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D3.1 – Knowledge Transfer for Green and non-invasive tech for CRM exploration, recovery, and mining exploitation monitoring

30/11/2024

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DOCUMENT CONTROL SHEET

Project	**WIDEX**– KNOWLEDGE TRANSFER FOR WIDENED EU EXCELLENCE IN ADVANCED GREEN TECHNOLOGIES, SUSTAINABILITY AND RESEARCH MANAGEMENT

General information				
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Description of the related task and the deliverable. Extract from DoA	The present document contains the results obtained in all the tasks of WP3 (T3.1, T3.2 and T3.3). Task 3.1 Knowledge Transfer Plan for green/non-invasive tech for CRM deposit exploration: ISMC will facilitate knowledge transfer for exploration using remote sensing, GIS, geophysics, and AI technologies, providing updated maps, efficient costs, and improved social acceptability. ICAMCYL will support material preparation and real case presentations. ISMC will implement research in industrial settings with industry partners experienced in various exploration techniques. Task 3.2 Knowledge Transfer Plan for green/non-invasive tech to recover CRM for the EU: IKTS and IDE will design, and plan knowledge transfer activities			

	based on their experience from previous EU projects. Both partners cover the recycling value chain, making their cooperation beneficial. Part A led by IKTS focuses on hydrometallurgy with green solvents and cutting-edge refining. They will present literature comparing current industry technologies with new academic approaches, emphasizing impurities' influence on product quality and the importance of monitoring and digitalization in recycling. Part B, led by IDE, will review common modelling and optimization techniques to develop presentations explaining mathematical models, optimization processes, computational techniques, and process digitalization. IDE will demonstrate real cases and the integration of models into a DT Tool. Task 3.3 Knowledge Transfer Plan for green/non-invasive tech for CRM mining monitoring: LAPLAND will create a visualization environment for mining monitoring scenarios using a game engine and gamified elements. It includes animation, 3D visualization, and interactive features for education. It can be widely distributed for training and knowledge transfer among partners, with additional training materials for blasting field.
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EXECUTIVE SUMMARY

To improve the theoretical and practical knowledge of TUKE researchers, specialised training sessions will be organised. These sessions will be carried out with the support of the centres of excellence involved as experts in the different thematic areas within the green and non-invasive technology (exploration, recovery, mining monitoring). The type of training and education will depend on the Strategic Line, which will be made up of a powerful package to ensure that the quality of knowledge and context covers the high level required. In the Deliverable 3.1 belonging to work package 3, the topics chosen for each of the knowledge areas will be shown as well as the methodology that will be carried out for both online and face-to-face trainings that will be carried out in work package 6/7.

ABBREVIATIONS AND ACRONYMS

Glossary	
Acronym	**Meaning**
SL	Strategic Line
KT	Knowledge Transfer
CRM	Critical Raw Materials
REE	Rare earths elements
VR	Virtual reality
UI	User interface
TRL	Technology Readiness Level
TUBAF	TU Bergakademie Freiberg

1. KT in Green and non-invasive Technology for CRM deposit exploration

ISMC with collaboration from ICAMCYL has organised specialised trainings regarding CRM deposit exploration, with regards to a green and non-invasive approach. To do this, the cluster has contacted several stakeholders specialised in each topic, covering geophysical prospecting, gravity data analysis and modelling, passive and active seismic methods, Laser Induced Breakdown Spectroscopy (LIBS), advanced optimal techniques, AI applied to data analysis and prospecting, and remote sensing and earth observation.

The trainings will be carried out during the second half of February 2025 and have been divided into two blocks: a first one-week geophysics block and a second one-week block dedicated to digital modern technologies applied to the raw materials exploration sector.

1.1. Geophysical Methodologies

1.1.1 Geophysical Prospecting with Geopotential Fields: Gravity and Magnetic Methods.

Dr. Javier Pavón Carrasco from the Universidad Complutense de Madrid (UCM, Spain) will offer an in-depth exploration of environmentally friendly and non-invasive techniques for subsurface exploration. Participants will learn the fundamentals of gravity and magnetic methods, which do not require physical penetration or chemical alteration of the ground, making them highly suitable for green exploration initiatives. By measuring natural variations in the Earth's gravitational and magnetic fields, these methods help minimize the environmental footprint while accurately delineating subsurface features. The course covers the physics underlying these geopotential field methods, instrumentation, data acquisition, and processing techniques, all tailored to ensure a minimal-impact approach to geophysical prospecting.

A major emphasis of the training is on integrating gravity and magnetic data to support sustainable exploration efforts, such as locating mineral resources without disruptive excavation or excessive land use. Participants will engage in hands-on exercises and case studies, demonstrating how data modelling and interpretation can be performed in an eco-friendly manner while maintaining accuracy and reliability. The training illustrates how non-invasive techniques can be aligned with broader environmental and sustainability goals, making them ideal for modern exploration demands, conservation-sensitive projects, and sustainable resource management.

1.1.2 Geophysical Prospecting with Electrical, Electromagnetic, and Seismic methods

During a second session, Dr. Javier Pavón Carrasco from UCM will focus on environmentally friendly and non-invasive techniques used to explore the Earth's subsurface. Participants will gain a comprehensive understanding of electrical resistivity, induced polarization, electromagnetic (EM), and seismic methods, all of which are designed to provide accurate subsurface imaging without intrusive drilling or excavation. Through theoretical and practical sessions, the training covers the principles, instrumentation, data acquisition, and processing techniques relevant to these methods. This green approach to exploration is especially valuable for resource detection, environmental assessments, and geotechnical investigations with minimal ecological disruption.

The training emphasizes the integration of electrical, electromagnetic, and seismic data to offer a holistic view of subsurface properties, such as electrical conductivity, resistivity contrasts, and seismic velocity variations. Participants will have the opportunity to work with hands-on exercises and case studies, learning to process, model, and interpret field data. This non-invasive exploration strategy aligns with modern sustainability goals by reducing the environmental impact of resource extraction and infrastructure projects, while still providing high-resolution results. By the end of the training, participants will be well-equipped to apply these techniques to support eco-friendly exploration and sustainable land-use management initiatives.

1.1.3 Gravity Data Analysis and Modelling: A Case Study in Geophysical Exploration

Through a third session, Dr. Javier Pavón will tackle a practical case study. It will offer participants an in-depth experience in analysing and modelling gravity data for subsurface exploration. This course focuses on the use of gravity surveys to identify variations in the Earth's gravitational field that correspond to changes in subsurface density, providing critical insights into geological structures, mineral deposits, and resource potential. Participants will explore data acquisition methods, processing workflows, and modelling techniques necessary to effectively interpret gravity data in geophysical exploration contexts.

The training emphasizes a practical, case-study-driven approach, allowing participants to work through real-world scenarios and apply gravity data analysis tools to solve exploration challenges. Hands-on exercises will cover data processing, terrain correction, Bouguer anomaly interpretation, and 3D modelling, using industry-standard software. By integrating gravity data with other geophysical and geological datasets, participants will gain a holistic understanding of subsurface structures and enhance their decision-making capabilities for exploration projects. This training prepares attendees to utilize gravity data for resource discovery and assessment while minimizing environmental impact and maximizing exploration efficiency.

1.1.4 Passive and Active Seismic Methods

This training, carried out by Dr. Javier Olona from TERRADAT, will provide participants with a comprehensive and in-depth understanding of the fundamental principles and applications of passive seismic methods, which involve monitoring natural seismic waves or ambient noise, and active seismic methods, which rely on controlled energy sources to generate seismic waves. Participants will explore how these approaches contribute to accurate subsurface imaging while minimizing environmental disturbances, making them suitable for projects with a focus on sustainability and ecological sensitivity.

The training emphasizes the advantages of integrating passive and active seismic data to investigate geological structures and subsurface properties. Through TERRADAT's real cases, participants will gain knowledge in data processing, interpretation, and modelling using industry-standard tools. By demonstrating how seismic waves can be harnessed to explore the Earth's subsurface without intrusive drilling, this training highlights how passive and active seismic methods can be effectively applied to applications such as mineral exploration, environmental monitoring, and geotechnical assessments, all while adhering to modern green exploration standards.

1.2. Digital Modern Techniques

1.2.1 Laser Induced Breakdown Spectroscopy

The training on Laser-Induced Breakdown Spectroscopy (LIBS) will be carried out by expert Dr. Carlo Ricci from the Università degli Studi di Cagliari (Italy). It will offer participants a detailed exploration of this rapid, environmentally friendly, and non-destructive technique for chemical and elemental analysis. The course covers the fundamental principles of LIBS, focusing on how short laser pulses can be used to create a plasma on the surface of a sample, resulting in light emissions that reveal its elemental composition. This approach eliminates the need for traditional chemical reagents and minimizes environmental impact, making it a green solution for analysing a wide range of materials in fields such as mineral exploration, environmental monitoring, and industrial quality control.

