Ref. Ares(2025)11145536 - 15/12/2025

D6.1 – Preliminary report on European Virtual Centre in green non-invasive technologies to recovery CRM for the EU

15/12/2025

Authors: Juraj Janocko, Zita Takacova

Entity: Technical University of Kosice, Slovakia

Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Research Executive Agency (REA). Neither the European Union nor REA can be held responsible for them.

DOCUMENT CONTROL SHEET

Project	**WIDEX**– Knowledge Transfer for Widened EU Excellence in Advanced Green Technologies, Sustainability and Research Management (Grant Agreement: 101159826)

General information				
Work Package	WP6			
Deliverable	D6.1 – Preliminary report on EUROPEAN Virtual Centre in green non-invasive technologies to recovery CRM for the EU			
Due Data	15/12/2025			
Submission Date	15/12/2025			
Deliverable Lead	Technical University of Kosice			
Dissemination Level	✓	Public (PU)		Confidential (CO)
Document Nature	✓	Report (R)		Other (O)
Description of the related task and the deliverable. Extract from DoA	The present document contains the results obtained in the task 6.4/7.4 of the work package WP6. Task 6.4/7.4: Contributors to create a European reference and unique virtual centra in green and non-invasive technique. The task consists of the creation of a European reference and unique virtual centre in green and non-invasive techniques (MS6), by means of using all the knowledge gathered in the present project supported by the creation of a new website by ISMC (MS2). First, TUKE will have an internal workshop will its interdisciplinary selected team to internally discuss TUKEs strengths. Three meetings involving all partners will be held to define and highlight TUKEs strengths and international position in the field. The following information will be prepared: **1)** Main presentation of the centre. Overall description of the different interdisciplinary areas of research covered by the centre in the field of green and non-invasive techniques considers the technical topic described in section 1.2, and description of WIDEX' network. **2)** Main industry collaborators across Europe and Worldwide green and non-invasive techniques: description of state-of-the-art technologies (section 1.2) with the support of the Mine the Gap platform (described in Task 8.1/9.1 and section 2.2.1). **3**) Description of TUKEs unique facilities for CRM recovery and valorisation. **4)** Research & Development: Including TUKE innovation in exploration, recovery, and mining			

	exploitation monitoring. A preliminary report will be delivered at M18 (D6.1) and updated at M34 (D7.1).			
Authors	Juraj Janocko, TUKE, Slovakia Zita Takacova, TUKE, Slovakia			
Reviewers	Ari Karjalainen, Lapland University of Applied Sciences, Finland Miika Puljujärvi, Lapland University of Applied Sciences, Finland			
Status		Draft	x	Final

Revision History				
Version	Date	Author	Organisation	Status
1	10/11/2025	Juraj Janocko	TUKE	Initial Draft
2	20/11/2025	Zita Takacova	TUKE	Draft
3	09/12/2025	Juraj Janocko & Zita Takacova	TUKE	Draft
4	12/12/2025	Ari Karjalainen & Miika Puljujärvi	Lapland	Review
5	15/12/2025	Juraj Janocko & Zita Takacova	TUKE	Final

INDEX

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

Glossary	
Acronym	**Meaning**
CA	Consortium Agreement
CRM	Critical Raw Material
DoA	Document Agreement
FBERG	Faculty of Mining, Ecology, Process Control and Geotechnologies
FMMR	Faculty of Materials, Metallurgy and Recycling
GA	Grant Agreement
GPR	Ground-Penetrating Radar
HPGR	High-Pressure Grinding Rolls
IRET	Institute of Recycling and Environmental Technologies
LIBS	Laser-Induced Breakdown Spectroscopy
R&D	Research and Development
R&I	Research and Innovation
RM	Raw material
SAR	Synthetic Aperture Radar
TUKE	Technical University of Kosice
WP	Work Package
XRT	X-Ray Transmission
XRF	X-Ray Fluorescence
NIR	Near-Infrared

EXECUTIVE SUMMARY

The WIDEX Virtual Centre, hosted by the Technical University of Košice (TUKE) in Slovakia, is a key initiative focused on advancing green and non-invasive technologies for Critical Raw Materials (CRM). The Centre is part of the European WIDEX project, which aims to implement innovative technologies for the exploration, extraction, processing, and recycling of critical raw materials. By combining TUKE's strengths in research management, coordination, and technical expertise, the Centre serves as a platform for knowledge transfer, networking, and collaboration across the European research and industrial landscape.

The Centre's core objectives include:

- Providing advisory and consulting services on green CRM technologies.
- Supporting dissemination and communication efforts to accelerate the adoption of innovative solutions.
- Building a strong ecosystem of stakeholders in the CRM sector, with an emphasis on sustainability.
- Fostering interconnections with EU initiatives like Horizon Europe, S3P, and RIS3 to drive investments and business development.

The WIDEX Virtual Centre brings together cutting-edge technologies in the fields of CRM exploration, extraction, processing, and recycling, including advanced geophysical prospecting methods, AI-based data analysis, remote sensing, and sustainable hydrometallurgical processes. The Centre also focuses on innovative recycling technologies, such as the COOL-Process for lithium recovery, and electrochemical recovery methods for metal separation.

Through strategic partnerships with industry leaders WIDEX enhances the application of AI, automation, and data-driven technologies in mining and resource recovery. These technologies are vital to meeting the growing economic and environmental demands of the mining industry.

