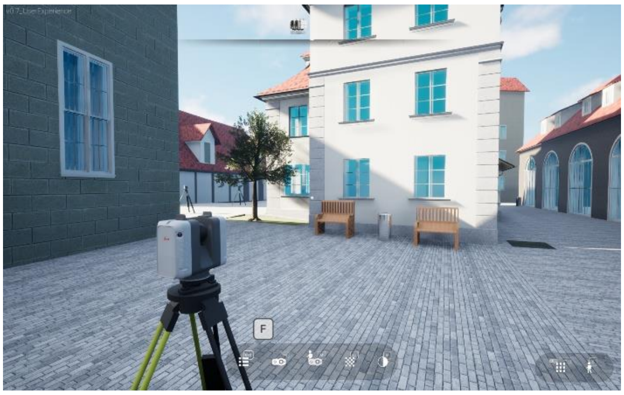

Figure 1. The virtual laser scanner simulator VRscan3D.

A distinguishing feature of VRscan3D is its ability to simulate dynamic scenes. Unlike static virtual environments, the simulator integrates moving objects such as pedestrians, passing vehicles, and rotating wind turbines. These dynamic elements introduce realistic artifacts, such as "ghosting" effects, which are essential for teaching students how to perform advanced data cleaning and outlier removal in professional processing software.

The system supports a complete end-to-end data workflow through an asynchronous export pipeline that generates industry-standard formats, including ASCII (TXT), PTX, and E57. These files can be seamlessly imported into professional registration and modelling packages such as Leica Cyclone, FARO Scene, or CloudCompare.

The reliability of VRscan3D has been validated against real-world datasets using detailed digital twins of specific locations:

- University of Bamberg (Germany): historical buildings with complex architectural monuments.
- University of Valencia (Spain): modern office buildings with challenging glass and mirrored surfaces.
- Gediminas Tower in Vilnius (Lithuania): a heritage site featuring difficult terrain and heavy tourist traffic.

During several practical project weeks at these universities, German and Ukrainian students performed scanning of these objects first in the simulator and then in real life. Results confirmed that practicing in the virtual environment significantly reduced errors during actual field measurements.

Currently, a mobile laser scanner simulator is in active development, with a prototype already supporting scenarios for handheld scanners (e.g., Leica BLK2GO), backpack systems (e.g., NavVis-style), and vehicle-mounted mapping (Fig. 2).
This simulation accounts for trajectory drift and SLAM (Simultaneous Localization and Mapping) errors, enabling students to analyze how movement speed impacts point cloud density.

Within the framework of the DAAD-funded GeoRek project (2025–2029), there is a strategic focus on training students specifically with mobile laser scanners. Using VRscan3D as the primary training tool allows Ukrainian students to acquire high-level competencies in 3D reconstruction and mobile mapping, even when physical access to expensive high-tech hardware is limited by logistical or security constraints.

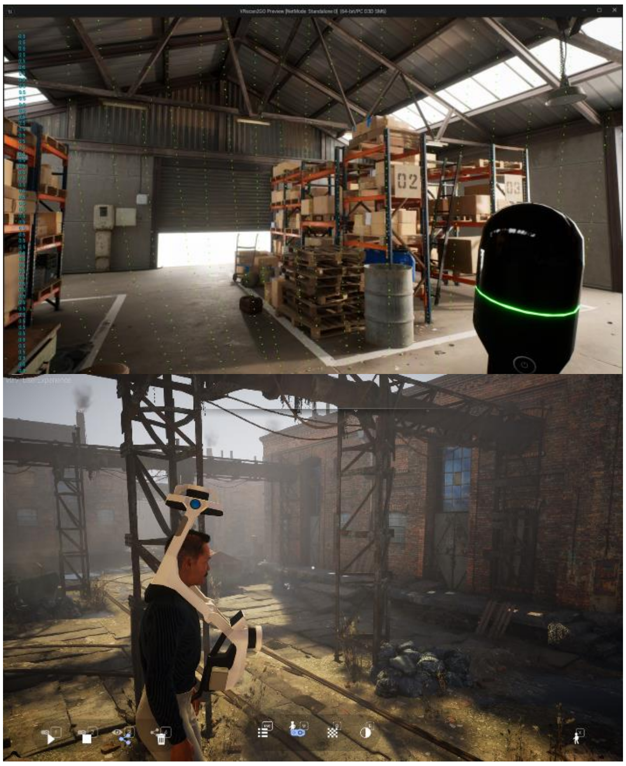

Figure 2. Example of virtual mobile scanning in VRscan3D.