Throughout the training, participants will gain practical knowledge in the setup and operation of LIBS systems, data acquisition, spectral analysis, and quantitative methods for elemental detection. Hands-on exercises and real-world case studies will demonstrate how LIBS can be effectively employed for rapid, in-situ measurements without damaging samples. This non-invasive technique offers a sustainable pathway to precise analysis, with applications that reduce hazardous waste and align with modern environmental standards. By the end of the course, participants will have the skills and knowledge to apply LIBS in various sectors, optimizing efficiency and environmental responsibility in elemental analysis projects.

1.2.2 Advanced Key Spectroscopy Techniques

In a second session of the training, Dr. Carlo Ricci will offer a detailed exploration of advanced optical methods for Critical Raw Material (CRM) exploration, with a particular emphasis on Raman spectroscopy. Participants will gain an in-depth understanding of the principles and applications of key spectroscopic techniques, including photoluminescence, time-resolved luminescence, and Raman spectroscopy. These non-invasive, environmentally friendly methods enable precise molecular characterization of materials by analysing their vibrational and luminescent properties. Raman spectroscopy will be highlighted for its ability to interact with mineral samples using laser light to produce distinct spectra, providing real-time, accurate identification of mineral phases without causing damage or alteration—an approach that aligns with green exploration practices.

Through Dr. Ricci's guidance, participants will engage in hands-on experiences, conducting measurements and analysing data using advanced Raman systems as well as photoluminescence and time-resolved luminescence techniques. This practical approach will allow attendees to understand the differences between these experimental instruments, acquire data, and integrate various spectroscopic methods for a comprehensive and sustainable approach to critical raw material identification. The training will emphasize spectral interpretation, data acquisition, and the integration of optical and geochemical techniques to enhance the efficiency, precision, and environmental responsibility of mineral exploration.

1.2.3 AI applied to geophysical data analysis and processing

The third session from this second block of trainings will offer participants an immersive experience in harnessing the power of artificial intelligence to enhance geophysical exploration. This course will be carried focuses on the integration of machine learning and data-driven approaches to efficiently analyse and interpret complex geophysical datasets, such as seismic, electromagnetic, gravity, and magnetic data. AI-driven methods provide a transformative way to uncover patterns, detect anomalies, and optimize data processing workflows, all while reducing manual effort and improving accuracy. These techniques allow for faster decision-making, making exploration more effective and sustainable.

Throughout the training, participants will gain practical experience in applying AI and machine learning algorithms to geophysical data, covering key concepts like data preprocessing, feature extraction, predictive modelling, and advanced clustering and classification methods. Hands-on exercises and case studies will demonstrate real-world applications in mineral exploration, subsurface imaging, and environmental assessments. By the end of the course, attendees will have the skills to integrate AI into geophysical workflows, significantly enhancing exploration capabilities, reducing environmental impacts through targeted efforts, and contributing to more sustainable and efficient resource management strategies.

1.2.4 Remote Sensing & Earth Observation

The training on remote sensing and earth observation will be a practical case study by Eleftheria Tetoula-Tsonga from the Institute of Communication & Computer Systems from the National Technical University of Athens (ICCS-NTUA). It will equip participants with essential skills for utilizing satellite imagery, aerial data, and remote sensing technologies in environmental and resource exploration. This hands-on course applies earth observation techniques to practical case studies, demonstrating how remote sensing data can provide detailed insights into mineral exploration for CRM. By leveraging non-invasive and environmentally friendly methods, participants will learn to collect and analyse data from diverse sensors, enabling comprehensive assessments without altering or disturbing the natural landscape.

Participants will engage with real-world datasets, learn data processing techniques, and apply remote sensing software tools to identify patterns, detect changes, and extract meaningful insights. The training emphasizes the integration of remote sensing data with other geospatial and geophysical datasets for enhanced decision-making. By exploring case studies, participants will develop the skills to effectively apply earth observation technologies to support sustainable management and exploration initiatives, optimizing resource use and minimizing ecological impact.

2. KT in Green and non-invasive Technology for recovery of European CRM

Fraunhofer IKTS together with IDENER have prepared the necessary material to be able to transfer the knowledge of optimised hydrometallurgical processes in which different critical metals are recovered. The material that has been prepared focuses on a first technical part led by Fraunhofer IKTS where three blocks corresponding to three breakthrough technologies have been defined and a second part of automation and optimisation in which IDENER takes as a basis the technologies and processes proposed by Fraunhofer IKTS (considering the interests of TUKE) and exhibits a comprehensive introduction to the modelling and simulation of chemical and hydrometallurgical processes using Python. It covers fundamental principles, including mass balance, reaction kinetics, mass transfer, and equilibrium, and applies these to various process units such as leaching, solvent extraction, and membrane separation. Python is introduced as a key tool, with a focus on scientific libraries like NumPy, SciPy, and Pandas for equation solving, optimization, and data visualization. Additionally, the document details how to structure models in Python using object-oriented programming to integrate and solve individual unit models, enabling an integrated simulation of the entire process.

2.1 Hydrometallurgical processes with green approaches and cutting-edge refining

The material, which will be used in WP6/7 is mainly presentations and videos showing a selection of the most novelty breakthrough technologies used for CRM recovery to be compared with the already stablished ones. Therefore, not only the principle of the technology itself is provided but also the potential industrial implementation. Concepts such as circular economy, sustainability and cost-efficiency and zero-waste holistic process are the key terms which make a technology feasible for an industrial use. For that reason, the content of the material is mainly defined as follows:

1. Definition of the technology
2. Comparison with classic and/or stablished processes (mainly hydrometallurgical ones)
3. Processes developed in laboratory scale (max. 4)
4. Processes developed in industrial scale (max. 2)
5. Top 5-10 companies in Europe/World who are experts in the specific technology

Different information is provided depending on each of the three selected technologies depending on the maturity of the approach (technology readiness level - TRL) as well as the target metal to be recovered, which had been selected by TUKE.

2.1.1 Block I: Solvometallurgy

In recent years a new technology has emerged called solvometallurgy in which metals are extracted from different primary and secondary sources using non-aqueous solutions. This technology has been chosen in spite of its current low maturity (3 < TRL < 4) because a priori it is in line with the principles that the European Commission claims in the European Green Deal respecting the planetary boundaries. Therefore, green solvents are used as digestion solutions to recover different metals. The content of the presentation for this technology is depicted in Figure 1:

A comparison has been provided in the presentation using wet processes (hydrometallurgical) specifying the different established and well-known technologies such as for example: leaching, solvent extraction, ion exchange, precipitation and electrolysis.

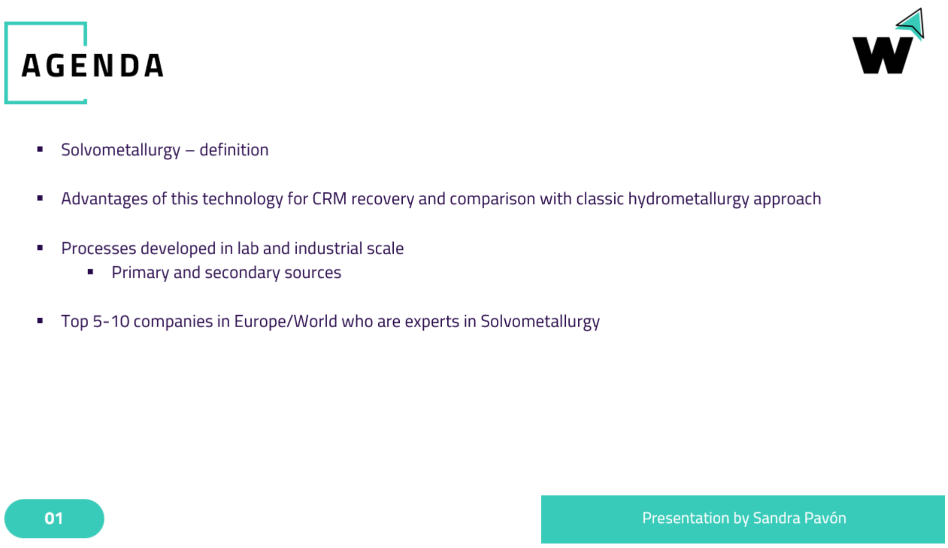

Figure 1: Block I: Solvometallurgy - Content

To make things clearer and to provide a more engineering profile to TUKE students, different flow sets (see example in Figure 2) have also been included to facilitate the understanding and comprehension of the entire recycling value chain and the whole process. In this way they are not only aware of the applied techniques but also able to identify input and output materials, possible chemicals to be added or obtained as intermediate products, etc.

