Institute of Mineral Resources Engineering

RWTH AACHEN UNIVERSITY

Abstract Volume

1st European Conference on

TEaching and Research in Sustainable Resource ExtrAction

(TERRA 2023)

Abstracts of the 1st European Conference on TEaching and Research in Sustainable Resource ExtrAction (TERRA)
6-9 September 2023, Boppard, Germany

Available via the institutional repository of RWTH Aachen University:
DOI: 10.18154/RWTH-2023-08124

Publisher & Editor
Prof. Dr. Bernd Georg Lottermoser
Institute of Mineral Resources Engineering
RWTH Aachen University
Wüllnerstraße 2
D-52062 Aachen, Germany
Phone: +49 (0) 241 / 8097976
E-Mail: info@mre.rwth-aachen.de
Internet: www.mre.rwth-aachen.de

Table of contents

ORAL PRESENTATIONS - *Current research activities in mining and related disciplines*

POSTERS

KEYNOTES - *Educating mining students for the 21st century*

The social licence to operate as a learning outcome in mineral and resource engineering education

Anne Johnson

Queen's University, Kingston, Canada

Since the late twentieth century, the number of stakeholders for mineral development projects has expanded as the general public, non-governmental organizations, and the investment community have become aware of the cumulative environmental risks of industrial activity. In addition, impacted communities have effectively communicated their concerns to a global audience that is now alert to the often continuing injustices of colonization: with the ratification of the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) and legislation protecting customary and indigenous title in many mining jurisdictions, exploration and development of mineral projects is more complex than ever before. While technical innovation in the metals and minerals sector has yielded cleaner and more efficient production, safer workplaces, and the ability to economically process marginal ore bodies, the policy and social challenges remain challenging. Mining schools have embraced new technical areas, such as AI and automation, but few schools have managed to integrate the social component of sustainability into their curricula, even as this dimension of project development is the key to providing minerals for the energy transition. As the concept of "responsible extraction" evolves, mining schools need to readjust their curricula to ensure that graduates are equipped to manage projects from exploration through to closure within a landscape of diverse perspectives and values. Where do we begin?

Reimaging mining education: putting students at the core

Claudia Mueller

York University, Toronto, Canada

Canada's mining industry is experiencing a talent shortage. Over the next few years, a significant number of the aging Canadian mining workforce will be retiring. In addition, the global move to a low carbon economy paired with Canada's critical minerals strategy are expected to increase the demand for diverse talent throughout the industry. Low recruitment rates suggest that the industry is not on pace to replace exiting employees or meet the rising labor demand. Similarly, the talent shortage is reflected in low enrolments in academic institutions. Enrolment numbers for mining focused university programs have been steadily declining, resulting in mining program closures and contractions. Globally, many of the established mining nations are experiencing similar challenges, both in industry and academia. Often, mining's negative perception and resulting image problem are discussed as the reasons for the talent shortage. Thus, many initiatives focus on sharing a more balanced picture of the industry's impact, including an emphasis on the importance of its contributions to a greener future. A different complimentary way to attract younger generations to work in the mining industry, is to focus on better understanding their values and ambitions. For university students, the choice of program is based on many factors such as personal interests, advice from family and teachers and natural ability. Existing research has provided a foundational knowledge level of students' values and ambitions that further underpin these decisions. This presents an opportunity for academics and academic institutions to rethink our approach to education. By putting students' values and ambitions at the core of the development and delivery of programs and curricula we can achieve collaborative, experiential, engaging, and dynamic programs that allow students to explore their interests across various fields of study. Many links to metals and minerals may be discovered through this new format, opening pathways into the mining industry to a previously disengaged pool of students and potential future employees.

ORAL PRESENTATIONS - *Educating mining students for the 21st century*

Minerals engineering: meeting the multidisciplinary challenge

Hylke J. Glass

Camborne School of Mines, University of Exeter, Exeter, UK

With a stable supply of critical metals and minerals forming an important pillar of sustainable development, effective processing of available resources is important. Valuable knowledge is required about interrelated themes which, at the heart of mineral processing, include:

- Technology
  - pre-concentration of coarse ore using sensor-based sorting
  - dry physical separation processes
  - separation performance
  - environmentally-friendly reagents for flotation and hydrometallurgy
  - selective processes for recovery of critical metals
  - bioprocessing
- Process design
  - energy efficiency of comminution processes
  - energy consumption per unit of processed ore
  - flowsheeting for mineral processing
  - recovery of valuable metals from tailings
  - stabilisation of tailings
- Process control
  - representative sampling
  - geometallurgically-informed decision-making
  - plant capacity utilisation
  - metal accounting

This paper discusses how minerals engineering can continue to fulfil an important role into the future.

Exploring the link between employer needs, employability and postgraduate module design in a contemporary mining education framework

Benedikt M. Steiner

Camborne School of Mines, University of Exeter, Penryn, UK

Lower metal prices between 2013 and 2018 and the recent global COVID-19 pandemic have resulted in variable industry workforce numbers and started a discussion and review of the link between employer and workforce needs, graduate skill sets, and postgraduate module design in mining education. Relating student satisfaction and employability to contemporary teaching practices is a key factor, driving the current UK Teaching Excellency Framework (TEF). Geoscientific, project management, and operational logistics-related skill sets are reviewed and put into context with industry employability rates and strategies as well as research-inspired teaching philosophies in Geoscience Higher Education, and exemplified by a case study outlining the development of a new module on the MSc Exploration Geology progamme at Camborne School of Mines, University of Exeter.

Engineers in the mining industry are not just engineers, they are T-Shape professionals

Tony Hand

Tallinn University of Technology, Tallinn, Estonia

The mining industry was once regarded as a sector where change occurred at a glacial pace, the ‘we have always done it this way’ attitude often prevailed to the detriment of progress and profit was the only goal. Thankfully this type of attitude has changed and many mining companies are now leading the field in the adoption of new advances in digitalisation, technology, equipment, stakeholder engagement, health and safety etc. Environmental, social and governance (ESG) represents the 3 main topic areas that companies are incorporating into their daily business activities.

Europe aims to be the first climate-neutral continent in the world by the year 2050. However, this future relies on minerals and metals sourced responsibly and managed sustainably along the full value chain. In addition, mineral exploration and mining face significant challenges around establishing a social license to operate (SLO). The newly introduced Critical Raw Materials Act (CRMA) will require a wide range of skills and talent to achieve the 2050 target. Key to the successful implementation of a climate-neutral Europe and the CRMA will be mining personnel, particularly mining engineers, that can adapt their ways of thinking and work practice that considers the necessary requirements of current and future policies or legislation and stakeholder engagement, to create greater trust and transparency in the mining sector. Simultaneously, engineers must fulfil their primary roles i.e. development and production targets and associated planning and scheduling work. This is where the mining engineer as a T-shape professional is invaluable.