TUKE's unique facilities in the Faculty of Mining, Ecology, Process Control and Geotechnologies (FBERG) and Faculty of Materials, Metallurgy and Recycling (FMMR) offer state-of-the-art infrastructure for research and development in CRM recovery and valorisation, particularly through hydrometallurgical and pyrometallurgical methods. The Institute of Recycling and Environmental Technologies (IRET) at TUKE plays a pivotal role by supporting the development of sustainable recycling solutions, focusing on the circular economy and critical metal recovery.

The WIDEX Virtual Centre is positioned to become a leading hub for innovation in the mining industry, driving the adoption of green technologies and promoting sustainable resource management. It aims to foster stronger links between academia, industry, and the global community, helping to address the challenges of securing critical raw materials in an environmentally responsible and economically viable manner.

1.Introduction

1.1 WIDEX project overview

The WIDEX project addresses the increasing importance of CRMs for Europe's economy, especially in strategic sectors such as green technologies and digitalisation. While demand for these essential resources is steadily rising, primary mining activities in Europe are decreasing, which results in growing dependency on imports from third countries. This challenge has been recognised by the European Raw Materials Act, which stresses the need to secure resilient supply chains and promote the use of green and non-invasive technologies for the recovery and refining of CRMs.

Slovakia, and particularly the Košice region, plays a central role in this context, as it holds 46% of Slovak geological reserves. TUKE, being the main Slovak reference centre for mining and raw materials, is uniquely positioned to bridge existing research and innovation gaps within the EU. The WIDEX project will reinforce TUKE's position through three strategic lines:

1. Advancing exploration, recovery, and mining exploitation monitoring.
2. Strengthening sustainability, circularity, and social assessment capacities.
3. Enhancing TUKE's research management, coordination, and administrative skills.

To achieve these objectives, WIDEX will establish several key innovation and networking instruments:

- a new cluster in Central Europe focusing on CRMs and sustainable technologies,
- a Virtual Centre as a European reference point for green and non-invasive technologies,
- a Stakeholder platform to build a strong ecosystem and foster collaboration,
- and the WIDEX Whitebook, compiling lessons learned and best practices.

Through these activities, WIDEX will strengthen TUKE's international position, build new synergies with top-class research institutions, and support Europe's long-term autonomy in CRM supply by promoting innovative, sustainable, and non-invasive approaches.

The WIDEX Consortium consists of ten partners lead by the Technical University of Kosice, Slovakia. The partners are from eight European countries (Table 1).

Table 1: Widex Consortium Participants.

Participants N°	Participant organisation name	Acronym	Country
1	TECHNICAL UNIVERSITY OF KOSICE	TUKE	Slovakia
2	FUNDACIÓN ICAMCYL	ICAMCYL	Spain
3	IBERIAN SUSTAINABLE MINING CLUSTER	ISMC	Spain
4	MNLT INNOVATIONS IKE	MNLT	Greece
5	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	IKTS	Germany
6	IDENER RESEARCH AND DEVELOPMENT AIE	IDE	Spain
7	CONSENTIA	CON	France
8	LAPLAND UAS	LAPLAND	Finland
9	AVENIR ENERGIE ENVIRONNEMENT AVENIA (POLE AVENIA)	AVENIA	France
10	EIT RAW MATERIALS CLC East	EITRM	Poland
11	KOSICE REGIONAL GOVERNMENT	KSK	Slovakia

1.2 Scope and objectives of the Deliverable

The deliverables D6.1 in M18, followed by D7.1 in M34, are designed to support the creation of a European reference framework for green and non-invasive technologies and to reinforce TUKE's role as a regional and European centre of excellence in CRMs. Their scope reflects both the scientific-technical priorities of the project and the capacity-building dimension, ensuring that knowledge, infrastructure, and management tools are fully aligned with the objectives of the European Raw Materials Act and the strategic positioning of the Košice region.

The main objectives of the deliverables are to:

- Map and highlight TUKE's strengths and unique facilities for CRM exploration, recovery, and valorisation, while providing a comprehensive overview of its interdisciplinary research capacities.
- Develop and launch the WIDEX Virtual Centre (supported by the ISMC website), which will serve as a reference hub connecting partners, industry stakeholders, and research institutions across Europe.
- Establish a stakeholder and industrial collaboration platform that identifies state-of-the-art green and non-invasive technologies and links them to European and global industrial ecosystems.

- Support networking and clustering activities by creating a new Central European cluster and reinforcing TUKE's role in international partnerships.
- Produce knowledge outputs, such as the WIDEX Whitebook, that consolidate lessons learned, best practices, and recommendations for the wider adoption of innovative CRM recovery approaches.
- Strengthen TUKE's research management and coordination capacities through targeted activities, internal workshops, and training.

The deliverables are structured to provide preliminary outputs – D6.1 *Preliminary Report on the European Virtual Centre in Green Non-Invasive Technologies for CRM Recovery* (M18) – and later a final version – D7.1 *Final Report on the Virtual Centre for Green CRM Recovery* (M34), ensuring that the outcomes evolve throughout the project and reflect the progress achieved by the consortium.