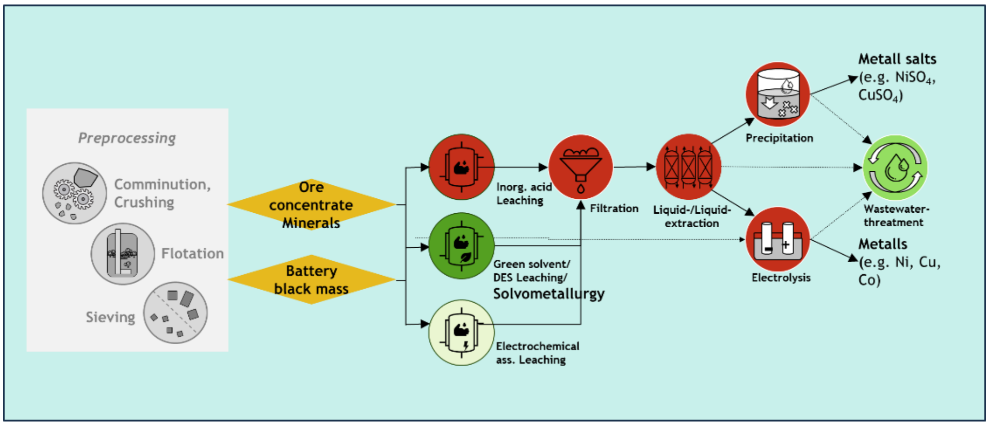

Figure 2: Flowsheet specifying the main technologies for primary and secondary resources recycling by recovering battery metals

Regarding the process developed in lab-scale, it has been selected considering the target metals recovered. TUKE interest is mainly focused on the recovery of rare earth elements (REE) from primary as well as secondary sources, battery metals as well as PGMs from secondary sources. In this sense, the following four process has been chosen for showing the potential of solvometallurgy including the main results and conclusions of the different processes.

I. Recovery of REEs from high grade bastnasite ore

II. Recovery of CRMs from nickel-cobalt-manganese cathode of spent lithium-ion-batteries
III. Recovery of PGMs from spent catalysts
IV. REEs recovery from Permanent Magnets

Due to the novelty and low TRL, to the best of our knowledge there is currently no company where solvometallurgical processes are fully implemented. For that reason, Fraunhofer IKTS have included in the presentation different companies that are researching and developing CRM recovery processes using solvometallurgical methods as well as a research centre (SOLVOMET, KU Leuven's Research and Innovation Centre for Circular Hydrometallurgy) that in the last years has gained relevance for the development of different processes using non-aqueous solvents.
In WP3 has also been defined the dates for transferring this knowledge including seminars as well as the on-side trainings. For the Block I: Solvometallurgy, the following dates are depicted in Table 1.

Table 1		
Seminar	Hybrid, MS Teams- PowerPoint -	15.10.2025 from 9 to 10:30h
Training	On-side, Fraunhofer IKTS - Freiberg	15.10.2025 to 17.10.2025

Table 1: Dates for KT from Fraunhofer IKTS to TUKE in Block I: Solvometallurgy

2.1.2 Block II: COOL - Process

In recent years the scientific community, including companies, has focused on recovering lithium because of its key role in the development of especially electromobility. In that sense, the established processes to recover lithium especially from the black mass were focused on the recovery and separation of nickel and cobalt with pyrometallurgical processes. This means that the lithium remains in the slag and therefore cannot be recovered economically due to the high energy costs. That is why the strategy proposed by TU Bergakademie Freiberg (TUBAF) together with Fraunhofer IKTS is the first stage extraction of lithium. In this respect a process patented by TUBAF called COOL-Process has been chosen to demonstrate the concept of circular economy and the robustness of the recovery process of a critical metal like lithium. Therefore, the content of this Block II is focused on showing TUKE students the promising technology of supercritical CO_2 leaching as main core of the COOL-Process not only for recover lithium from primary sources (spodumene) but also from secondary materials like black mass (Figure 3).

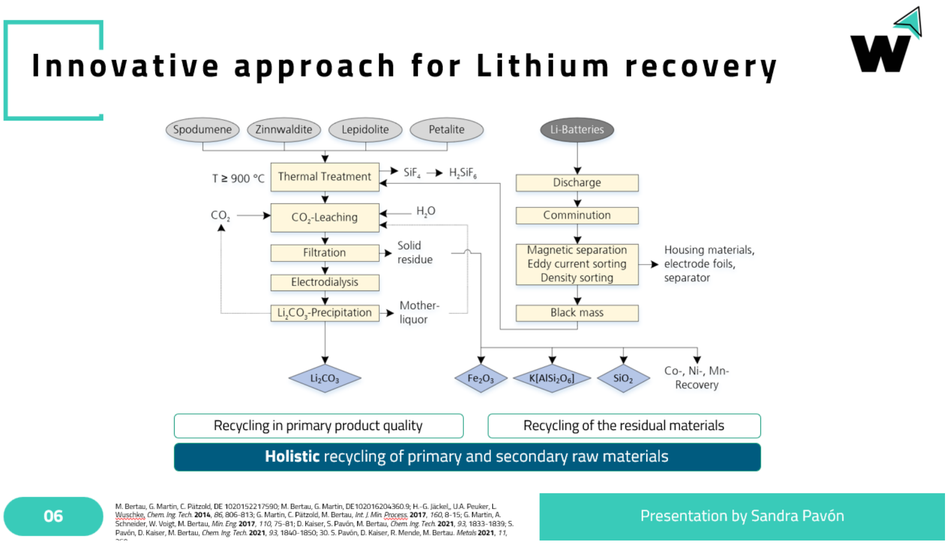

Figure 3: COOL-Process for Lithium selective extraction

This process was patented with lab-scale results and nowadays, Fraunhofer IKTS is carrying out the validation step with a 200 L reactor starting with spodumene as representation of primary sources as well as black mass coming from end-of-life battery – secondary source. These validations experiments are performed within two projects, which are shown in the content of the Block II to demonstrate the robustness of the process since regardless the input material used, Li_2CO_3 is obtained in battery grade quality. The detailed content of the presentation for this approach is depicted in Figure 4:

Figure 4: Block II: COOL-Process - Content

In WP3 has also been defined the dates for transferring this knowledge including seminars as well as the on-side trainings. For the Block II: COOL - Process, the following dates are depicted in Table 2.

Table 2		
Seminar	Hybrid, MS Teams - PowerPoint & Videos-	06.10.2025 from 9 to 10:30h
Training	On-site, Fraunhofer IKTS - Freiberg	06.10.2025 to 10.10.2025

Table 2: Dates for KT from Fraunhofer IKTS to TUKE in Block II: COOL- Process

2.1.3 Block III: Electrochemical approach

Electrochemical processes have been gaining importance and notoriety as an example of technology with a modular approach as an alternative to traditional chemical/thermal swing-based separations. In particular, this technology is being considered as an alternative to be combined with typical hydrometallurgical technologies such as solvent extraction or ion exchange in order to achieve synergies in which the number of stages to separate complex individual feedstocks is reduced, thereby increasing economic efficiency and reducing chemical consumption.

Although most of the published results and research carried out have mainly used this technology as a purification method to obtain final products in metallic form, here Fraunhofer IKTS wants to offer a new vision of these electrochemical techniques in which they can not only be used in the last stages of the value chain but as a technique to recover metals. Therefore, the content of the material to KT has been prepared considering both purposes (CRM recovery and CRM purification) including the differences of these strategies. The detailed content of the presentation for this approach is depicted in Figure 5:

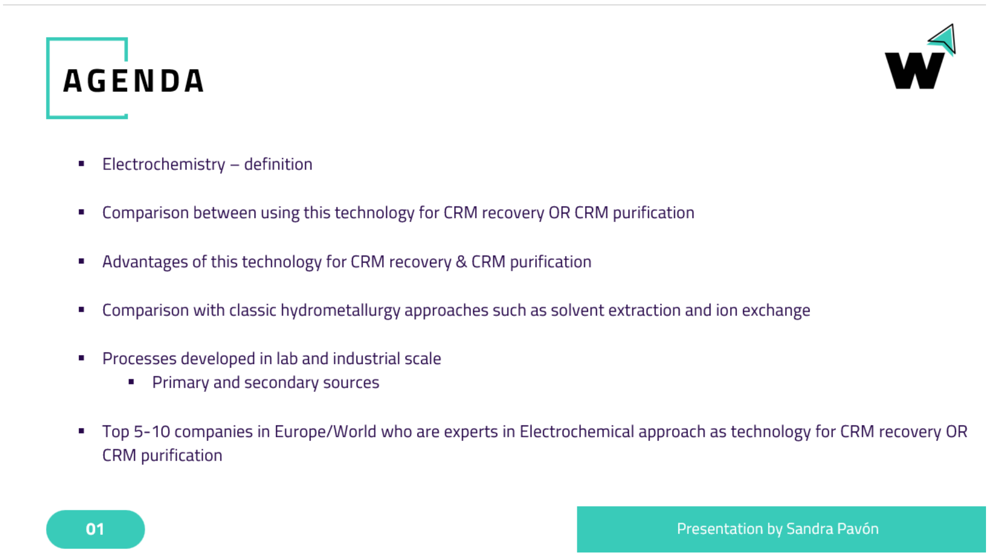

Figure 5: Block III: Electrochemical approach - Content

It has been selected different published processes considering the selected target metals by TUKE relevance. Following the same. interest, the focus lies under REE and battery metals. Hence, the following three process has been chosen for transferring the knowledge of CRM recovery by using electrochemical approaches:

I. Lithium recovery from leachate coming from COOL-Process
II. Recovery of Sm, Co and Cu from spent Sm-Co permanent magnets
III. Recovery of battery metals from black mass

In WP3 has also been defined the dates for transferring this knowledge including seminars as well as the on-side trainings. For the Block III: Electrochemical approach, the following dates are depicted in Table 3.