Well trained T-shaped engineers can help deliver on the company's production targets and strategic objectives faster. Companies that provide access to training and education for mining engineers to develop skills in wider roles can enhance their attractiveness for future employees and retain their current ones. The future of mining is T-shaped.

Entrepreneurship program for PhD candidates in the raw materials sector

Veiko Karu

Tallinn University of Technology, Tallinn, Estonia

Our everyday life depends on the raw materials supply. That can be challenging for our industries to have the raw materials to produce the needed equipment for any sector that is important for our societies (security, defence, health care, etc). Therefore, the raw materials sector is continuously searching for new talents for the industry at any level.

For the PhD candidate level, TalTech together with partner universities developed an innovative entrepreneurship program designed specifically for PhD candidates in the raw materials sector. This course program aims to empower and equip aspiring entrepreneurial minded PhD candidates with the necessary skills, knowledge, and resources to navigate the unique challenges and opportunities in this sector, while fostering innovation and sustainable development.

The entrepreneurship program for PhD candidates in the raw materials sector is involving PhD candidates from any discipline because to be successful in the raw material sector, you need to build interdisciplinary teams. For building successful teams we need to educate PhD candidates on key components of entrepreneurship and these skills can be used always also when they are doing their own research for a research project.

Key components of the program include Interdisciplinary Approach (challenges and pains in the industry); Entrepreneurial Skill Development (market fit, the market size for the solution, interviews with potential customers etc); Industry Collaboration (mentorship and incubation); Sustainability and Social Impact (ESG and SDG development goals). These key components are delivered via online course material, summer/autumn/winter schools (a total of three schools) and incubation period after school.

To summarize, this program seeks to drive technological advancements, promote sustainable practices, and unlock the economic potential of mineral resources. It aspires to create a new generation of entrepreneurial leaders who will shape the future of the raw materials industry, driving innovation, economic growth, and environmental stewardship.

Finding raw materials sector technological solutions via full online course: Masters course in circular economy for materials processing

Karin Robam

Tallinn University of Technology, Tallinn, Estonia

Tallinn University of Technology (TalTech), is currently running an online course CircPro for Masters. The aim of the Master's course "Circular economy for Materials Processing" is to give an overview about raw materials processing, i.e from exploration, mining, processing, manufacturing until material recycling and re-use thru the lens of resource efficiency and circular economy.

The course aim is to build knowledge and capacity in state-of-the-art circular economy and resource efficiency practices – in order to ensure that future graduate engineers have the skills to develop more sustainable processes in raw materials value chains. The course contains virtual lectures via the „flipped classroom teaching method“, i.e students learn individually basics of the raw materials value chain.

What are the advantages of an online course? The biggest advantage of an online course is that classroom and study materials are available all day long, seven days a week and you can study any time you want. When completing any online course, you will be learning how to get information via the Internet opens up a world of possibilities for your personal and professional life. The possibilities are practically endless. Generally, most of what we learn in a course is forgotten within a week or two of the end of classes. Having that spark of interest and knowing how to find information online insures that what your learning is always available. The motivation to study in an online course has to come from yourself, we can call it student-centered or active learning, from where the student takes responsibility for the course of studies and matures into an individual for whom learning and accomplishment are highly valued.

This course preparation has been financed by EIT Raw Materials and created by the following Universities and Institute: Aalto University; Lappeenranta University of Technology; KTH Royal Institute of Technology; Mineral and Energy Economy Research Institute of the PAS; Technical University of Košice; University of Trento. Developed into full online course by Tallinn University of Technology.

There are probably many more advantages to online courses, we are living in an ever-changing world. The ability to learn new information whenever you want and wherever you want offers greater opportunities for education than ever before. The reach and knowledge of education broadens to greater horizons that perhaps we can ever imagined. Of course, there would be some disadvantages as well but an online course demands that student develops personal time-management skills, those courses require the self-discipline to set aside chunks of time to complete your studies.

Swedish School of Mines: education, research, and infrastructure

Saeed Chehreh Chelgani

Swedish School of Mines, Lulea University of Technology, Luleå, Sweden

Luleå University of Technology is Sweden's mining university. Swedish School of Mines combines research, education, and infrastructure across the entire value chain of minerals and metals. The world's growing population and climate changes demand new thinking and transition in our society. The need for metals and minerals will increase to cope with this transition. Engineers with relevant skills that cover the entire value chain are required to meet tomorrow's challenges. Within the framework of the Swedish School of Mines, several master's and engineering programs, as well as a new international bachelor's program, are offered. The latter gives students knowledge of the entire value chain in the mining industry and eligibility for in-depth studies within the master's programs. Swedish School of Mines is an initiative to deliver the skills and competence for the whole mining and recycling value chain that the world demands through the green transition. The Swedish School of Mines has played an important role in developing the Swedish mining industry and has produced many highly skilled engineers who have significantly contributed to the field. Today, the school continues to provide high-quality education and research in mining and related fields, and it is considered a leading institution in its field.

Innovative and interactive teaching

Behzad Ghodrati

Luleå University of Technology, Luleå, Sweden

Involving and encouraging student participation in teaching by preparing lectures and presentations can be a valuable learning experience for students. They are young, enthusiastic, energic, and curious to learn new things; therefore, they look for the latest and new resources and references to use in their lectures. But, of course, the basic concepts and fundamental topics, subjects, and issues are better to be thought by the main and experienced teachers. Here are some benefits of involving and encouraging student participation in teaching:

Benefits:

1. Active learning: Preparing lectures and presentations requires students to actively engage with the course material and develop a deeper understanding of the topics.
2. Improved communication skills: Preparing and delivering presentations can help students develop strong communication skills, including public speaking, writing, and critical thinking.
3. Increased confidence: Delivering a lecture or presentation in front of peers, instructors, and classmates can help build confidence and self-esteem.
4. Peer learning: Encouraging students to teach each other can foster a collaborative learning environment and promote peer-to-peer learning.

Tips:

1. Provide guidance: Provide clear guidelines and expectations for the lectures and presentations, including the format, length, and content.
2. Offer support: Provide resources and support to help students prepare their lectures and presentations, such as access to research materials or guidance on effective presentation techniques.
3. Set deadlines: Set clear deadlines for students to submit their lecture or presentation outlines and offer feedback to help them improve their work.
4. Assess and provide feedback: Assess the quality of the lectures and presentations and provide feedback to help students improve their communication and presentation skills.