VRscan3D has gained significant international recognition, receiving the Gold Prize at the ISPRS CATCON 8 competition and the Wichmann Innovations Award in 2022. To further enhance its pedagogical impact, the software is currently undergoing expansion through the integration of serious gaming elements, such as the automatic evaluation of scan completeness, which encourages active learning within the virtual environment. These advancements are supported by a redesigned user interface (UI) that systematically guides the user through the entire scanning workflow – from initial station setup and active data capture to post-processing and final export. By providing real-time feedback and immersive interactive tools, VRscan3D effectively bridges the gap between theoretical knowledge and practical field experience, facilitating the mastery of complex geodetic reconstruction methods.

3. Micro-credentials

The concept of lifelong learning has become a central principle of modern higher education and professional development. It refers to continuous learning throughout an individual's career, enabling professionals to regularly update their knowledge and acquire new competencies in response to technological, economic, and social changes (European Commission, 2021). In engineering and geospatial professions, where technologies such as laser scanning, photogrammetry, and digital modelling evolve quickly, lifelong learning mechanisms are essential to maintain professional relevance and technical competence.

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Within this framework, micro-credentials are defined as short, competency-based learning units that certify the achievement of specific learning outcomes after completing a focused training module. According to the European Commission, micro-credentials document the knowledge, skills, and competences acquired through a small volume of learning and are designed to be transparent, portable, and potentially stackable within larger qualification frameworks (European Commission, 2022). Typically, such courses range from a few hours to several weeks of study and may correspond to a small number of ECTS credits.

Micro-credentials are particularly relevant in the Ukrainian context due to the growing need for rapid reskilling and professional reintegration of veterans and displaced specialists. Many engineers returning from military service or reconstruction-related activities require flexible pathways to update their technical skills and adapt to modern digital workflows used in surveying, reconstruction planning, and infrastructure monitoring. Short modular training formats allow them to acquire targeted competencies – such as terrestrial laser scanning, point cloud processing, or BIM integration – without involving in full degree programs. Examples of micro-credential initiatives already exist in Europe. Programs developed within the European Digital Credentials for Learning framework and various university alliances offer short courses in areas such as digital engineering, geospatial technologies, and data science. These initiatives demonstrate how micro-credentials can complement traditional academic programs while supporting flexible professional development and rapid upskilling in technical fields (Gamage, 2025).

The development of effective micro-credentials requires several key elements. First, the learning outcomes must be clearly defined and aligned with recognized competency frameworks such as the EQF. Second, the courses should focus on practical skills that are directly applicable in professional workflows. Third, transparent assessment criteria and digital certification mechanisms are necessary to ensure credibility and recognition across institutions and employers.

Besides the enhancement of the VRScan3D Software, the project aims to develop micro-credentials in several subjects designed for both university curricula and continuing education programs. These micro-credentials function as short, focused learning units that certify specific competencies in terrestrial laser scanning, photogrammetry, and 3D data processing. These short, skill-oriented learning modules represent a verified learning outcome in terrestrial and mobile scanning and 3D/BIM modelling, providing learners with recognized proof of expertise that can be accumulated and transferred across institutions. The implementation of this system follows European standards based on ECTS and the European Qualifications Framework (EQF), ensuring transparency and interoperability across the common European higher education area. This initiative supports flexible, modular education and promotes lifelong learning in the field of geospatial technologies. This approach is particularly critical for the Ukrainian context, where there is an urgent need for the rapid reskilling of displaced specialists and veterans who require flexible pathways to master modern digital workflows without committing to full degree programs. By aligning with the EQF, the program ensures interoperability and promotes lifelong learning in the field of geospatial technologies. Such programs of professional development might also be recognized by National Agency of Qualifications in Ukraine – the central body for micro-qualifications awarding – facilitating a resilient educational infrastructure capable of adapting to post-war reconstruction needs.

To successfully integrate these learning units into the Ukrainian higher education ecosystem, the following path should be undertaken:

- Each GeoRek module should be described using the EU standard metadata, this includes: learning outcomes and workload (ECTS); the level of the learning experience (aligned with the National Qualifications Framework/EQF); clear assessment criteria and the identification of the issuer (e.g., the partner universities).
- GeoRek micro-credentials should be included to study plans and credited toward formal Bachelor’s or Master’s degrees. This provides Ukrainian students with flexible pathways to gain specialized qualifications during the disruption of war.
- Connection of the GeoRek curriculum directly to the needs of the Ukrainian Ministry of Infrastructure, Ministry of Education and Science and private construction enterprises. By focusing on competency-based learning, the project addresses the immediate skill gap in digital documentation of damaged infrastructure.

By following these steps, the GeoRek project transitions from a temporary crisis-response initiative into a long-term, scalable model for Ukrainian engineering education. It ensures that the digital expertise gained through VRscan3D and collaborative learning is recognized across borders, supporting both the professional development of individuals and the structural integrity of Ukraine’s future infrastructure.