Table 2		
Seminar	Hybrid, MS-Teams - PowerPoint -	09.10.2025 from 9 to 10:30h
Training	On-site, Fraunhofer IKTS - Freiberg	09.10.2025 to 14.10.2025

Table 3: Dates for KT from Fraunhofer IKTS to TUKE in Block III: Electrochemical approach

Considering that the COOL - Process includes an electrodialysis step (Figure 3), in the training that will take place in October 2025 corresponding to WP6/7 on-site at the Fraunhofer IKTS facility, this knowledge will be transferred in the laboratory considering the whole COOL - Process so that TUKE students will not only see separate technologies but also how they can be combined with each other and make the most of each other's strengths. Furthermore, in this sense not only research knowledge is provided on a laboratory scale but also on a pilot plant scale as the electrodialysis plant reaches a TRL 5 (Figure 6).

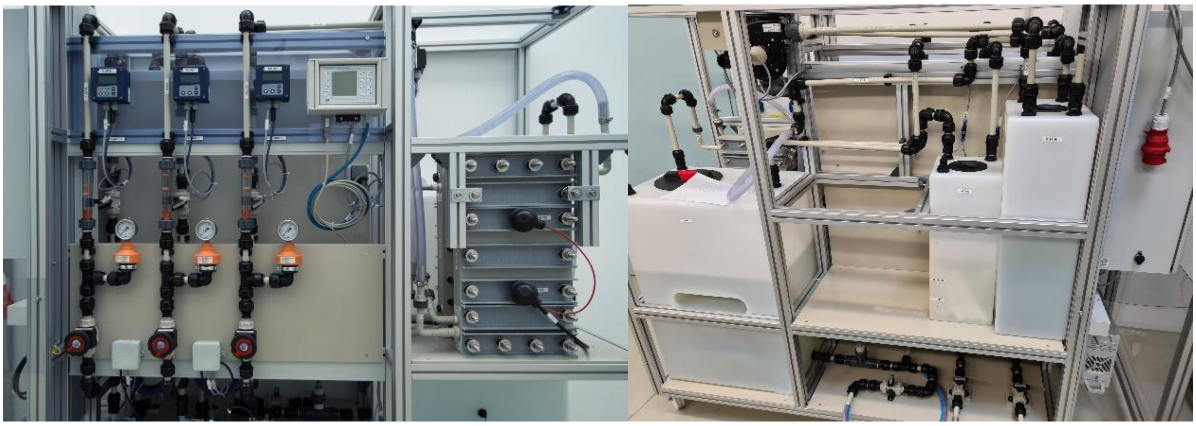

Figure 6: Electrodialysis pilot plant in Fraunhofer IKTS facilities – Freiberg.

2.1.4 Training methodology

The training, which will be performed in mWP6/7, has been designed by Fraunhofer IKTS in two phases (Figure 7):

1) Material (presentations, videos, references, etc.) to be shared ca. one month before the beginning of the on-side training activities.
2) On-side training including seminars and immersion in the technical laboratory IKTS facility. Two TUKE participants will travel to Fraunhofer IKTS facilities in Freiberg, Germany for 2 weeks. During their stay, they will have the opportunity not only to get seminars from the three defined blocks of green technologies for CRM recovery but also for being immerse and learning how to work in a technical laboratory with pilot plants carrying out experiments using these breakdown technologies (solvometallurgy, COOL-Process and electrodialysis/electrowinning).

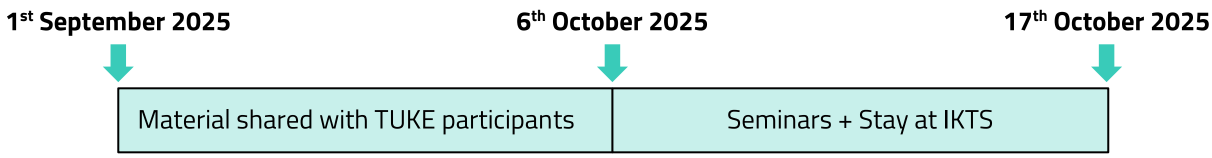

Figure 7: Tentative calendar proposed by IKTS to carry out the training related to CRM recovery using hydrometallurgical processes

2.2 Model, optimisation, and digitalisation knowledge transfer in green technologies

2.3.1. Mathematical modelling and optimisation relevance within WIDEX project

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 (Figure 8).

Models are developed based on key aspects of the process, including the reaction kinetics, equilibrium, and mass transfer, which dictate how a system evolves over time and space. By capturing these mechanisms, the models can simulate a variety of scenarios and guide the processes design and operation. In practice, chemical and hydrometallurgical process models can vary in complexity, ranging from simple steady-state models to more sophisticated time-dependent or spatially resolved models. Some processes are controlled primarily by reaction rates (kinetics), while others are dominated by equilibrium considerations or mass transfer limitations. Additionally, the models may involve different independent variables, such as time or spatial coordinates, depending on the process under study.

In the development of training material within the WIDEX project, it will be explored how these fundamental concepts are incorporated into various chemical processes, from reactors to separation units. Each section will delve into specific process models, presenting both the underlying mathematical framework and examples of real applications. Additionally, it the material will provide a comprehensive introduction to the modelling and simulation of chemical and hydrometallurgical processes using Python, which is introduced as a key tool, with a focus on scientific libraries like NumPy, SciPy, Matplotlib, and Pandas for equation solving, optimization, and data visualization.

Finally, the material will detail how to structure models in Python using object-oriented programming to integrate and solve individual unit models, enabling an integrated simulation of the entire process.

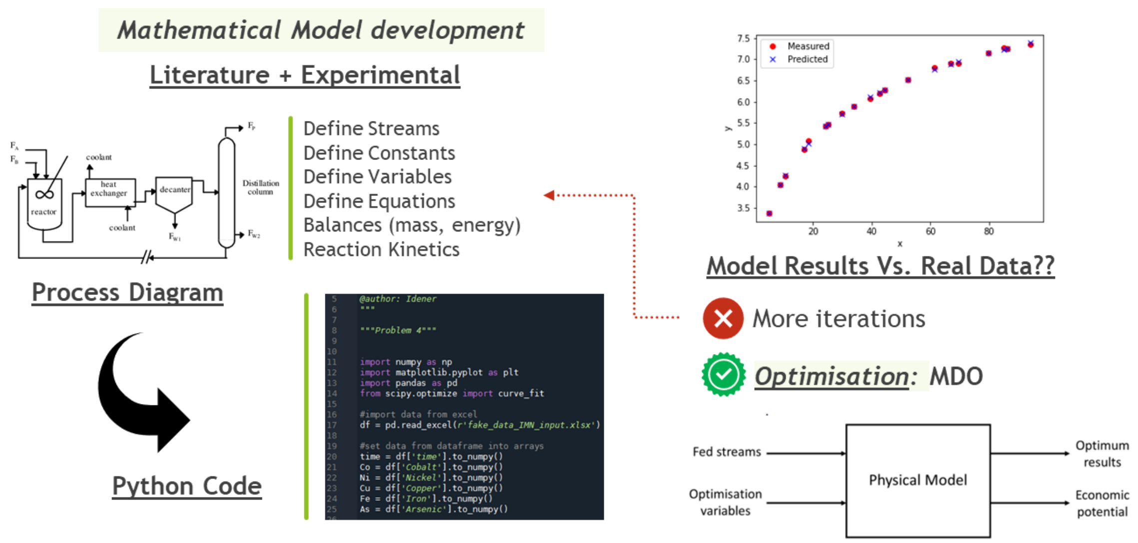

Figure 8: Schematic workflow of the principles of mathematical modelling and implementation for optimization to be transmitted during the trainings in the WIDEX project.

2.3.2. Survey among TUKE's participants prior to material development.

In the framework of the WIDEX project, IDENER team launched an internal questionnaire shared with TUKE's team, to prepare the material in the most adapted way to their expertise and interests. The questionnaire gathered information mainly related to the academic profile of the participants, areas of interest and previous experience with mathematical modelling and programming languages. The results from the 10 participants revealed a major interest in processes related to hydrometallurgy such as leaching, solution refining, precipitation, etc. (Figure 9). Additionally, these are also the most interesting areas, from the participants' point of view, to be modelled. The potential candidates for the training leaded by IDENER present a very high qualification, as PhD holders or candidates. Nevertheless, their experience with mathematical models or programming is more limited: only two candidates have experience modelling chemical processes, which resulted to be very concrete and with very specific and dedicated software (e.g. CFD Modelling with Ansys software for zinc evaporation). In terms of programming languages, the scenario seems to be very similar: only two candidates had previous experience programming, having attended to crash courses of python or C++, specifically dedicated to Arduino controlling. Therefore, after analysing the results, the knowledge transfer opportunity visualized in the WIDEX project becomes increasingly important due to two key factors: i) the interest and relevance of the proposed topics to be modelled for TUKE candidates and ii) the great margin of skills improvement during and after the trainings.