So, involving and encouraging student participation in teaching by preparing lectures and presentations can be a valuable learning experience for students, promoting active learning, communication skills, confidence, and peer-to-peer learning.

TIMREX – a new MSc programme in the field of mineral exploration

Boglárka Anna Topa[1], Ferenc Mádai[1], Norbert Zajzon[1], Sibila Borojević Šoštarić[2], Gabriela Paszkowska[3], Nils Jansson[4]

[1]University of Miskolc, Miskolc, Hungary
[2]University of Zagreb, Zagreb, Croatia
[3]Wroclaw University of Science and Technology, Wroclaw, Poland
[4]Luleå University of Technology, Luleå, Sweden

Twelve European academic and non-academic partners joined forces to train earth science specialists capable to track and implement modern techniques and up-to-date developments of the raw materials sector within the frame of a new EIT-labelled MSc program called TIMREX. This **T**-Shaped Master Programme for **I**nnovative **M**ineral **R**esource **Ex**ploration offers structured mobility windows and double-degree schemes built on the ongoing master's programmes of the University of Miskolc (Hungary), University of Zagreb, Faculty RGN (Croatia), Wrocław University of Science and Technology (Poland) and Luleå University of Technology (Sweden). The programme is supported by the EIT RawMaterials and received the EIT label in 2022.

Partners of the consortium provide a strong basis for students to get insight into the latest development of innovative raw materials prospecting and exploration methods incorporating their achievements into the training. So, students of the programme will have the possibility to develop boundary-crossing competencies binding classical disciplines of geosciences with innovative mineral exploration technologies in every environmental condition. Meanwhile, entrepreneurial, and socio-civic skills will be also improved to train specialists who can also be a link between the raw materials sector and society. An intensive fieldwork period between the two academic years is also a part of the training, besides students are encouraged to participate in internships offered by the partners.

The first pilot cohort of the program has already launched in September 2022 and students of the second cohort begin their training in September 2023 or in February 2024 depending on the mobility schemes they will choose. In 2023 the first summer fieldwork has been organized in Sweden. Meanwhile, in 2022 and 2023, one-week summer field school opportunities have been also offered by the project for MSc students from Europe.

Creating educational applications that use virtual reality technology - scenarios, training methods, effectiveness studies

Szymon Łagosz

Główny Instytut Górnictwa (Central Mining Institute), Katowice, Poland

Virtual reality (VR) technology has been used in the entertainment industry for many years now, to create immersive environments that allow for a very realistic perception of participation in virtual gaming. For some time now, the benefits of VR have also been recognized by those interested in developing tools for education.

It has been proven time and again that training courses using VR elements can yield better results than traditional training. Compared to traditional teaching methods, such trainings are more attractive, cause greater involvement of the participant in the training process, and above all, thanks to the high intensity of sensations, help to better remember educational content. VR technology makes it possible to enrich training programs with activities in which participants are presented with challenges that would be impossible to apply during practical, traditionally implemented classes. Digitally generated environment creates an opportunity to put trainees in difficult, dangerous situations that require quick and efficient action. Such an approach allows for repeated repetition of procedures and practice of necessary practical skills, without putting participants at risk of losing their health.

Effective use of VR technology requires a methodical and conscious approach, as well as the selection of appropriate content that forms the canvass of the training. This issue becomes particularly important when the main goal of training is to improve the safety of people working under stress, caused by difficult working conditions, emergency situations, at times when incorrect action, or inaction, can lead to catastrophic consequences. As part of the Improving work safety and communication of small work teams using the networked VR environment (SENSE VR) project, an attempt was made to assess the possibility of introducing VR technology into ongoing training programs aimed at representatives of the mining industry.

Mining engineering study cycles at University of Porto – Future expectations based on retrospection of the last twenty years

Maria Cristina Vila, Maria de Lurdes Dinis

University of Porto, Porto, Portugal

The present work analyses the trajectory of those who enrolled in the Mining and Geo-Environmental Engineering programme at the Faculty of Engineering of the University of Porto over the last 20 years. It is then compared with the main socio-economic situations experienced by the extractive sector in the country and Europe, as well as with the reforms experienced by the program in the European context, such as the Bologna process. The results show conflicting trends between the future that is envisaged for the mining industry and the higher education of mining engineers, providing a basis for reflection and defining possible solutions capable of putting higher education and the needs of the industry on a converging path.

In Portugal, rather like in other European Union countries, there is little public awareness of the importance of mineral resources in daily life and in the economy. Therefore, education in Mining Engineering in Portugal faces difficulties in attracting new candidates. There is a great lack of knowledge about Mining Engineering among the population and in the community at the all-school levels, despite some funded projects in the last years invested in the mineral resources literacy of younger groups, especially pre-schoolers, and their families. The possibilities for careers in the field of Mining Engineering are even less considered as the field is not well known or not perceived as attractive. Hence, the number of candidates seeking this scientific area of engineering is small, which makes the number of Mining Engineering students in Portugal also very small. The few students, who enter in Mining Engineering, do so as a second choice, being students with results far from excellence. Nevertheless, the graduates succeed in leaving the university with grades above those with which they entered, motivated, and finding their first job in the mining field with ease.

Acknowledgments: This work was financially supported by: Base Funding - UIDB/04028/2020 and Programmatic Funding - UIDP/04028/2020 of the Research Center for Natural Resources and Environment – CERENA - funded by national funds through the FCT/MCTES (PIDDAC).

Towards sustainable mining: the importance of cooperation projects to boost the training of mining engineers and geologists for the transition to „Sustainability“

Giovanna Antonella Dino

University of Turin, Turin, Italy

Issues such as "Sustainability", "Responsibility", "Eco-compatibility" represent the cornerstones to proceed towards a "wise" management of the georesources: the economic development of countries must go hand in hand with the improvement of environmental, health and social sustainability. In this perspective, the exploitation of the georesources needs to be managed approaching in an interdisciplinary way, that combines the technical, economic and environmental issues, with the social, legislative and human health ones.