2. WIDEX Virtual Centre and Its Interdisciplinary Research Areas

2.1 Presentation of the Centre

The WIDEX Virtual Centre is an online hub hosted by the Technical University of Kosice, Slovakia focused on green and non-invasive technologies for Critical Raw Materials. The establishment of the Virtual Centre relates to the implementation of the European project WIDEX, which is focused on adopting cutting-edge technologies in the field of raw materials (RM): exploration, extraction, processing, and recycling. It is the engine for impact (exploitation, clustering, dissemination), connecting TUKE's capabilities with European industry, authorities, researchers, and society. In practice, it is a digital centre within the WIDEX website that builds on TUKE's strengths, brings together state-of-the-art solutions and partners in the RM field, and accelerates knowledge transfer. It is interconnected with the Mine the Gap platform to leverage an EC-funded stakeholder base for networking and partner discovery.

The main objectives of the WIDEX Virtual Centre

- Advisory and consulting services in the field of green & non-invasive CRM technologies.
- Launching and supporting Dissemination, Communication & Exploitation activities as an impact accelerator.

- Grow an ecosystem of stakeholders around CRM (with emphasis on green/non-invasive techniques).
- Interconnect with EU platforms (e.g., S3P) and RIS3 strategies to enable future investments and business.

These objectives are related to TUKE's strength in the field of 1) green and non-invasive technologies for exploration, recovering, processing and recycling of RM and 2) experience in research management, coordination capacities and administrative skills.

Expected impact

- Increased science and innovation capacity for all actors in the Research and Innovation (R&I) system in widening countries.
- Reformed R&I systems and institutions, leading to increased attractiveness and retention of research talent.
- Higher participation and success rates in Horizon Europe and coming EU funded instruments, including more consortium leadership roles.
- Stronger linkages between academia and business, resulting in improved career permeability.
- Improved international outreach for all actors.

2.2 Overview of Green Technologies in Exploration, Extraction, Processing, and Recycling

Current developments bring many new techniques that are increasingly entering the application phase and are being adopted by the mining industry both in Europe and worldwide. The WIDEX virtual centre offers several cutting-edge technologies for the needs of the mining industry in the fields of exploration, extraction, processing and mining, from which we select the following:

Exploration:

- Geophysical Prospecting with Geopotential Fields: Gravity and Magnetic Methods.
- Geophysical Prospecting with Electrical, Electromagnetic, and Seismic methods
- Gravity Data Analysis and Modelling
- Passive and Active Seismic Methods
- Laser Induced Breakdown Spectroscopy
- Advanced Key Spectroscopy Techniques
- AI applied to geophysical data analysis and processing

- Remote Sensing & Earth Observation

Processing and recycling:

Hydrometallurgical processes with green approaches and cutting-edge refining

- Solvometallurgy

A flowsheet specifying the main technologies for primary and secondary resource recycling, aimed at recovering battery metals, is shown in Figure 1 (@Fraunhofer IKTS).

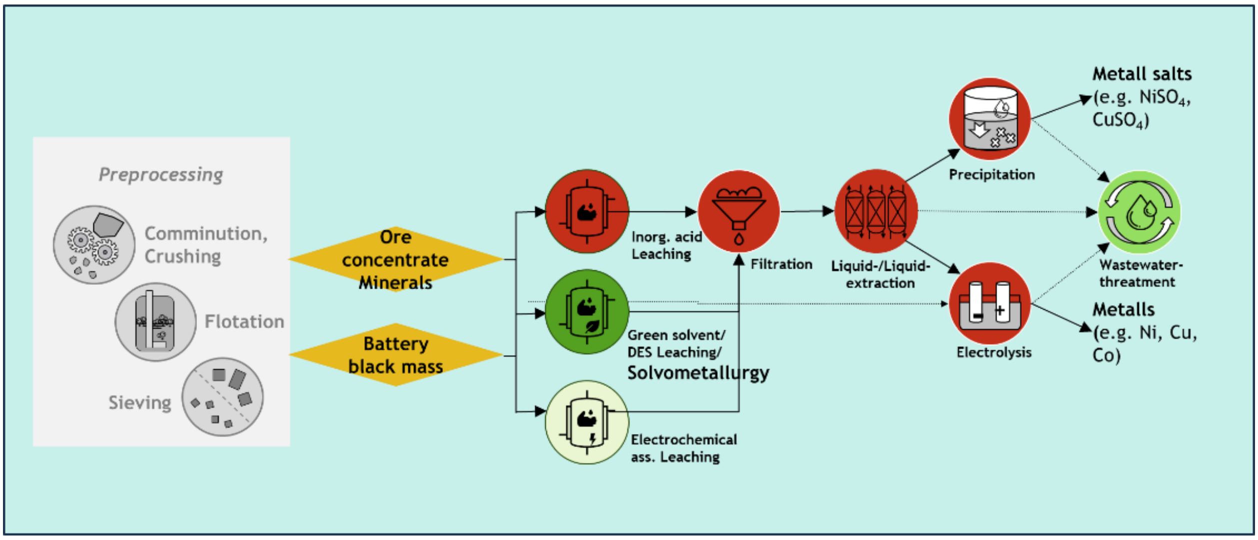

Figure 1: Flowsheet specifying the main technologies for primary and secondary resources recycling by recovering battery metals, @Fraunhofer IKTS.

- CO_2 leaching

In recent years, lithium recovery has gained attention due to its key role in electromobility. Traditional pyrometallurgical processes focus on nickel and cobalt, leaving lithium in the slag and making its recovery economically unfeasible.

To address this, TU Bergakademie Freiberg (TUBAF) developed the COOL-Process, a first-stage lithium extraction method based on supercritical CO_2 leaching. This technology allows lithium recovery from both primary sources (spodumene) and secondary materials (black mass). Lab-scale results have been validated in a 200 L reactor, producing battery-grade Li_2CO_3 regardless of the input material, demonstrating the robustness of the process.