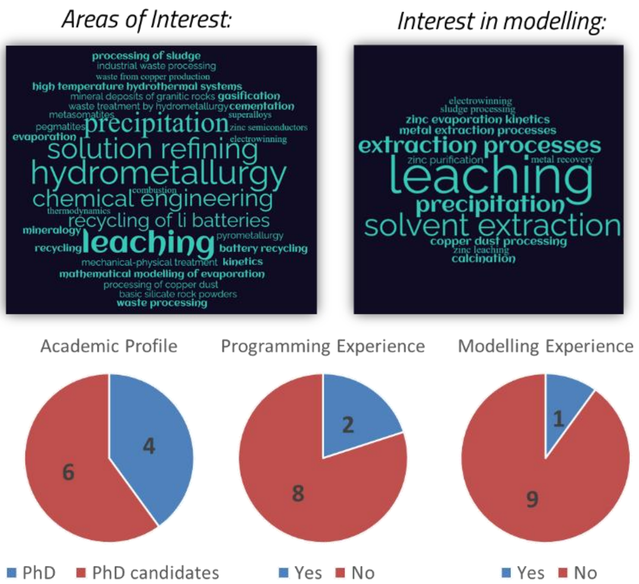

Figure 9: Results of the questionnaire distributed by IDENER to TUKE personnel. The "Tag Cloud" pictures highlight the most representative areas of interest and the preferences in modelling. Below, results of the academic profile, programming experience and modelling experience are shown.

2.3.3. Modules and Contents for the trainings.

The prepared material will be divided in 3 different modules, attending to the specifics needs reflected in the questionnaire distributed:

Module I: Mathematical Models of Individual Units.

The first module includes theoretical information regarding individual chemical engineering processes highly related to hydrometallurgy. This selection has been done considering the preferences of TUKE participants and also the experimental training to be carried out under IKTS supervision, in order to complement it and deepen in their knowledge.

1. Introduction to mathematical modelling for chemical engineering processes.
2. Leaching.
3. Bioleaching.
4. Solvent extraction (column).
5. Solvent extraction (mixer-settler).
6. Chemical precipitation.
7. Size reduction.
8. Membrane separation.
9. Chemical reactor.
10. Adsorption.
11. Flotation.
12. Process economics.
    12.1. Net Present Value (NPV).
    12.2. Internal Rate of Return (IRR).
    12.3. Payback (PB).
    12.4. Return on investment (ROI).
13. Process optimization.

For every individual process (Nr.2 – Nr.11), it will be included a description, model definition, mass transfer, mass balance, assumptions, boundary conditions, kinetics, equilibriums, etc.

Module II: Process modelling in Python.

This module is designed to equip TUKE personnel with essential Python tools and methods specifically tailored for modelling chemical and metallurgical processes. Beginning with an Introduction to Python, participants will set up their development environment and access resources, forming a solid base for the training. The module then delves into Key Python Libraries crucial for handling scientific data: NumPy for numerical computations, Pandas for managing and manipulating datasets, SciPy for advanced mathematical functions, and Matplotlib for effective data visualization. To address the mathematical backbone of process simulations, techniques for solving linear and nonlinear equations as well as differential equations are explained, which commonly represent reaction kinetics and process dynamics. This module also covers Models' Integration, emphasizing the importance of modular coding to link unit models into a cohesive process. Finally, Post-Processing and Data Visualization provides essential tools for analysing, visualizing, and exporting results, ensuring clarity and professionalism in data presentation. Below is a breakdown of the contents covered in this module:

1. Introduction to Python
    1.1. Working with Python: development environment
    1.2. Helpful material for Python Introduction
2. Key Python Libraries for Process Modelling
    2.1. NumPy
    2.2. Pandas
    2.3. SciPy
    2.4. Matplotlib
3. Mathematical Methods for Process Simulation
    3.1. Solving Linear Equations Using linalg in NumPy
    3.2. Solving Nonlinear Equations Using fsolve from SciPy
    3.3. Solving Differential Equations Using odeint from SciPy
    3.4. Solving Differential Equations Using Discretization
4. Models' integration
5. Post-Processing and Data Visualization
    5.1. Data Cleaning and Transformation with Pandas
    5.2. Exporting Data to Excel Files
    5.3. Customizing Plots for Reporting

Module III: Real Case Study.

The last module will treat the IKTS COOL+ process. It will serve to give the participants an overview of modelling a complete process and learn, step by step, the previous information provided in Modules I and II.

2.3.4. Training methodology.

The training has been designed in three phases (Figure 10):

1) Material to be shared 1 month before the beginning of the training activities. This material will be composed of a guideline or manual with all the necessary content for the course: text, videos, model examples, references, etc.
2) Online sessions: During the first two weeks of the training, two online sessions will be maintained with TUKE participants. In those sessions, the most important aspects of the previously distributed material will be explained in detail. Additionally, there will be an opportunity for a first interaction for questions and answers. These sessions will be held in a teleconference platform (e.g. MS Teams) and the information will be transmitted by a presentation (e.g. MS Power Point).
3) Finally, two TUKE participants will travel to IDENER facilities in Seville, Spain, for 2 weeks. During their stay, they will have the opportunity to treat the material more in detail with IDENER staff as well as starting their own projects. The knowledge acquired during the previous 45 days will be put in practise during these two weeks, counting on the support of IDENER experts to implement the basics in real case scenarios. These abilities will result essential for a better comprehension of the processes to be treated at IKTS facilities.

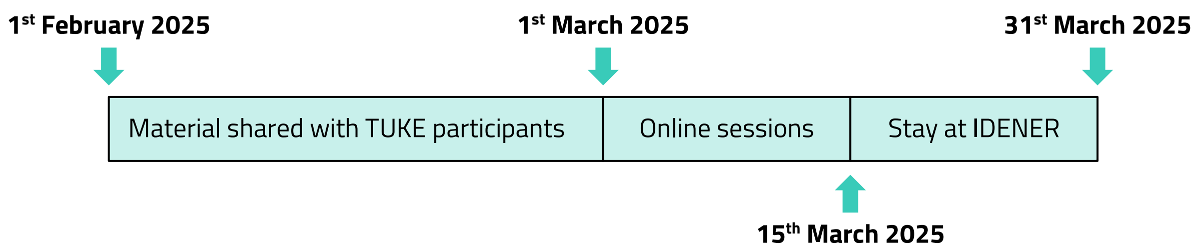

Figure 10: Tentative calendar proposed by IDENER to carry out the training related to mathematical modelling of chemical processes and optimization.

3. KT in Green and non-invasive Technology for CRM mining monitoring

Lapland UAS, in collaboration with ISMC and ICAMCYL, developed a virtual mining environment where users can experience the mining tunnel environment in real scale and perform tasks related to the tunnel excavation process known as drifting. The virtual environment purpose is supporting the TUKE training and provide users with a visually realistic mining environment. The monitoring mining operations perspective has been incorporated, particularly in the context of the reinforcing task.

3.1. Background

Lapland University of Applied Sciences (Lapland UAS) has prior experience with mining-related projects spanning several years. Earlier implementations have primarily focused on training students in the mining field. In the Kaivi project, a multi-user environment was developed where mining students were able to manage the mining processes collaboratively. The Migael project, on the other hand, was a scenario-based mining education program implemented across multiple platforms including VR, smarpthones and desktop PCs. These projects served as sources for 3D models and audio files for the new VR environment created in WIDEX. They were also considered as fallback training environments in the event of insurmountable obstacles encountered during the development, provided they were translated into English. More information about previous projects by FrostBit Software Lab and Lapland UAS can be found at https://www.frostbit.fi/en/portfolio/.

Figure 11: Still images from the previous VR environments created by Lapland UAS

The acquisition of extensive point cloud and photogrammetry data was a goal set by us to enhance the VR environment developed for TUKE personnel training. The preliminary plan involved creating an interactive miniature model collection based on static environments, where mining monitoring data would be brought into the user's hands alongside text-based information. This plan was chosen because it concretely highlights the continuous measurement and monitoring data in the mining environment and the geospatial accuracy of the visualizations derived from this data. Additionally, it was straightforward to implement, allowing time to ensure the solution's reliability and user-friendliness.