In recent years, Europe has promoted several cooperation projects aimed at boosting sustainability in the extractive industry; indeed, in order to achieve and guarantee concrete and truly sustainable mining, stronger and “interdisciplinary” educational and training skills are required. With these objectives in mind, two different EU-Africa Erasmus+ Capacity building projects have been set: the ongoing SUGERE project (which will end on 14th September 2023) and the funded (and nearly ready to start) GEODES one. Objectives of these projects are the implementation of bachelor, master and doctoral curricula in geology and mining engineering. GEODES, indeed, enlarged the basin of universities which can benefit from the cooperation EU-Africa for new carriers of mining engineers and geologists, guarantying stronger competences linked to sustainability and responsibility in mining planning and exploitation. Together with teaching and training activities based on scientific and technical issues, the promotion of social economic development, thanks to the training of experts able to cooperate and work in an interdisciplinary manner, will help the sustainable approach to local mining exploitation.

Further to this, several seminars and PhD courses concerning “Sustainable mining: resource efficiency and environmental risks associated to extractive activity“ have been set. These courses and seminars focus, with different in-depth analysis and using an interdisciplinary (“resource efficiency” and “environmental risk” integrated) approach, topics such as the management of waste connected to extractive industry, promoting their reuse-recovery-recycling.

Defining the mining engineering graduate of the future – mining engineering education within the European Union vs. industry demands and challenges

Georg Meissner, Helmut Mischo, Md Ariful Islam

TU Bergakademie Freiberg, Freiberg, Germany

In a holistic approach, this study was created with the goal of defining the mining engineering graduate of the future and showcasing whether the current mining engineering education offered by universities in the European Union (EU) meets the mining industry's expectations and requirements to achieve the objectives of the EU for a more fair and sustainable future. To realize the goals of the Paris Climate Agreement, European Green Deal, and sustainable development, critical raw materials (CRMs) are required and crucial for a great variety of strategically important branches, applications, and goods that define our modern everyday life. While the demand for CRMs is anticipated to surge dramatically in the near future, the EU's self-supply of most CRMs is alarmingly low. Strongly dependent on imports from many quasi-monopolistic supplier countries, the EU is currently left in an economically and strategically unfavourable position. To satisfy the increasing raw materials demand and to strengthen the EU's competitiveness and strategic resilience against countries outside the EU, a boost in (local) raw materials production and skilled mining engineering graduates, educated according to the principles of environmental and social sustainability to plan and operate the mines of the future, are required. Therefore, the undergraduate and graduate mining engineering education offered by universities in the EU is evaluated with a focus on the methods of implementing content on sustainability. The different teaching concepts and contents are summarized and compared, to assess the average EU undergraduate and graduate mining engineer's education. Also, a profile of the mining engineering graduate of the future is proposed with the help of the analytical hierarchy process, according to the opinions of mining industry experts, after defining key areas of interest. Ultimately, the proposed profile is compared with the current mining engineering education offered by universities in the EU.

New geo-engineering and mining programs at TUBAF - We'll mine the future

Helmut Mischo, Jörg Benndorf

TU Bergakademie Freiberg, Freiberg, Germany

Over the last decades, geo-engineering education has evolved from a mostly mining-related subject towards a vast array of different specializations, all serving the needs of a sustainable and comprehensive use of the underground space and its mineral resources. At Technical University Bergakademie Freiberg (TUBAF) as Germany's oldest university on resources, the four major study subjects mining, geotechnics, mine surveying as well as geo-energy systems have been representing this traditional approach on geo-engineering studies.

With the newly developed and implemented study programs in geo-engineering and mining, the traditional five year Diplomingenieur education has been brought to a new level. In close cooperation with globalized industry demands as well as completely adherent to the requirements of a European and worldwide student mobility approach, these new programs path the way for the geo-engineering education at TUBAF for years to come. In a unique manner, they combine both, the proven and successful courses of the traditional study programs with new and modern course contents as defined by a globalized market, the need for the implementation of sustainability in mining and geo-engineering as well as the continuous development towards mining and industry 4.0. For the first time, students have the full flexibility to chose from a wide range of different subjects while still qualifying as specialists in one of the four above mentioned traditional degrees.

Virtual learning environments for engineering education at Aalto University

Mateusz Janiszewski, Lauri Uotinen, Mikael Rinne

Aalto University, Espoo, Finland

Engineering education and training are undergoing a transformation to meet the increasing demand for more innovative teaching methods and learning experiences. Extended Reality (XR) technology, such as Virtual Reality (VR) is a powerful tool that can enhance engineering education through Virtual Learning Environments (VLEs). VLEs offer students hands-on experiences in a controlled and safe setting, which is particularly relevant in fields such as rock engineering and mining where on-site training can be dangerous and expensive. A key element is an immersive 3D model of a real environment digitized using photogrammetry. The models are then integrated into virtual learning systems built using game engines. The immersive visualizations and interactive experiences can complement traditional teaching methods by providing hands-on experiences or virtual site visits that can complement fieldwork and provide access to inaccessible sites. Despite the potential benefits of VLEs for engineering education, their creation remains a challenge. Specialized knowledge in fields such as 3D scanning, photogrammetry, computer graphics, and game development is necessary to create effective VLEs. Aalto University has been extensively studying the development of VLEs for rock engineering and mining education. We have developed various VLEs, including a virtual tunnel and a gamified rock mass mapping exercise. These VLEs offer students the opportunity to practice in a safe and controlled environment, which can be tailored to their needs and offer greater flexibility than traditional training methods. This presentation will provide an overview of the research and educational development activities at Aalto University aimed at creating virtual learning environments for rock engineering and mining education. The presentation will highlight their benefits for engineering education, the challenges associated with their development, and the potential applications in various fields. The presentation will also discuss the future directions of VLE research at Aalto University and the potential for collaboration with other institutions interested in VLE development.

European Mining Course (EMC)

Mikael Rinne[1], Rodrigo Serna-Guerrero[1], Nikolaus Sifferlinger[2], Bernd Lottermoser[3], Yannick Feldmann[3]

[1]Aalto University, Espoo, Finland
[2]Montanuniversität Leoben, Leoben, Austria
[3]RWTH Aachen University, Aachen, Germany

About 25 years ago, a group of universities with mining background took the initiative to establish a joint programme named to European Mining Course (EMC). Today, the EMC is a two-year (120 ECTS) MSc program consisting of three semesters of courses and one semester thesis project. The program builds on the strengths and the complementary expertise of the three partner universities: Aalto University, Montanuniversität Leoben and RWTH Aachen. A triple degree is awarded, and the coordination is carried out by Aalto.