The assessment process within these modules partly uses some functions of VRscan3D simulator. A primary metric involves the automatic evaluation of scan completeness, which requires students to ensure that the virtual laser scanner has captured all necessary surfaces without significant data gaps. The system also visualizes quality parameters such as point density and scan overlap to help users improve their workflows. Furthermore, simulated data contains realistic artifacts, such as "ghosting" effects from moving objects (people, traffic), ensuring students can perform advanced data cleaning before transitioning to real-world field equipment.

4. Project weeks

The third pillar of the project are intensive working-weeks with German and Ukrainian students, who, as in previous years, spend a week together testing modern laser scanning and photogrammetry technologies under real-world conditions. This successful cooperation has proven to be an efficient and instructive event for students from both countries and fostered continuous relationships between the students (Fig. 3).

Figure 3. German and Ukrainian students and teachers during the project week 2024 in Vilnius.

Structured learning evaluations conducted before and after the training indicate substantial improvements in participants technical abilities, especially in scan-site planning and the assessment of geodetic accuracy. (Chizhova, 2021).

The project’s pedagogical approach emphasizes mixed-nationality teams, requiring students to collaborate across linguistic, cultural and disciplinary boundaries. This enhances teamwork, communication skills and cross-cultural competence – critical abilities in international educational practice. Participants also demonstrate significant improvement in task coordination, shared data-management processes and collaborative report writing.

It is expected that students will continue their cooperation past the training period, producing joint bachelor’s and master’s theses and submitting co-authored papers to ISPRS and other geomatic/geospatial engineering conferences. The development of these lasting research connections underlines the dual value of the project weeks: they build technical competence and strengthen international academic ties.

5. Practical use cases

The fourth area of activity involves conducting real-life case studies on buildings or technical infrastructure destroyed by the Russian attacks in Kyiv and Dnipro, together with local authorities and experts, in order to test and further develop the methods developed in the project for reconstruction on real objects. This pillar directly leverages the institutional strengths of KNUCA and DniproTech, which are deeply involved in the reconstruction process at the regional and national level. The universities actively fulfil "third mission" of societal engagement by providing critical expertise in sustainable construction materials, innovative building technologies, and energy-efficient solutions. In this context, students at both universities, supported by skilled research mentors, play a significant role by developing and applying remote technologies for damage assessment and reconstruction planning.

The project makes an important contribution to technology and knowledge transfer, to the internationalization of the participating universities, to intercultural exchange, and to the very practical tasks involved in reconstructing war damage. Thus, it helps to deepen German-Ukrainian relations and also sees itself as an active element in long-term peacekeeping and integration into the European community.

The simulator software was also integrated in the regular teaching course “Imaging techniques and 3D capture” at the Bamberg university on Digital Technologies in Heritage Conservation. In this course, the main processing step, e.g. laserscanning survey planning, placing targets and device as well as point cloud generation and registration, are explained gamified bevor starting to use a real laserscanning instrument.

Beyond the European education area, teaching in 3D digitisation of cultural heritage has been tested in Africa. As part of Erasmus teaching mobility, the training course on 3D imaging technologies in archaeology and cultural heritage was successfully conducted for doctoral students and students at Félix Houphouët-Boigny University in Abidjan (Ivory Coast). Since the university itself does not have any 3D measurement technologies, it was very easy to explain the basics of laser scanning in a simple and understandable way. The software has gained a very positive reaction (Fig. 4).

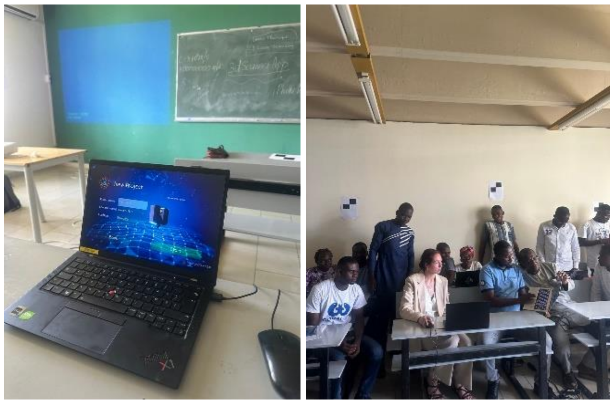

Figure 4. Demonstration of the VRScan3D software at Félix Houphouët-Boigny University in Abidjan (Ivory Coast).

Many African universities therefore lack the necessary equipment and adequate training. As part of a collaboration at the Faculty of Humanities and Cultural Studies at the University of Bamberg, there are teaching/research collaboration with Félix Houphouët-Boigny University (Côte d'Ivoire) and Ecole Polytechnique d'Architecture et d'Urbanisme (Alger) on the topic of cultural heritage conservation within the framework of an ERASMUS+ partnership. The mobility activities focus on the transdisciplinary exchange of experience and the applied use of expertise in the field of 3D technologies and the digitisation of cultural heritage objects. This involves active participation in teaching and training activities on 3D digitalisation techniques, whereby the virtual simulator VRScan3D is a valuable alternative to practising with real, cost-intensive scanners. Laser scanning exercises with the simulator were successful even under difficult conditions (no powerful computers, no prior knowledge about laser scanning) and, thanks to their game-like format, were more effective in terms of learning.