To obtain the laser scanning and photogrammetry data, we contacted consortium partners and Lapland UAS's own network. The acquisition of the required data within the time limit of the project proved insurmountable, so the focus was shifted toward 3D-modelled environments. The VR environment visualization was scaled down, focusing on the strengths of VR technology, namely immersion, authentic perspective, and interactivity through handheld controllers. Unlike traditional visualization methods, VR allows the user to become part of the environment, enhancing memory retention and improving spatial understanding of distances and dimensions. The development of a simple VR implementation consisting mainly of static objects was considered feasible within the six-month time frame—a relatively short period in game development. Due to the challenges in acquiring measurement data, the development process shifted from a final-phase testing plan to iterative testing of individual functionalities throughout the development cycle. This approach would also serve to ensure the final product met the quality standards for functionality and usability. As interactive features increased, so did the amount of testing required to ensure effective communication between various systems and components. Building VR implementations specifically requires significant time and especially thorough testing, as the medium is not yet as standardized as traditional desktop solutions where user agency is more restricted. Time and resources have been allocated for additional testing, corrections, and adjustments beyond November 2024.

3.2. User Considerations in VR

The amount of available virtual reality applications has multiplied rapidly as hardware computing power has increased and device prices have dropped. The commercial production of VR games has grown significantly in recent years. Lower hardware costs have also enabled wider adoption of applications designed for educational purposes. There are several ways to present information within VR applications to users that differ from traditional desktop applications. While certain basic principles have become widely adopted over the years, VR has not yet developed universally agreed upon conventions comparable in scale to those for desktop software. One of the biggest challenges is accommodating individual differences in spatial perception and movement, which requires developers to account for various scenarios and find solutions that work for all or at least most users.

Motion sickness is a common issue in VR, and to mitigate this, we chose to implement instantaneous teleportation for movement in this VR environment using teleportation rings. Simultaneously, the user's view is temporarily faded to black to create an association with the passage of time. Fading to black is a familiar effect from movies and shows, and in VR it aids in avoiding abrupt visual changes in front of the user.

Figure 13: Teleportation Rings

Figure 12: VR origin point is represented as footprints, showing the middle point and heading of the configured play area.

The user must be able to move their head and hands freely. This requirement needs to be considered when designing areas to avoid unexpected situations, such as the user clipping through a wall. It is also essential for users to remain aware of the real-world environment to prevent unnecessary injuries or accidents. For this reason, footprints are displayed at the center of the user's play area, indicating both how far they are from the center and the primary viewing direction of the headset. VR headsets manufactured by Valve and Meta include an automatic boundary system that helps users understand their position, but these boundaries are only visible at or beyond the play area's limits. Thus, it is important to have some form of compass or a similar solution within the play area to help users orient themselves in the real world.

Over the years, various user interface (UI) options have been developed for VR, many of which still rely on windows and panels like those in desktop environments. This is a clear and familiar way to present information to users and ensures they recognize it as a distinct game element. Many games and implementations have experimented with a more contextual approach where users interact with the VR environment and make choices primarily through objects and mechanisms (e.g., levers, tools etc.) without the aid of UI. However, since the primary users of this implementation are not expected to have extensive experience with VR environments, a contextual approach was deemed unsuitable. Instead, the user is accompanied by a floating panel that displays necessary information and allows interaction through buttons.

The placement of UI elements in VR environments is often an iterative process aimed at maximizing usability. We tested various ways to present information to the user, making sure that the window would not obstruct their view while remaining easy to locate. We settled on a solution where a question mark icon is positioned to the user's left. Looking at this icon opens a window displaying the desired information. The window can also be minimized if it obstructs the user's view. The window is rendered on top of world objects, even if it is spatially within or behind them. This approach was chosen because much of the user's activity occurs close to tunnel walls, making it difficult and cumbersome to read the UI at such close distances. A significant portion of individuals using a VR environment for the first time find using the physical VR controllers challenging. This is because the view of their hands and controllers is blocked, and the controllers themselves are unfamiliar in shape, particularly in terms of button layout. To simplify the use of controllers, 3D models of the controllers have been incorporated into the VR environment, allowing users to visualize the shape of the controllers and the positions of the buttons they are holding. The buttons are color-coded to make them easy to distinguish from the controllers and from each other. Additionally, hovering text connected by strings to the buttons indicates their functions.

Figure 15: Info panel that follows the user and guides them through the environment. Colour highlights correspond to VR controller buttons.

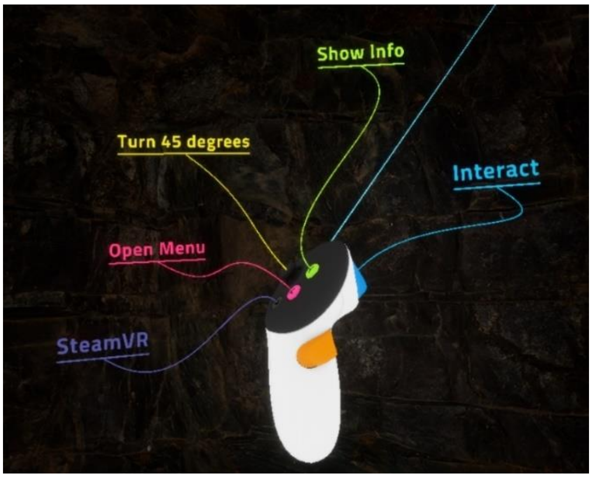

Figure 14: Thread labels display currently available controls.

3.3. Development Process

3.3.1 Project Management of the VR environment

Meetings for WP3.3 participants were held approximately once a month to review the current state of the VR environment and to evaluate viable solutions. These meetings included personnel from Lapland UAS, ISMC, and ICAMCYL. Representatives from TUKE were also invited from time to time. These meetings were conducted via Teams.

FrostBit, the software laboratory operating under Lapland UAS, utilizes Microsoft's Azure DevOps platform, providing comprehensive tools for agile methodologies. Weekly sprints were organized among the project team members to monitor progress and task status. Internal communication within the development team primarily used the Teams platform. Weekly meetings were held via Teams, with additional in-person meetings organized as needed and were easy to arrange because all team members worked on the same campus.

Version control is a critical aspect of software development. The project utilized project repositories hosted on Azure DevOps servers and accessed through GitHub Desktop—a user-friendly and reliable visual interface for git version control. Two repositories were created for the project: a primary project repository that contains the environment and game engine files, and a separate art repository for storing and sharing graphic and 3D model source files. Keeping these repositories separate was practical, as only artists required the large source files. The art files for primary project repository and game engine were limited to finalized models and textures intended for user presentation.

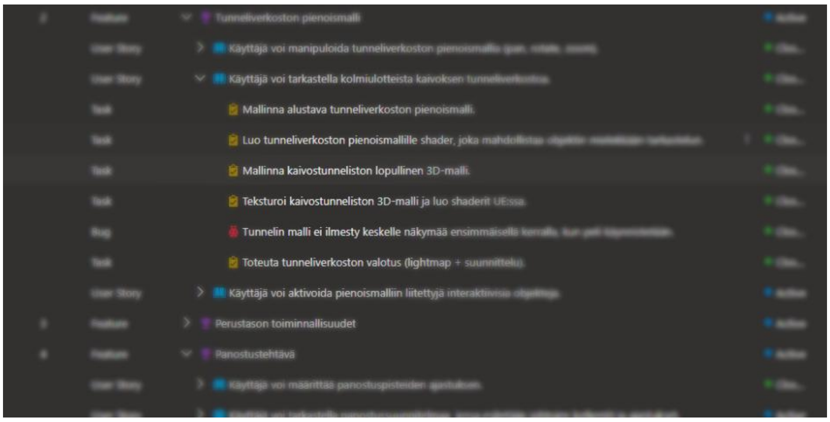

Figure 16: Backlog section of the Azure DevOps environment.

3.3.2 Game Engine and Platform Selection

The implementation of the VR environment began by attempting to gather the necessary materials with the help of project partners. The goal was to leverage existing point cloud and photogrammetry data to enable the examination of real-world measurement data in a VR environment, where the user could interact with the environment as if it were a physical scale model.

Simultaneously, the development for the core components of the VR project was initiated. A desktop VR platform was chosen, as it supports hardware from Meta (formerly Oculus) and Valve, the most popular brands in the market currently. Other devices utilizing SteamVR and OpenXR services are also expected to function well. Another critical reason for selecting desktop VR was the computational power it offers. A desktop computer's processing and rendering capabilities for game objects and code far exceed the internal computing power of devices like Meta Quest 3. Maximizing computational power and optimizing game performance are particularly important in VR applications, as the headset renders two separate images dozens of times per second to achieve stereoscopic vision. While standard desktop applications typically refresh at 60 frames per second, VR headsets require 90 frames per second per lens, basically tripling the required frame output.

The game engine selected for this VR environment is Unreal Engine 5 (UE5). UE5 was chosen due to its exceptional visual quality, a key criterion for virtual scale models. A secondary consideration was UE5's robust and user-friendly, albeit basic, VR template, which could be expanded with existing solutions previously created by Lapland UAS.