The goal is to generate professionals who will be the future decision-makers and game-changers in the mineral resources and associated engineering trade, with a strong vision of the future developments in the field. The purpose is to provide a unique educational programme that supports the needs of the European mineral resource industry, keeping it competitive, innovative, and economically fruitful. The programme strives to provide state-of-the-art education in the fields of resource engineering by means of economically and environmentally sustainable systems and technologies. The curriculum covers courses in geology, mineral resource estimation, mineral extraction, mineral processing, and metallurgy. To ensure continuation and survival of mining and minerals engineering education programs in Europe, the Federation of European Mineral Programs (FEMP) was established in 1999. FEMP is a network of about 35 companies connected to mining. The strong link to the mining industry through FEMP is one of the most important factors in the success of the EMC.

This presentation will give an overview of EMC and FEMP. It aims to initiate discussion about co-operation between mining universities, EMC and FEMP.

The TERRA project – tertiary education in sustainable resource extraction

Yannick Feldmann[1], Bernd G. Lottermoser[1], Nikolaus Sifferlinger[2], Mikael Rinne[3]

[1]RWTH Aachen University, Aachen, Germany
[2]Montanuniversität Leoben, Leoben, Austria
[3]Aalto University, Espoo, Finland

The European Union aims to ensure a secure and sustainable supply of raw materials. Mineral raw materials are the basis of almost all industries and are critical for renewable energy technologies and thus, achieving the goals of the European Green Deal. TERRA aims to meet the growing demand for experts in the field of mineral raw materials by bringing together key players of Europe's mining and mineral raw materials education.

Mining programs across Europe face similar challenges with decreasing numbers of students and difficulties in offering the full range of relevant topics at their universities. To address these challenges, the TERRA project is working on modernizing innovative learning and teaching methods and promoting cooperation between universities. The existing structures and experiences of the three project partners RWTH Aachen, MU Leoben and Aalto University of the renowned European Mining Courses (EMC) and the Federation of European Mineral Programs (FEMP) serve as a sound basis for this.

The results of the TERRA project include establishing a database for students with information about personal career and educational opportunities across Europe, creating an Academic Expert Network to bring together key players of the educational landscape to tackle common challenges, and organizing an academic conference to facilitate direct collaboration between key players in Europe's mining education. TERRA will also benchmark and improve the EMC curriculum with demands from industry, governmental bodies, educational institutions, and students to further increase the quality of the triple degree program. Finally, the project will create a summer school as a joint module between the three partner universities, opening up to interested participants outside of EMC.

The TERRA project will have a significant impact on the mineral raw material education landscape by increasing the number of well-educated future decision-makers and ultimately improving the sustainable supply of minerals, fighting climate change, and promoting a clean energy transition with responsible mineral raw materials.

KEYNOTES - *Current research activities in mining and related disciplines*

Mining and environmental impacts - considerations from an Arctic perspective

Christian Juncher Jørgensen[1,2], Jens Søndergaard[1,2], Lis Bach[1,2], Kim Gustavson[1,2], Janne Fritt-Rasmussen[1,2], David Boertmann[1,2], Anders Mosbech[1,2]*

[1]Aarhus University, Aarhus, Denmark
[2]Danish Centre for Environment and Energy (DCE), Aarhus University, Aarhus, Denmark

Modern mining relies on responsible stewardship of environmental resources, balancing the needs of global society, local community and conservation interests. Failure to effectively manage the potential adverse impacts of mining on these shared resources can result in the deterioration of environmental resources and have adverse consequences for the environment and human health.

Mining will unavoidably lead to some impacts on ecosystems functions in the physical environment where mining activities occur. Public acceptance of where, when and for how long a given impact may be tolerated is not an exact science and is often a matter for discussion before an agreement can be made between communities, authorities and mining companies. Mitigation of mining related impacts on local environments often require special consideration on the overall footprint of the mining operations with a focus on both spatial, temporal, ecological and project-specific aspects and dimension following a combined set of best environmental practices.

In this talk we will present an overview of the most recent principles for the protection of the environment following mineral extraction operations from an Arctic perspective. The talk will include discussion of recent international guidelines and standards on environmental protection illustrated with examples from sensitive Arctic ecosystems in Greenland.

Perspectives on the potential recovery of critical raw materials from mining and industrial wastes based on case studies

Carlos Ruiz Cánovas, Jose Miguel Nieto, Manuel Olías, Francisco Macías, Ainara Rodrigo, Maria Dolores Basallote, Rafael León, Jonatan Romero, Rafael Pérez-López

University of Huelva, Campus “El Carmen”, Huelva, Spain

The increasing demands for critical raw materials may boost mining activities worldwide. The generation of wastes in the vicinity of the mines and industrial processing plants may lead to severe environmental problems and human health risks. Therefore, mining and industrial companies have to face huge investments in remediation options. However, these wastes could be a source of critical raw materials due to the high concentrations observed for some elements. This is especially important in those countries with absence of primary deposits, which suffer from a strong external dependence for supply. The recovery of these critical raw materials could constitute a great opportunity to satisfy this demand while helping to offset expensive waste treatment costs. However, the effective recovery of these valuable elements requires a vast amount of previous work such as site-by-site studies to determine the potential metal grade in wastes and deep investigation of mineralogical siting of valuable metals in these wastes or selective recovery methods. In this sense, there are some social, economic and technological barriers that must be faced to achieve the final recovery. The use of waste materials has commonly met resistance in the industrial sector and only being accepted after solid experience is achieved. On the other hand, the application of technologies may face technical and economic obstacles such as the non-selectivity of procedures developed or the high initial costs which put in risk the return on investment and the cost efficiency of the recovery scheme. Therefore, deep case-by-case investigation is required to achieve cost-effective secondary source of critical raw materials from these wastes.

Acid mine drainage as a potential source of REE. The Iberian Pyrite Belt case study

Jose Miguel Nieto, Carlos Ruiz Cánovas, Francisco Macías, Ainara Rodrigo, Maria Dolores Basallote, Rafael León, Jonatan Romero, Manuel Olías, Rafael Pérez-López

University of Huelva, Campus "El Carmen", Huelva, Spain

The Tinto and Odiel rivers drain the central and eastern part of the Iberian Pyrite Belt (IPB) in SW Spain. Both rivers are highly polluted by Acid Mine Drainage (AMD). Conventional passive treatment systems were tested in the region, showing serious problems of clogging and loss of reactivity. After more than 10 years of laboratory and pilot field experiments, DAS treatment system has been tuned up to overcome most of the typical operational problems faced by conventional passive treatments at the IPB.