- Electrochemical approach

Electrochemical processes are gaining importance as a modular technology that can complement traditional hydrometallurgical methods, reducing the number of stages needed to separate complex feedstocks, increasing economic efficiency, and lowering chemical consumption.

These techniques are increasingly being considered not only for the purification of final metallic products but also as a method for recovering CRMs earlier in the value chain, offering a more flexible and sustainable approach to resource recycling.

- Mathematical modelling

Chemical and hydrometallurgical process modelling plays a crucial role in understanding, optimizing, and controlling chemical reactions and processes. It provides a mathematical representation of the behaviour of chemical systems, enabling engineers and scientists to predict the outcomes of different process conditions. Whether it is designing reactors, optimizing production rates, or improving process efficiency, accurate models are essential for decision-making in chemical engineering and industrial applications (see Figure 2).

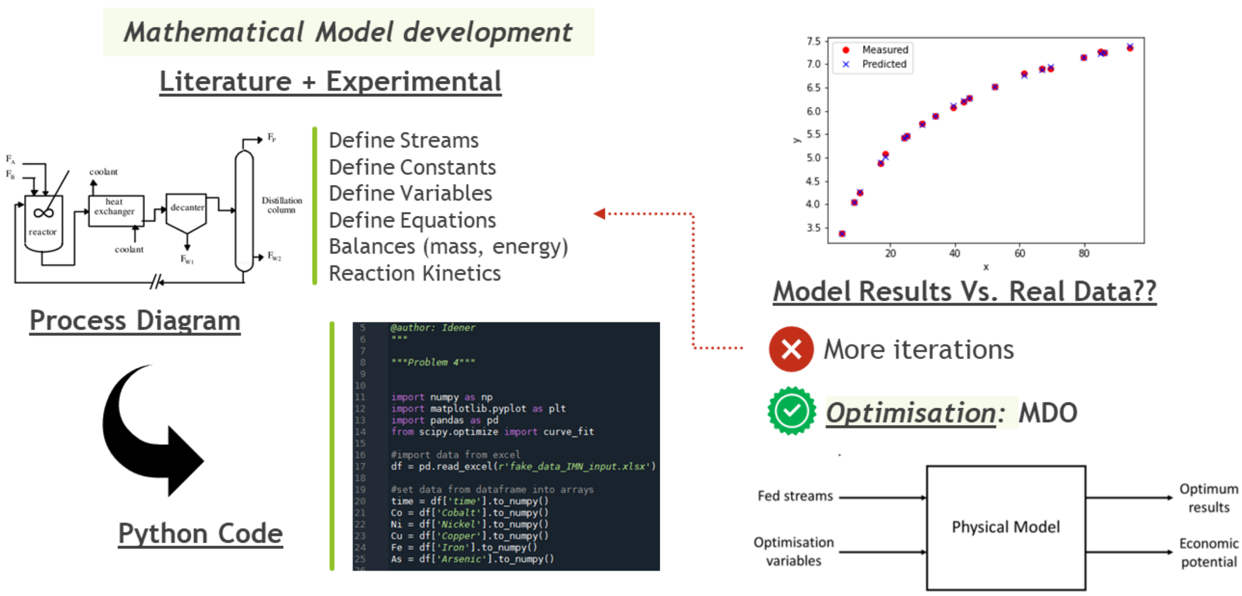

Figure 2: Schematic workflow of the principles of mathematical modelling and implementation.

Extraction:

Virtual reality: mining monitoring

The example of using virtual reality. The user can view the key steps of the drifting process in person inside a virtual mine environment. There they can, among other features and tasks, inspect the structural reinforcements of a drift tunnel and apply shotcrete, as shown in Figure 3.

Figure 3: Example of using virtual reality when the user can view the structures inside the walls with their controller.

3. Industry Collaborators and State-of-the-Art Green and Non-Invasive Techniques

3.1 Main industry collaborators across Europe and worldwide

In the world of mining exploration and mineral processing, several large companies and specialized firms dominate the market in both the Europe and worldwide. These players supply advanced equipment, technologies, and services that are critical to successful exploration, extraction, and processing of minerals. From the point view of our WIDEX project and the WIDEX virtual centre, the most interesting are companies with similar focus as our project has. In the following we list some of the companies dealing with and interested in the field, which also is around expertise of the WIDEX virtual centre:

Metso Outotec:

Focus: Mineral processing, metal refining, and water treatment.

Key Technologies: Flotation cells, crushers, grinding mills, and energy-efficient equipment. Metso is also a leader in bioleaching and hydrometallurgical processes.

Outotec:

Focus: Engineering and technology for metallurgy and mineral processing.

Key Technologies: Pressure oxidation, flotation, and magnetic separation. Known for green technologies such as energy-efficient solutions for hydrometallurgy and sustainable tailings management

Schlumberger:

Focus: Oilfield services, but also active in geophysical and geological survey technology.

Key Technologies: High-performance geophysical data acquisition and analysis systems, including seismic and electromagnetic surveys.

Trimble Inc.:

Focus: Surveying, mapping, and geospatial data collection.

Key Technologies: GPS, LiDAR, and UAV-based systems for mining exploration, environmental monitoring, and surveying.

Geosense:

Focus: Geotechnical instrumentation for exploration and mining.

Key Technologies: Measurement tools and systems for ground behavior and structural monitoring. Used to assess the stability of mining operations and geological hazards.