Unreal Engine employs Nanite and Lumen technologies to maximize graphical quality. Lumen provides real-time lighting calculations, which were intended to enhance the project's visual quality. While Lumen has long been a viable light computation system for desktop applications, it has been too resource-intensive for large and complex environments in VR. The implementation of this project began with Lumen and Nanite, but performance optimization necessitated a shift to traditional precomputed lighting. Similarly, ultra-detailed surface models were abandoned to boost performance, as the detailed geometric shapes were not required without real-time lighting.

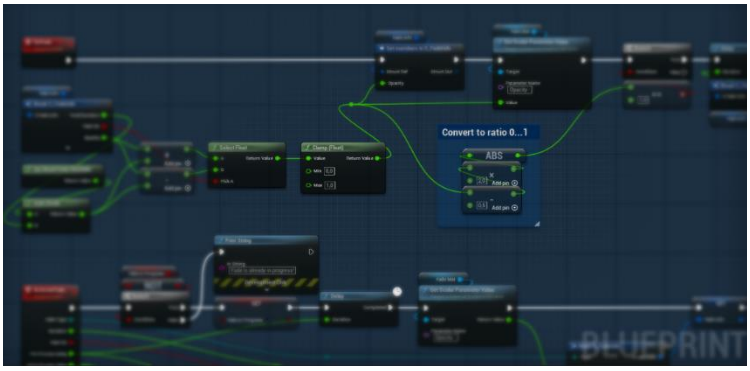

Figure 17: Blueprint coding environment. The blueprint in question is part of the fading process that blocks the user's view.

Unreal Engine offers two methods for implementing executable software code: the C++ programming language and Blueprint scripting. C++ is widely used in the fields of computer science and game development and is valued for its efficiency and extensive libraries. Blueprint scripting, on the other hand, is a visual, node-based programming method integrated into the game engine. Blueprint scripting utilizes a layer of and is built with C++, presenting the user with a visual coding environment. The WIDEX VR project utilizes Blueprint scripting, as the project team did not have advanced C++ expertise. Moreover, the project was not technically complex or demanding enough to require the highly optimized code structure and performance that C++ could provide. The main performance challenges were related to VR rendering and graphical quality rather than code efficiency.

3.3.3 Software Development and Testing

Game development requires the combined input from various specialists, each with expertise in specific areas. Software developers build the core structure and functional components of the game. Graphic designers and graphical artists define and create user interfaces and other visual elements. Modelers and 3D artists are responsible for creating objects and landscapes for the game environment. Larger projects often involve additional specialized roles requiring dedicated teams, but in smaller projects, these tasks are typically handled by the aforementioned programmers, modellers and graphical artists. Such roles include sound design experts, technical artists, environmental and lighting artists, game designers, and testers.

Testing of game environments and functionalities in commercial products is typically conducted by professional testers. Numerous companies specialize exclusively in game testing and quality assurance, offering their services to game developers. In smaller public projects and particularly in prototype development testing is often carried out internally by the development team. Subsequently, the product is handed over to the client for further testing. Based on client feedback, the product is modified, and previously unnoticed errors are corrected. This iterative process aims to maximize both customer satisfaction and functional reliability of the product. Lapland UAS has allocated time and resources for testing the VR environment and implementing fixes and changes based on the findings. Feedback from TUKE and consortium members regarding the software is an integral part of this process.

3.4. VR Environment Content and Functionalities

3.4.1 Core Functionalities

The first step in implementing the VR environment was building its core functionalities. Specific component names are written in italics.

Opening and Closing Levels

Every game and virtual environment contains at least one level, also known as a scene. In Unreal Engine, levels can be loaded in two different ways. The traditional method loads one level at a time, removing the previous one from memory at the same time. While this allows for seamless transitions between levels and is a reliable way to handle levels, changes to the previous level are lost unless saved in a *SaveGame* object. Another downside is the duplication of data; loading and unloading levels is inefficient if each level is a copy of another save for one or two objects. The second method is additive loading, which allows multiple levels to exist simultaneously. In this case, objects from different levels can interact with each other. This method, called Level Streaming in Unreal Engine, was chosen for this project.

Level Streaming enables the player and other critical objects to be created once and preserved across levels. By placing critical objects in their own level, other levels can be loaded on top of it without recreating them during transitions. This simplifies data transfer between levels and enables the use of a *GameManager* object for storing information, tracking execution states, and managing references within the VR environment.

Blocking the User's Vision During Content Loading and Unloading

To avoid motion sickness from user movement, teleportation and screen fading techniques were implemented. Fading to black is utilized during level loading and unloading, as it prevents the visually jarring real-time appearance and disappearance of tunnel textures and models.

A solution for fading the user's view was achieved by placing an oval-shaped object in front of the *VRPawn* camera. This object has a material with adjustable transparency, allowing for controlled fading to and from black. Commands for animating the fade effect were integrated into the *VRPawn*, which also notifies other systems on process start and end. For instance, level transitions only occur when the user's view is fully obscured, and the process to fade from black is initiated after all required levels have been successfully loaded.

Interacting with UI components

UI elements in traditional desktop applications and games are typically fixed to the screen. In VR, UI cannot be screen-bound due to different perspectives rendered for each eye. Instead, the *Widget* component enables UI elements to be displayed within the game world on floating panels. Adjusting the position, orientation, and size of these panels allows users to interact with buttons and access information by pointing at them.

To assist the user in navigating the VR environment, an info panel displaying instructions and information was introduced. This panel is attached to the user's left-hand position and is given an offset that keeps it in the peripheral view for easy access. Although primarily designed for the left controller, users may occasionally need the right controller to activate buttons.

Various approaches for presenting the UI were tested during development. Positioning the info panel in a predefined location worked well in some situations but proved inconvenient for tasks in the tunnel environment. Alternatively, anchoring the panel to the user's view made it difficult to focus on by turning their head. Ultimately, an arrangement where the panel is represented by a smaller icon when not focused on was chosen.

Background sounds and UI audio

Sound sources were added to the VR environment to create a realistic tunnel ambiance and enhance immersion. Audio feedback was also integrated into the UI panel and buttons, providing immediate confirmation for user actions. Different audio cues were selected for different situations. For example, teleporting plays a sound effect that suggests a rush of air, while toggling through the timing presets of a blasting cap sounds digital.

Interactions with objects in the environment

Interaction between the user and the environment is a fundamental part of any VR experience. An *Interactable* class was designed to serve as the base class for all interactive 3D objects, such as teleportation rings and blasting caps. VR controllers' laser pointers were linked to interaction mechanics and programmed to change colour when pointed at with a laser depending on whether the target object was interactive.

Main Menu and Pause Menu

The main menu serves to start and exit the game, adjust rendering settings, and display information about WIDEX. The pause menu allows users to switch between levels or return to the main menu. Initially, the pause menu appeared as a floating UI panel but was later implemented as a separate level to prevent overlapping with interactive objects in the environment.

3.4.2 Miniature Environment

The miniature environment's code was initially designed for inspecting photogrammetry and point cloud models from various angles, both inside and out. Due to challenges in acquiring the material, the focus for the miniature map was instead changed to a simplified 3D model of a mine tunnel. Users can view this model from different perspectives and scale it, while transition objects in the environment act as gateways to individual tasks and are displayed as glowing rings in separate layers of the tunnel network.

The controls for the miniature environment were designed to be as simple and easy to use as possible. There are no established standards for manipulating miniatures in VR, so examples were explored from other platforms for control systems that could potentially be adapted to a VR environment. Eventually, the solution chosen involved controlling the model much like the way touchscreen functions work in map applications. A popular example of such functionality is Google Maps, where dragging one finger across the screen pans the image, rotating with two fingers turns it, and changing the distance between the two fingers alters the scale. Instead of fingers, the user's VR controllers handle the changes to the view. The environment can be moved using the grip button on one VR controller. The relative position of the controllers determines the orientation of the environment and the distance between them adjusts the scale when both controllers' grip buttons are held.

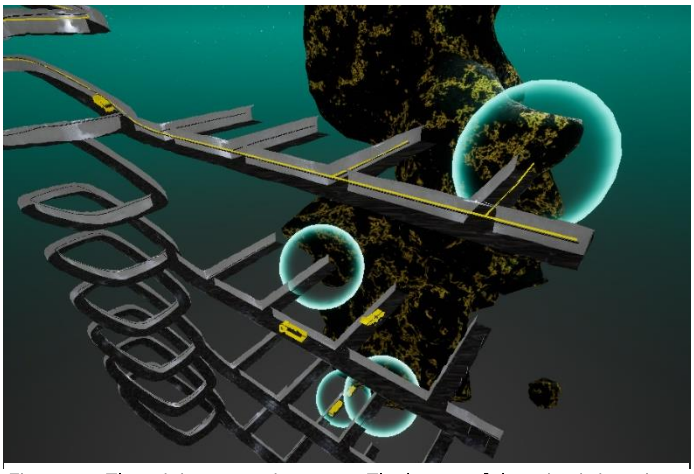

Figure 18: The miniature environment. The layout of the mine is imaginary and serves as an example.