Two full-scale DAS treatment plants have been installed in the IPB, located at Mina Esperanza and Mina Concepción, in the upper part of the Odiel watershed. Both plants consist on two DAS reactive tanks based on limestone dissolution, and serially connected with two decantation ponds. The DAS plant at Mina Esperanza started operating in December 2014, treating a mean water flow of 0,8 L/s (with peaks up to 2 L/s in the rainy season) of AMD with mean pH values of 2,7 and high metal contents (683, 117, 16, 15 mg/L of Fe, Al, Cu, Zn, and 0.1-3 mg/L of As, Cr, Cd, Co, Ni). All metals at plant outflow are below detections limits but Fe, with a retention ranging 90-97%. The outflow discharge is net alkaline, with a mean pH of 6,6. After 3 years of continuous operation, in December 2017, alkalinity started to decrease in the first reactive tank. The DAS plant at Mina Concepción started operating in April 2016, treating a mean water flow of 1 L/s (with peaks up to 3 L/s in the rainy season) of AMD with mean pH values of 2,66 and high metal contents (446, 85, 11, 26 mg/L of Fe, Al, Cu, Zn, and 0.1-3 mg/L of As, Cr, Cd, Co, Ni). All metals at plant outflow are below detections limits but Co and Ni, with a retention of 95%. The outflow discharge is net alkaline, with a mean pH of 7. Permeability reduction and/or alkalinity generation decrease at the outflow has not been observed up to now.

AMD is commonly considered as a huge environmental pollution issue. However, REE concentrations in AMD can be between three and four orders of magnitude higher than in the rest of continental and marine waters. The huge amount of AMD producing sites in the IPB make the region a world scale paradigm of AMD and a natural laboratory to study the geochemistry and potential recovery of REE. Preliminary evaluations of the flow and concentration of these critical elements in the AMD of the IPB suggest that the recovery of REE in these waters could be of economic interest. In addition to the environmental benefits of the treatment, AMD is expected to run for hundreds or thousands of years and therefore, potential reserves of REE in the area are virtually unlimited.

ORAL PRESENTATIONS - *Current research activities in mining and related disciplines*

Sensor-based multi-level characterization of mine waste: unlocking economic benefits

Feven Desta, Lucas Landeweerd, Willem Aarens, Mike Buxton

Delft University of Technology, Delft, The Netherlands

The ever-growing demand for mining products has led to the extraction and processing of large volumes of materials, resulting in the production of significant amounts of mine waste. While the composition of mine waste materials can vary and may cause environmental impacts, they can also be a valuable source of raw materials to meet the current and future mineral demand. The efficient re-mining of minerals of economic interest from mine waste materials requires accurate and reliable estimation. This can be achieved using state-of-the-art sensor technologies such as laser-induced breakdown spectroscopy (LIBS), x-ray fluorescence (XRF) and Fourier transform infrared spectroscopy (FTIR). This study evaluates the usability of LIBS, FTIR, and XRF technologies for the characterization of ferronickel slag materials at a multi-level. A methodological approach was developed to assess the usability of each technique for the identification, classification, or semi-quantification of the target elements (such as Ni, Li, Ti, Pb, and Cr) in the analyzed samples. The results demonstrate that the use of the techniques enabled a comprehensive compositional analysis of slag materials. Moreover, the findings suggest that such an approach could promote sustainable mining practices by providing valuable insights into the potential economic benefits of reusing slag materials for secondary recovery. Such an approach could contribute to reducing the possible environmental impact of waste and could enable achieving a circular economy.

Towards a sustainable transition in extractive activity: a decision support tool to assess, evaluate and promote the reuse and recovery of extractive waste

Marco Casale, Susanna Mancini, Giovanna Antonella Dino

University of Turin, Turin, Italy

The need to guarantee the raw materials (including the critical ones) supply has stimulated EU policies to find alternative and integrative sources to explore and (eventually) exploit. Raw and critical materials can be exploited from natural (orebodies) and anthropic (landfills and extractive waste facilities) deposits and from productive activities at large, including productive cycles connected to mining exploitation and processing.

The present research focuses on the potential exploitation of anthropic deposits such as extractive waste facilities (both connected to mining and quarrying activities), which should be managed and faced following the “landfill mining” approach. To assess, whether the EW facilities prove to be suitable to become sustainable exploitable, a Decision Support Tool (DST) for EW facilities exploitation has been designed. The outputs of the DST are represented by several possible scenarios, useful for different kinds of stakeholders to decide if and how to approach EW exploitation. The present research aims to update, improve, and make more user-friendly the already existent tool (draft designed as an excel file). The implementation consists in the investigation of EW facilities:

- using quantitative (economic and environmental impacts and specific data about the investigated materials and technical processes) and qualitative (social impacts) data.
- improving the parts connected to economic impacts, including also the long term previsions, the (global) market conditions, the amortisation of processing plant and machineries, etc.;
- including information about (EU and local) policy and the links to bibliography and case histories.

UNEXMIN, UNEXUP and ROBOMINERS: innovative ways for raw materials exploration and resource extraction

Norbert Zajzon, Ferenc Mádai, Boglárka Anna Topa

University of Miskolc, Miskolc, Hungary

To sustainably serve the raw material needs of the European Union, H2020 and EIT RawMaterials projects are being executed to develop innovative methods for mineral exploration and also for extraction. UNEXMIN and UNEXUP (UNEXMIN Upscaling) projects developed a robotic explorer capable to create 3D-maps of flooded underground mines down to 1.5 km water depth meanwhile delivering geoscientific data also. ROBOMINERS H2020 project aims to develop a new underground mining technology concept and ecosystem, where a set of robots excavate the ore through a large diameter borehole without human presence underground in the mine.

UNEXMIN and UNEXUP projects successfully built the UX series robots (UX-2Deep) and established the UNEXMIN Georobotics Ltd. spin-off company where the exploration service is already available at the market for different closed, flooded underground spaces, like abandoned mines, water wells and reservoirs, caves, dams and different pipelines. ROBOMINERS is developing the first bio-inspired excavating robot, which will be capable of autonomous selective mining in small diameter even in underwater, without the need of dewatering of the area, and with minimizing the produced mining waste. The ROBOMINERS technology develops mining ecosystems to exploit abundant, ultra-deep seated ore deposits, or small ore bodies extraction of which is uneconomic by conventional technologies.

These environmentally sound technologies also have been integrated in the teaching of the different partners involved in the projects all over Europe, both geology/exploration and engineering/robotics side to educate the students, and to produce professionals capable to uptake the technology in the industry quickly.