The technical workflow for reconstructing damaged buildings begins with the rapid and precise acquisition of spatial data using Terrestrial Laser Scanning (TLS) and Mobile Mapping Systems (MMS). The workflow starts by creating a "digital twin" of the structural remains. Using the methodologies and skills learned through above mentioned micro-credentials and use of VRscan3D simulator, surveyors have skills, strategically place scanners to capture the most critical structural deformations and cracks, ensuring that even hard-to-reach or dangerous areas are documented without putting personnel at unnecessary risk.

Accuracy analysis is the cornerstone of this workflow, as the resulting data must be reliable enough for structural engineering decisions. The point clouds generated from the field are compared against the "ground truth" or original architectural plans when available. Through registration and filtering processes – skills that students practice virtually before heading into the field—the team calculates the deviation of walls, the volume of debris, and the extent of structural damage. This analysis ensures that the digital model is a few millimetre-accurate representation of the building's current state, which is vital for determining whether a structure can be repaired or must be demolished.

Once the accuracy is verified, the data integration into Building Information Modelling (BIM) begins and the raw point cloud is transformed into a digital BIM model, where physical elements like beams, columns and walls are identified and digitized/modelled as intelligent objects. By having the damaged building represented in a BIM environment, stakeholders can simulate different reconstruction scenarios and estimate the quantity of materials needed for repairs.

The scalability for national reconstruction lies in the standardized nature of proposed approach. Because the project utilizes open-access tools and follows international standards like the European Qualifications Framework (EQF), the workflow can be rapidly taught and deployed across different regions. What starts as a case study in Kyiv or Dnipro can be scaled into a nationwide digital inventory of damaged infrastructure. By empowering a new generation of Ukrainian engineers with these scalable digital skills, the project ensures that the massive task of national recovery could be handled with modern precision and transparency.

6. Discussion

The GeoRek project is one more step of supporting Ukrainian academia in research and teaching. Especially in the field of reconstruction of damaged infrastructure, geodesy and geoinformation play an important role. Currently the situation at Ukrainian universities is extremely difficult due to ongoing attacks and lack of energy. However, several examples have been published showing the constant ability and will to continue research under these circumstances (AVN, 2026).

Besides pedagogical purposes the VRscan3D simulator provides additional advantages for research and development. Since user-defined 3D environments can be imported it is possible to support geodetic network planning and design by providing error-free or noisy reference data. Within the graphical user-interface quality parameters (e.g. completeness, point density, overlap) can be visualized to help developers and users to improve their workflows. Another promising feature of VRscan3D is the possibility to generate 3D training data for AI-based analysis. Since high-resolution BIM models can be scanned virtually, the resulting point cloud already contains material or object properties. Creating high quality and labelled training data in another way would result in high manual effort.

7. Summary

The GeoRek project serves as an excellent example of active support of the Ukrainian academic field through scientific cooperation, knowledge transfer and intercultural exchange. Up to date photogrammetric and geodetic methods will be introduced, further developed and applied to real world. Severe damages caused by military actions throughout the country require urgent reconstruction under participation of academic, governmental and industrial stakeholders. Education is a key part in this process.The proposed project is very interesting and relevant from a humanitarian perspective, as it is a virtuous example of scientific cooperation, knowledge transfer and cultural exchange between Germany and Ukraine in this process of reconstruction following the Russian military attacks. Academic participation in this process is fundamental for future generations from an educational perspective.

Future activities are expected to significantly expand both the technical capabilities of the platform and its educational impact.

The impact of the project will extend across several levels, from individual learners to the broader reconstruction capacity of society. In the short term, the main beneficiaries are students in geodesy, photogrammetry, civil engineering and heritage documentation, as well as displaced specialists, early-career professionals and veterans who need rapid upskilling in digital reconstruction methods. Because the training is based on simulation, modular micro-credentials and online delivery, its effects can begin during the project implementation itself, without waiting for large-scale investment in physical laboratories or equipment.

In the medium and long term, the project will also benefit universities, public institutions and society as a whole by strengthening the human-capacity base needed for evidence-based reconstruction of damaged buildings and infrastructure. By preparing specialists who can work with laser scanning, mobile mapping, point clouds and BIM-based workflows, the project supports faster, more accurate and more transparent recovery processes. Its social impact therefore goes beyond education: it contributes to professional reintegration, international academic cooperation, digital transformation of engineering training, and the creation of a qualified workforce capable of supporting Ukraine's post-war recovery and long-term integration into the European educational and technological space.

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