3.4.3 Tunnel Environment

Level Streaming was utilized for designing the tunnel environment, enabling one base level and multiple task-specific levels to coexist. This facilitated parallel work by different developers and minimized conflicts in version control by allowing them to focus on different levels at the same time. Git can handle simultaneous edits to a single text file, but as level data in game engines is typically stored in binary format, the data cannot be parsed together resulting in a conflict. The tunnel environment works as a backdrop for individual task levels. The four drifting process phases selected for this VR

Figure 19: Base level of the tunnel environment. All tasks use this level as their backdrop and add objects on top of it.

environment are marking, charging, blasting, and reinforcement. The blasting task doesn't contain much interaction and was included to emphasize safety aspect.

3.4.4 Marking Task

The marking task is a critical step in the drifting process, as incorrectly placed relief holes can result in incomplete or faulty rock fragmentation, which can result in a cave-in. During the planning phase, placing the user inside the drilling rig cabin was considered. However, because the system is largely automated and such placement would not help the user understand the importance of relief hole positioning, it was decided to place the user in front of the drift end with a tablet and a spray paint can. The user's task is to mark the correct locations of the relief holes for drilling. The margin for error in marking is relatively small, requiring the user to carefully examine both the drill plan on the tablet and the wall's shapes and textures to locate the correct positions. The user is given six attempts to mark the holes to ensure the task does not feel excessively difficult.

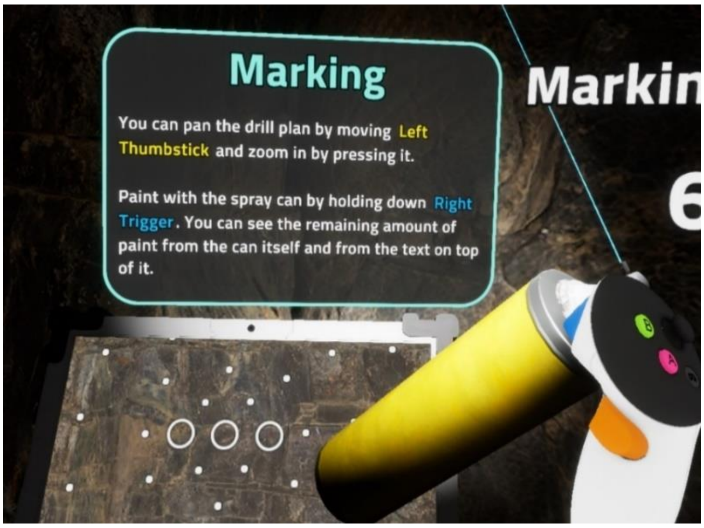

Figure 20: Marking task provides the user with a spray can and a tablet.

The painting function was implemented by applying a material with a *RenderTarget* texture to the 3D model of the tunnel face. This *RenderTarget* receives data from the spray can whenever the user presses the trigger on the right-hand controller. The spray can use an invisible ray to measure the distance to and location of the drift end's 3D model. When the ray intersects the model's surface it calculates the impact point's position in the surface's UV coordinate system and marks a slightly lighter spot on the *RenderTarget* texture. Practically, the render target acts as a mask between two different surface shaders, displaying the marked spot as yellow paint instead of the rock texture. Simultaneously, the spray measures the distance between the impact point and the invisible relief hole points. The spray then generates feedback indicating whether the user created the mark close enough to the correct relief hole location.

After completing the task, an info panel displays the number of remaining attempts and notifies the user whether the task was successfully completed. The panel draws the user's attention with a sound and appears regardless of whether the user previously closed it. The user is presented with a "Restart" button to reset the task for another attempt and a "Map" button to return to the miniature environment. These buttons are displayed at the end of every task.

3.4.5 Charging Task

The charging phase follows the drilling phase, during which the holes are filled with explosive emulsion, and blasting caps are placed at their ends. Each cap must be precisely timed to ensure the fragmented rock moves toward the relief holes. Incorrect timing can, much like the relief hole locations themselves, cause unpredictable fractures in the wrong direction.

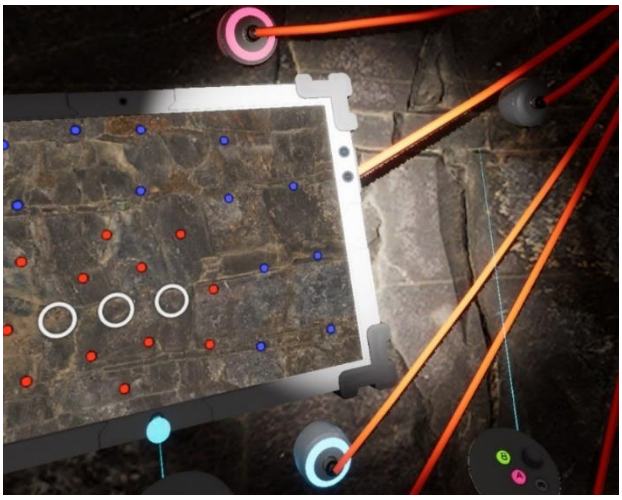

Figure 21: Charging task uses the same tablet and displays the correct colours for the caps.

During the task, the user sees a tablet in their left hand, which displays the relief holes and surrounding blasting caps in three colours, representing the delays between detonation initiation and individual explosions. The red zone is closest to the relief holes and detonates first, followed by the blue zone, and finally the yellow zone on the tunnel edges. The user's task is to ensure that the timers (colours) of the blasting caps on the wall match the plan displayed on the tablet. The VR implementation simplifies the timers and levels of adjustment compared to real-life procedures, as the primary objective is to help the user understand the relationship between relief hole distances and timer settings. The blasting caps were implemented by inheriting from the *Interactable* class. Each cap was assigned a target colour, and the 3D model was given a material instance to allow individual colour changes. Initially, each cap is set to its target colour, but before starting the task, and whenever the task is reset, the colours of 15 caps are randomly turned off. Using a laser pointer and trigger, the user cycles through colours (red, blue, yellow, and back to red) for the selected cap. The user must identify all 15 uncoloured caps on the rock face and set the correct timer for each.

3.4.6 Blasting Task

Virtual reality enables users to experience environments that would be life-threatening in real life. The blasting task was added to the project to emphasize the importance of safety during blasting operations by presenting a scenario where a blast propels rock debris far into the tunnel. This task differs significantly from the real-life blasting procedure, where personnel vacate the site before detonation. The drift end blasting was implemented using Unreal Engine's Chaos system, a physics engine for destructible objects. A block of rock was modelled as the drift end and fragmented using in-engine calculations. The resulting fragments were simulated with physics and cached for playback during the task, eliminating the need for real-time calculations. This task does not involve scoring or performance evaluation, as the only input from the user is initiating the blast itself.

3.4.7 Reinforcing Task

The walls and ceiling of the tunnel must be reinforced to prevent loose rock and collapses. Large bolts and steel mesh are concealed beneath the shotcrete surface, making the amount of reinforcement and the work required to anchor them less apparent. In this task, the user is given the ability to view inside the sprayed shotcrete layer using an X-ray-style effect and to manually apply shotcrete to a section of a freshly blasted, ventilated, scaled, and meshed tunnel using a shotcrete sprayer. The task provides a tangible understanding of the amount of steel and work beneath the finished shotcrete surface. The user also observes the shotcrete layer's thickness and can infer its adequacy based on surface coloration, which transitions from green (optimal thickness) to yellow and finally red (excessive thickness). For enhanced immersion, memory retention, and engagement, the spraying is performed manually rather than by an automated sprayer, despite the process being largely automated in real life.

The shotcrete spraying was implemented by modifying the spray paint code. The receiving material was adjusted to change its surface position relative to the surface normal in the world space, pushing outward in the direction the surface already faces. Instead of yellow spray paint, the *RenderTarget* serves as a mask between rock and shotcrete textures. This task does not involve scoring or performance evaluation.

Figure 22: The user can view the structures inside the walls with their left controller.

CONCLUSIONS

In this Deliverable 3.1 has been depicted and explained how the different material, which will be used in work package 6/7 for knowledge transfer has been prepared by the different partners involved in work package 3. The type of training and education provided has a direct correlation to the kind of knowledge which will be transferred to TUKE for CRM deposit exploration, CRM recovery as well as for CRM mining monitoring. As expected, in KT in Green and non-invasive Technology for CRM deposit exploration the involved of industry partners is crucial. Therefore, according to the necessities of TUKE, the Geophysical methodologies as well as the different digital modern techniques were on focus. For getting more experience by working in technical scale laboratories by including the optimization of processes using digital approaches, the training on-site is crucial. Thus, the KT in Green and non-invasive Technology for recovery of European CRM is planned to be a combination of online/hybrid seminars as well as on-side trainings in IKTS and IDENER facilities. The material for the KT in Green and non-invasive Technology for CRM mining monitoring has been prepared using the gamification as the main tool for such transfer.