The UNEXMIN and ROBOMINERS projects were funded by the European Union thru the Horizon 2020 research and innovation programme under the no. 690008 and the no. 820971 grant agreement. The UNEXUP project was funded partially by the European Union through EIT RawMaterials no. 19160.

Practical implementation of machine learning (ML) in quarry mining operations

Hakan Basarir, Ozge Akyildiz, Steinar Løve Ellefmo

Norwegian University of Science and Technology, Trondheim, Norway

The mining industry puts special emphasis on responsible mining practices leading to efficient resource utilisation, maximised production, and reduced environmental impact. To achieve all the objectives, mine digitalisation and automation solutions have been attracting more interest. Thus, nowadays even for small scale companies it becomes routine to collect data from different machines such as blast hole drillers, crushers. The main question now is how to use such data to obtain mine specific parameters needed by the company.

In this study different examples of the development of machine learning (ML) base predictive models to be used as decision making tool for routine operations are presented. The examples were collected from two different mines in Norway. In the first example for the detection of the thickness of disturbed zone due to blasting of previous bench a model is constructed. Such model can be used for safe drilling and blasting operations. The second example presents the development of a ML model for real time detection of marble quality to facilitate optimum batching plan for desired product quality. The last example is about the prediction of the lithology of rock to minimise dilution and optimise blasting operations.

Overarching goal of the paper is to exemplify the development of hands-on teaching materials showing practical implementations of modern computational tools to daily operations for efficient and responsible resource extraction. Such materials will encourage the students to familiarize themselves with up-to-date tools like ML and to improve their mining engineering knowledge to be able to successfully use these tools.

Novel applications of characteristic impedance in mining engineering

Adeyemi Emman Aladejare, Zongxian Zhang, Toochukwu Ozoji

University of Oulu, Oulu, Finland

Rock mass classification continues to be an integral part of mining design and analyses. The methods for classifying rocks have played an important role in rock mechanics and rock engineering, but they have certain drawbacks. Major engineering classification systems like rock quality designation (RQD), tunnelling quality index (Q), rock mass index (RMI) and rock mass rating (RMR) mostly require sample collection, testing of intact rock properties, and extensive field investigations. As a result, establishing reliable classification for a rock mass is cumbersome for many mining projects. Therefore, to address the above drawbacks, a classification system that is simple, reliable, and easy to use is needed. Based on our recent studies, it has been discovered that using characteristic impedance to evaluate a rock mass and classify rocks may be an easier and reliable method. This is because the characteristic impedance of rock could represent the geological structures of the rock mass, e.g., joints, faults, bedding, and mineral composition, to a certain extent. In this study, the characteristic impedance of rock is defined as the product of the P-wave velocity and the density of the rock. Non-destructive methods can be used to estimate the characteristic impedance; hence it can be used to study various problems related to stress waves in rock mechanics. The proposed approach was applied to classify rock at real-life mining engineering sites. Results show that the reliability of the index in classifying rock mass is high and can predict the drillability of rock and rock burst proneness at mines and tunnels.

Closing the loop of battery raw materials with froth flotation

Rodrigo Serna-Guerrero, Tommi Rinne, Anna Klemettinen

Aalto University, Espoo, Finland

There is a significant activity worldwide dedicated to the development of more efficient recycling technologies for battery materials. The recovery of materials from urban mines represents the activity that closes the material loops in the circular economy models. Froth flotation is currently one of the most promising techniques for the recovery of active battery materials. Our research team has explored the use of flotation from two perspectives: i) as means to recover active materials in a chemical form useful for direct remanufacturing; and ii) as a preparation stage to integrate end-of-life batteries into industrial metallurgical operations to minimize waste and recover valuable components. In this presentation, we will provide an overview of the challenges and opportunities identified on the use of froth flotation to recover critical materials from battery waste.

Restoration actions and techniques for recovering degraded landscapes after mining activity under Mediterranean conditions

Luna Morcillo[1], Diana Turrión[1], Alberto Vilagrosa[1,2]

[1]Mediterranean Center for Environmental Studies (CEAM Foundation). Joint Research Unit University of Alicante-CEAM, San Vicente del Raspeig – Alicante, Spain
[2]University of Alicante, San Vicente del Raspeig – Alicante, Spain

Open-pit mining results in profound modifications at different environmental scales that may persist for very long time, or even indefinitely. Considerable research efforts in mine reclamation strategies have been made, although reclamation failures are still common. Moving from remediation and rehabilitation to ecological restoration, may contribute to restore and recover essential ecological losses along with promoting positive impacts on society, even beyond the area directly affected by mining. In dry climates, such as in the Mediterranean Basin, successful actions may depend on features related to proper species selection and restoration techniques, which may substantially contribute to provide substrate stability and facilitate the regeneration of the main ecological processes. In this context, we developed the LIFE TECMINE project.

The restoration strategy planned in TECMINE was designed at the landscape level with two main goals: the recovery of the natural geomorphology and the ecological restoration, including vegetation recovery and soil quality, based on suitable reference ecosystems. The implemented actions included: (i) surface remodelling to improve substrate stabilization and minimize the visual impact; (ii) an accurate species selection according to the microhabitat characteristics; (iii) high-quality plant production; and (iv) the implementation of low-cost techniques to enhance resources availability, soil fertility and the amelioration of abiotic conditions for the introduced seedlings. Within TECMINE, we developed a monitoring program to assess the success of the implemented restoration techniques over time and a dissemination program to ensure knowledge transfer to a wide variety of actors (including citizens, students at different levels, mining companies, policymakers, and scientists). The LIFE TECMINE project has demonstrated the economic feasibility of restoring mining-affected landscapes from an ecological approach, provided that there is good planning within a sustainable transfer mining.