Geovariances (part of SUEZ):

Focus: Geostatistics and data analysis software for resource estimation and exploration modeling.

Key Technologies: Advanced software platforms like **Isatis** for geostatistical modeling, mineral resource estimation, and spatial data analysis.

Technology and Service Providers in Mineral Extraction & Processing

Barrick Gold (Gold Mining + Exploration):

Focus: Gold mining and exploration across multiple continents.

Key Technologies: Barrick is a leader in deploying AI for exploration, predictive maintenance in processing plants, and real-time ore body modelling.

Rio Tinto:

Focus: Multinational mining company involved in copper, iron ore, bauxite, and uranium.

Key Technologies: Implementation of autonomous vehicles, robotic drills, and remote-controlled ore sorting systems. Their **Mine of the Future** program uses AI and predictive analytics for mineral processing and exploration.

Earth AI:

Focus: AI-driven solutions for mineral exploration.

Key Technologies: Earth AI uses machine learning and geospatial analysis to assist in identifying new mineral deposits, helping companies save time and money during exploration.

American Battery Technology Company:

Focus: Lithium extraction and recycling.

Key Technologies: Advanced hydrometallurgical and direct lithium extraction technologies for more efficient and eco-friendly lithium processing

3.2 State-of-the-Art Technologies in Exploration, Extraction, Processing, and Recycling

The new technologies, as well as the geopolitical situation, have conditioned the significant development of innovative techniques in the mining sector, which must meet demanding economic and environmental requirements. Some of them are also applied at the TUKE Kosice. These may include:

Remote sensing and aerial techniques:

- *Hyperspectral & multispectral imaging* — High-resolution satellite or drone sensors detect mineral-specific signatures by analysing light reflection across many wavelength bands. This helps identify alteration zones, lithium brines, rare-earth-element rich clays, and other mineral indicators even over large or remote areas.
- *Thermal infrared & spectral monitoring* — Surface temperature anomalies or subtle thermal patterns can betray hydrothermal alteration or hidden ore-body footprints. Paired with spectral data, these help refine target zones before drilling.
- *Synthetic Aperture Radar (SAR)* — Useful in cloudy or weather-challenged regions; SAR penetrates cloud cover and allows frequent, all-weather monitoring, revealing subtle surface deformation or structural cues that may indicate underlying mineralization.

Drone / UAV-based geophysical & geochemical surveys:

- *Drone-mounted magnetometry, electromagnetic, and ground-penetrating radar (GPR)*
- *Real-time data analytics + AI integration* — Data collected by drones (magnetic, spectral, geophysical) are processed by machine learning models immediately or soon after collection.

This allows better anomaly detection, prioritization of drill targets, and faster iteration of exploration plans.

Advanced geophysical imaging: 3D / 4D seismic, ambient noise tomography, passive methods:

- *3D seismic surveys (and even 4D seismic over time)* —These methods give detailed subsurface images showing faults, folds, intrusions, ore-body geometry, and structural controls that govern mineralization. This is especially useful for deep or structurally complex deposits (e.g. base metals, PGEs, gold).
- *Ambient Noise Tomography (ANT) & passive geophysical methods + AI fusion* — New workflows combine passive seismic data (ambient noise) with machine learning to build high-resolution subsurface models without needing large artificial sources. This approach can lower environmental impact and reduce costs while still mapping deep ore bodies.

Data-fusion, AI / Machine Learning / Big-Data Analytics / Digital Twins:

- *Multimodal data integration* —Data from remote sensing, geophysics, geochemistry, historical records, and drilling are integrated into unified models using AI and machine learning. This triangulation improves predictive targeting and reduces false positives.
- *Predictive modelling & drill-target prioritization* — models trained on historical data and geology help predict new mineralization zones.
- *Cloud computing and collaboration platforms* — Large datasets (satellite + drone + geophysics + geochemistry) are processed, stored, and shared globally. This enables remote teams to collaborate in real time, speeding up decision-making.
- *Digital twins / 3D geospatial modelling* — Exploring teams build virtual 3D models of terrain and subsurface geology to simulate drilling scenarios, reduce risk, and plan operations in detail before committing real-world resources.

Sensor-Based Ore Sorting:

Modern ore sorters use *X-ray transmission (XRT), X-ray fluorescence (XRF), near-infrared (NIR), laser-induced breakdown spectroscopy (LIBS),* and *hyperspectral* imaging to separate ore from waste *before* grinding.

- *High-Pressure Grinding Rolls (HPGR)*

Recent HPGR designs use:

- *Micro-crack generation* for higher downstream recovery
- *Dry grinding integrations*
- *AI-controlled pressure adjustments*

- *Electro-Pulse Fragmentatio*n - This technology applies high-voltage electrical pulses to fracture rock selectively along natural grain boundaries, reducing overgrinding and overall energy consumption.
- *Flotation 4.0 – Digital, Automated, and Selective Processing* - Advanced flotation systems employ AI-powered reagent optimization, novel collectors, nano-reagents, and environmentally friendly surfactants, along with engineered hydrophobic and hydrophilic bubble systems to improve selectivity and recovery.
- *Advanced Gravity Separation* - Modern gravity separation techniques are used to efficiently recover valuable minerals based on density differences.
- *Magnetic & Electrostatic Separation* – High-intensity and high-precision magnetic and electrostatic separators are applied to enhance mineral separation efficiency, particularly for fine and complex ores.

Hydrometallurgy

Modern hydrometallurgical processes focus on maximizing metal recovery while minimizing environmental impact. Key advancements include:

- Bioleaching: Use of microorganisms to extract metals from ores and waste in an eco-friendly manner.
- Selective Leaching: Optimized chemical and green reagent use for targeted metal extraction.
- Green Chemistry Innovations: Use of less toxic reagents, lower energy processes, and water-efficient methods. Integrated Recovery Schemes: Combination of hydrometallurgy with flotation, gravity, and electrochemical methods for enhanced efficiency.
- Closed-Loop and Recycling Approaches: Recovery of metals from secondary sources and process residues to minimize waste and environmental footprint.
- Digital Monitoring and Control: AI and sensor-based systems to monitor reaction parameters, improving yield, reducing energy consumption, and enabling predictive maintenance.

4. TUKE unique facilities for CRM recovery and valorisation

Research and development for the raw material field is concentrated at two TUKE faculties – Faculty of Mining, Ecology, Process Control and Geotechnologies (FBERG) and Faculty of Materials, Metallurgy and Recycling (FMMR). This also determines the allocation of TUKE facilities for CRM recovery and valorisation.

4.1 Key Technological Facilities of FBERG

Laboratory of Seismic Engineering

The laboratory is focused on measurement and evaluation of velocity propagation and vibration velocity of seismic waves in rock environment. From the results of laboratory research are assessed the physical-mechanical properties of the rock environment, structure and internal structure, negative impacts of blasting operations and evaluation of seismic safety.

Laboratory equipment:

- Terraloc Mk 8 seismic apparatus for measuring the velocity of seismic wave propagation. The basis of the apparatus is a 24-channel seismograph, which contains internally built-in software SeisTW and 24 geophones type SM-4B with a frequency of 10Hz,
- ESS-100 hammer, serves as seismic source for achieving greater depth of seismic record - Material tester 543 ultrasonic device with 1MHz, 100 kHz and 40 kHz source frequency - seismic device VMS 2000 MP made by Thomas Instruments and seismic sensors (Geospace company) for measurement and graphical recording of seismic effects, - the seismograph ABEM Vibraloc and ABEM seismic sensors for measuring and graphical recording of seismic effects,
- digital four-channel seismic scanner UVS 1504 and seismic sensors from Nitro Consult company are used for measuring and graphical recording of seismic effects.

Services:

- measurement, processing, evaluation and prediction of seismic effects of blasting operations,
- assessment of rock environment internal fracturing,
- geological structure interpretation base on of seismic wave propagation (refractive and reflective seismic, seismic tomography; software processing and interpretation).

Geological computer laboratory

- research tasks related to statistics (Isatis), hydrogeology (Surfer), structural geology, seismic (Petrel, ReflexW, Isatis), static and dynamic modelling (Petrel).

The 3D structure model of the Košice basin basement, created in Petrel, is shown in Figure 4.

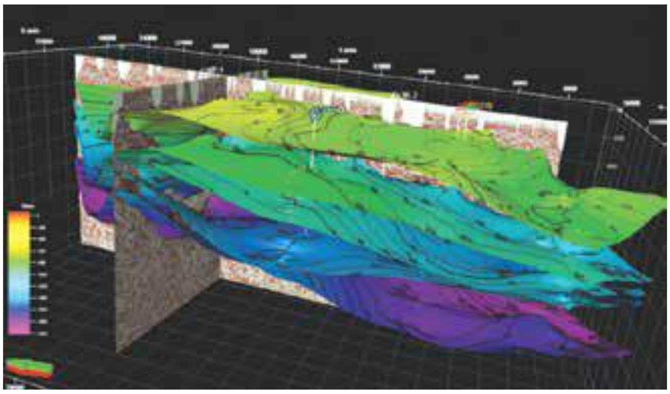

Figure 4: 3D structure model of Košice basin basement (in the Petrel).

Optical laboratory

The Optical Laboratory is the main tool for rock and mineral research at the BERG Faculty. It contains modern laboratory instruments, scanning devices and software.

The results are used to:

- microscopic analysis of rocks and minerals in the field of basic and applied research
- teaching vocational subjects, preparing students'final theses
- for research on microtectonics, paleopiezometry, sedimentology, ore, environmental and engineering geology

Laboratory Equipment:

- stereomicroscope Olympus SZ61-TR with polarizing attachment, camera Promicam and softvear equipment for pictures editing - polarizing microscope Olympus BX-53 with digital camera Lumenera
- polarizing microscopes Jenapol
- polarizing microscopes Amplival
- thin section maker Logitech CL-50

Services:

- microscopic analysis and identification of igneous, sedimentary and metamorphic rocks as well as basic rock-forming minerals,
- optical analysis of ore samples.

An example of a druse of crystal quartz analysed by the stereomicroscope SZ61-TR is shown in Figure 5.

Figure 5: *Druse of crystal quartz analysed by stereomicroscope SZ61-TR.*

Laboratory of Luminescence dating

A top scientific laboratory for the youngest Quaternary sedimentary rocks dating. The sediments ranging in age from several years to several hundred thousand years.

The results from dating analyses are available to use for:

- Quaternary sediments dating (TL/OSL-DA-20)
- climatic record changing
- neotectonic motion analysis
- research of fluvial terraces and glacial valleys

Laboratory equipment:

The laboratory consists of two smaller laboratories. Both meet the necessary conditions of the photochamber:

- laboratory for processing and preparation of analysed samples - enables chemical treatment of the sample drying and sieving,
- dating laboratory with device TL/OSL (model TL/OSL-DA-20).

GIS Laboratory

The Laboratory of Geographic Information Systems is designed primarily for the education of geographic information systems, CAD systems, BIM technologies, digital cartography, as well as subjects focused on big data processing, statistics, and applied statistics. In the near future, an augmented reality system consisting of a Kinect sensor for the Xbox game console, data projector, and kinetic sand, should also become a part of the laboratory. This system processes the 3D data of the sand surface scanned by Kinect in real-time, creating a 3D model of the sand surface and calculating its specified parameters (see Figure 6: Augmented reality sandbox). Various spatial analyses, terrain model analyses, and visualisations can be realised on this model. The model will serve for the presentation of GIS analyses results, education of digital cartography, as well as for scientific and research purposes.

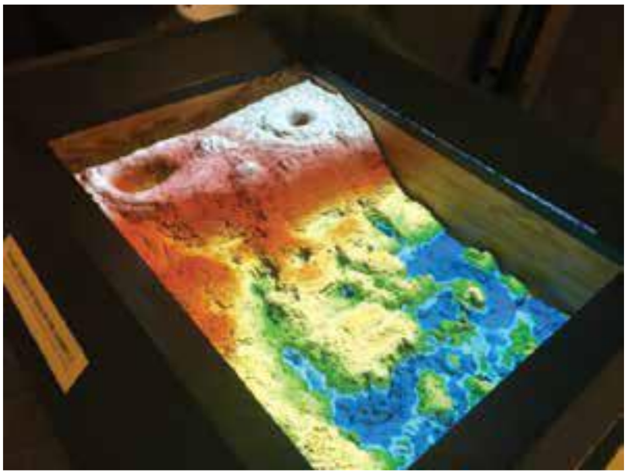

Figure 6: Augmented reality sandbox.

Laboratory of remote sensing

Remote sensing as a process of obtaining image and non-image information about the Earth has become a powerful tool for acquiring geographic information for several disciplines in recent decades. The scientific and educational centre for remote sensing is focused on professional training and scientific activities of experts in the field of Earth Observation data processing: satellite and aerial remote sensing, digital terrain modelling, mapping the state and development of changes in the country and natural phenomena, monitoring of surface mining activities including its impact on the environment, monitoring and evaluation of soil erosion, mapping of floods and flooded areas by using GIS tools (QGIS, Google Earth Engine, SNAP), in geology, urban design, transport and in crisis management. The concept of the laboratory develops innovative methods of education based on high-tech satellite technologies with the support of quality hardware equipment. Software tools and satellite data are provided as free and open-source by European Space Agency ESA (Sentinel-1, Sentinel-2, Sentinel-3 and 5), NASA and other space agencies. The laboratory has a data server as storage of processed data and individual projects.

4.2 Key Technological Facilities of FMMR

IRET, FMMR, TUKE is a specialized workplace dedicated to research, development, and practical validation of technologies in recycling, waste processing, environmental chemistry, and the circular economy. Within the planned virtual centre, IRET will contribute unique expertise, laboratory infrastructure, and professional know-how to deliver comprehensive solutions for sustainable resource and waste management.

IRET comprises multiple laboratories, specialized workstations, and pilot-scale technological units that support the full spectrum of recycling processes — from material preparation and mechanical treatment, through physical and chemical operations, to analytical quality control of outputs. This integrated approach represents one of IRET's key contributions to both university and industrial projects.

Equipped with a complete set of technological units and infrastructures, IRET provides a robust system for research and development in recycling, waste processing, and environmental technologies. This chapter presents the main functional equipment groups and highlights the workplace's strengths that are essential for the planned virtual centre.

Mechanical–physical pre-treatment of materials

IRET is equipped with extensive systems for waste pre-processing prior to chemical and thermal operations:

- equipment for crushing, milling and homogenizing various types of waste,
- sieve classifiers, vibrating screens and separation systems,
- magnetic and eddy-current separators for physical separation of metals,
- technological units for mechanical treatment of composite, metallic and multilayer materials.

Pilot-scale hydrometallurgical and chemical processes

One of IRET's major strengths is its own pilot-scale equipment that:

- enables testing of recycling technologies at near-real industrial scale,
- provides capabilities for leaching, extraction, filtration and metal separation from different types of industrial waste, serves as a platform for transferring research results into industrial practice (see Figure 7: Pilot-scale hydrometallurgical equipment).

Pyrometallurgical technologies and thermal processing

The facility includes:

- laboratory high-temperature furnaces, (see Figure 8: Laboratory furnaces),

- equipment for pyrolysis and other thermal pre-treatment of various input materials, such as industrial wastes, ashes, sludges and others.

Electrochemical processes

IRET is equipped with:

- functional electrolyzers for electrochemical recovery and separation of metals,
- equipment for electrocoagulation, electrolysis and other specific processes complementing hydrometallurgical and mechanical methods.

Environmental and analytical capabilities

IRET provides a modern instrument base for quality control and process evaluation:

- XRD PANalytical X'Pert PRO RV-11 – an X-ray diffraction system used for identifying minerals, determining phase composition and studying crystalline structures of solid materials (see Figure 9).
- Handheld XRF (portable energy-dispersive X-ray fluorescence spectrometer) – a portable device enabling rapid, non-destructive elemental analysis, suitable for quick screening of waste and raw materials.
- Atomic Absorption Spectrometry (AAS) – the spectrometer shown in Figure 10 is used for accurate determination of metal concentrations in waste, water, leachates, and other environmental samples.
- UV/VIS spectrophotometry – a method for quantitative analysis of chemical species in water and technological solutions based on their absorption of UV and visible light.
- Sample preparation workstations – facilities for mechanical, chemical and thermal preparation of materials prior to instrumental analysis, ensuring accuracy and reproducibility of results.

Figure 7: Pilot-scale hydrometallurgical equipment.

Figure 8: Laboratory furnaces.

Figure 9: XRD PANalytical X'Pert PRO RV-11 – X-ray diffractometer.

Figure 10: AAS spectrometer.

5. Research & Development: TUKE Innovations in Exploration, Recovery, and Mining Monitoring

Research and Development, FBERG, TUKE

The scientific-research activity is currently focused on basic and applied research, which fully reflects the needs not only of our society but also of the international community within Europe. In addition to basic geological research aimed at the deep structure of the Carpathians and the geodynamic evolution of sedimentary basins, it concentrates primarily on a broad spectrum of environmental issues associated with hydrogeological and engineering-geological factors. In this field, the dominant topics include slope deformations and other geohazards, as well as the protection of groundwater from pollution and methods for remediating ecological accidents. Emphasis is also placed on research into global changes, including climatic conditions and the study of natural paleo-environments in the past. The renewed needs of the international community related to oil and gas extraction have also been reflected in the department's recent activities in the field of hydrocarbon exploration within the territory of Slovakia.

Geotechnologies of Exploration and Prospecting of Mineral Resources

- Study of ore-forming processes of mineral resources and their occurrence (deposits of ores, non-metallic minerals, precious and decorative stones, coarse and building stone, and caustobiolites in the Western Carpathians and other regions of the world).
- Applied structural geology of deposit fields (study of structural-tectonic, paleostress, and stability conditions of the rock mass in mineral resource deposits).
- Applications of mineral resources in industry and agriculture.
- Applied geophysics (study of geophysical fields and logging of ore-forming areas; geophysical research and surveying in engineering geology, hydrogeology, and environmental studies; radon risk assessment in mineral deposits and environmental evaluation).
- Geological-deposit aspects applicable to comprehensive underground coal gasification technologies.
- Engineering geology (engineering-geological, soil-mechanical, and rock-mass stability studies; engineering-geological solutions for waste management repositories; study of the

impact of mine closure on hydrogeological conditions and the quality of groundwater and surface water).

- Exploration for hydrocarbon deposits.
- Exploration for non-metallic mineral resources.

Research and Development, IRET, FMMR, TUKE

IRET specializes in research and development of technologies for recycling metallic and non-metallic materials, environmental waste treatment, and valorisation of secondary raw materials. IRET focuses on recycling a wide range of waste materials, including municipal and industrial wastes, batteries, electronic waste, metallurgical by-products, slags, dusts, and other secondary metal-bearing materials, using mechanical-physical, hydrometallurgical, and pyrometallurgical processing methods to efficiently recover metals, at both national and international levels.

Its research activities include the optimization of processing and recycling methods, development of economically efficient recycling technologies, material characterization, and assessment of environmental benefits. IRET's expertise supports the recovery of strategic and critical metals and their reintegration into the circular economy. The institute's involvement in national and international projects ensures that developed technologies and know-how are relevant at both regional and European levels.

This research directly contributes to innovations in the circular economy and enables the development of sustainable technological solutions for the recycling of critical raw materials and industrial and municipal waste materials.

6. CONCLUSIONS

The WIDEX Virtual Centre, established at TUKE, serves as a digital hub for advancing green and non-invasive technologies within the CRMs sector. Its primary mission is to integrate cutting-edge technologies for CRM exploration, extraction, processing, and recycling, focusing on sustainability and minimal environmental impact. The centre aims to foster collaboration among academia, industry, and research institutions, with key objectives including the provision of advisory services, the acceleration of knowledge transfer, and the development of a robust ecosystem of stakeholders around CRM.

The WIDEX Virtual Centre also leverages TUKE's strengths in research management and coordination, aligning with European initiatives like Horizon Europe and RIS3 strategies to enhance science and innovation capacity. The centre fosters stronger ties between academia and business, creating pathways for new investments, projects, and international collaborations. Through cutting-edge green technologies, such as AI-driven exploration tools, remote sensing, and advanced geophysical methods, the centre addresses the mining industry's evolving needs for sustainable resource extraction.

The TUKE facilities supporting CRM research, including the FBERG and FMMR faculties, provide comprehensive infrastructure for exploring and processing critical raw materials, incorporating innovative approaches such as hydrometallurgical processes, selective leaching, and process intensification techniques. The facilities support the circular economy by enabling the efficient recovery and recycling of valuable metals through various specialized processes, including electrochemical recovery and closed-loop recycling strategies.

In collaboration with leading global industry players WIDEX promotes the deployment of advanced technologies in mining exploration, mineral processing, and resource recovery. As the mining industry faces increasing environmental and economic demands, WIDEX's focus on green technologies, automation, and data-driven solutions ensures that the industry can meet these challenges in a sustainable and efficient manner.

Overall, the WIDEX Virtual Centre exemplifies the growing trend towards green innovation in the mining sector, creating opportunities for sustainable mining practices, advancing critical raw material recovery, and enhancing international cooperation in the field of mining exploration and processing.