Global assessment of the impact of mining construction minerals on biodiversity, policy coverage, and mitigation strategy

Aurora Torres[1,2,3], Sophus O.S.E. zu Ermgassen[4,5], Francisco Ferri-Yanez[6], Laetitia M. Navarro[6], Isabel M.D. Rosa[7], Fernanda Z. Teixeira[8], Constanze Wittkopp[9], Jianguo Liu[3]*

[1]University of Alicante, Alicante, Spain
[2]Université Catholique de Louvain, Belgium
[3]Michigan State University, USA
[4]University of Oxford, Oxford, United Kingdom
[5]University of Kent, United Kingdom
[6]Estación Biológica de Doñana-CSIC, Seville, Spain
[7]Bangor University, Bangor, United Kingdom
[8]Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil
[9]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

Construction minerals – sand, gravel, limestone – are the most extracted solid raw materials and account for most of the world's anthropogenic mass, which as of 2020 outweighed all of Earth's living biomass. The COVID-19 pandemic, the war in Ukraine, and decarbonization efforts have highlighted the strategic importance of mining. However, it also entails direct and indirect ecological impacts that must be considered to stop and reverse biodiversity loss. Balancing protection efforts and extraction to meet society's needs requires designing sustainable pathways at a system level and hinges on a good understanding of the mining impacts on biodiversity and the restoration efforts and policies to reverse them. Combining long-term data from the IUCN Red List and new species descriptions our team has provided the first systematic evaluation of species threatened by mining of construction minerals globally. We found 1,047 species in the Red List impacted by this type of mining, of which 58.5% are threatened with extinction and four species already went extinct. We also identified 234 new species descriptions in 20 biodiversity hotspots reporting impacts from mining. Temporal trends in the assessments highlight the increased saliency of this threat to biodiversity. Additionally, we quantified the degree to which mining threats are addressed in high-level biodiversity policies including the new Kunming-Montreal Global Biodiversity Framework. Finally, I will present an 8-point strategy to support a global strategy to close existing data gaps and reduce the impacts of construction minerals mining in biological systems.

POSTERS

Sustainable development goals in the mining industry of the new era

Emmanouil A. Varouchakis, Konstantinos Komnitsas, Michail Galetakis

Technical University of Crete, Chania, Greece

Achieving Europe's goal of a green, digital economy and climate neutrality by 2050 means that we need to boost capacity in green mining, processing, production, reuse, and recycling and implement sustainable mining practices. A prerequisite for sustainability is the long-term conservation of natural resources. Modern and sustainable societies will continue to demand, produce and purchase metals and minerals. The mining industry should follow the sustainability principles considering people, the environment, and the economy. Human aspects include health, social and cultural elements. Environmental considerations must include emissions, waste management, post-extraction remediation, nature conservation, energy use, and climate. Economic aspects include social development, prosperity, competitiveness, resource management, and circular economy. At the same time, the mining industry should cope with other sustainability challenges, as the current carbon and climate footprints and activities are far from sustainable in many respects. A complete approach to sustainability focuses on social and environmental issues within six categories—water, land, air, socioeconomic, health and safety, and quality of life. These complex problems require systemic approaches to identify the root causes and prevent further degradation.

Sustainable mining addresses these issues and positively contributes to the communities in which it operates. Economic, social, and environmental initiatives have points of overlap, such as focusing on renewable energy reducing operational costs, improving efficiency at the mine site through a more stable power supply, and reducing carbon emissions. With our strong focus on sustainable development, there is great potential to support the mining and metals industry in making a significant and lasting contribution towards the UN's global goals. SDG4 calls for the extension of quality education for all and equitable access to technical and vocational training to support decent jobs and enterprise development. EU-funded projects such as Digital and Innovative Mine of the future-DINAMINE, Bright concepts for a safe & sustainable digital mining future-illuMINEation, New solutions for raw materials and mining-MINE.THE.GAP creates a framework to align SDG goals and priorities to the new era mining industry, contributing to the educational goal and encompassing economic, social, and environmental dimensions. The role of education and in particular of European Universities (https://www.eurecapro.eu/) in achieving the SDG goals is crucial and special emphasis need to be given in the near future promoting international joint research on global issues.

Current state of digital twin implementation in the extractive industry

Joana Duarte, João Santos Baptista

University of Porto, Porto, Portugal

As new horizons are rising with the emergence of Industry 5.0, the impacts of Industry 4.0 (I4.0) are still taking place: the traditional industrial sectors are rushing their transition to smart environments with the assistance of automation towards operation excellence. One of the greatest promotors of this technological leap is the “digital twin” (DT) concept. In simple terms, DT refers to the virtual replicas of the physical objects, models and systems that help monitor, plan, predict and manage the mining operations. Due to its potential, complete process automation is also expected to prevent environmental problems and thousands of injuries and deaths due to occupational accidents. Though the advantages are straightforward, the actual state of such implementation is not yet understood. Therefore, a systematic review addressed this question regarding the extractive industry (EI).

The Preferred Reporting Items for Systematic reviews and MetaAnalyses (PRISMA) Statement was used to conduct the research. The publication period focus ranged between 2018-2023 since there was an apparent “boom” in the field in the past few years, which would lead to an information overload, most outside the intended scope. To be included in this work, articles should be within the context of the EI (either underground or surface exploitation). They should be practical (in opposition to theoretical frameworks) despite the implementation level of their digital twin models.

Following the PRISMA Statement recommendation criteria, only 23 studies fit the defined criteria in three different exploitation phases: exploration, exploitation and ore processing. The analysis of the results showed that most articles pursued optimised solutions to not-so-new problems regarding, mostly, equipment maintenance and ore processing model optimisation. While maintenance actions are commonly reactive, preventive maintenance constitutes the most reliable option to diminish the periods of stopping time. Both mean stops in productions which are, outmost, avoidable through predictive maintenance. The combination of DT with backpropagation (BP) neural network algorithms train models to perform this task which, in one of the studies, achieved a 98 % accuracy level just after the fifth optimisation cycle. Due to their potential, the digital models were often used to test and simulate scenarios, anticipating potential machine complications and optimised operational solutions. Most of the time, the core objective underneath the developed work was assuring operational excellence. Notably, since most of these studies were related to underground exploitation, workers’ safety was assured by guaranteeing optimal technical conditions.

The technological revolution imposed by I4.0 is changing how mining is done. Moving from human-dependent operations to autonomous or semi-autonomous intelligent mines increase outcome quality, transparency and collaboration. As for the actual operation level of such technologies, particularly concerning the digital twin implementation, it was evidenced during the analysis of the results that much road has to be paved towards its full integration. However, the exception to the rule comprises far more advanced techniques, such as machine learning.

Breaking the mould: Revitalising higher education in geo-resources for a dynamic world

João Santos Baptista, Joana Duarte, Jacqueline Castelo Branco

University of Porto, Porto, Portugal

Over the last few decades, the availability of raw materials on global markets has led the European Union (EU) to progressively abandon the production and training of professionals in this field. Simultaneously, the poor environmental and social practices of many companies, along with the increasing demands of society on these issues, have driven decision-makers towards options for sourcing outside of the EU. This situation has resulted in a lack of investment in training new professionals in the different areas of the extractive industry.
The prolonged under-investment in training and the consequent lack of staff specialized in geo-resources has led public policies, supervisory and control bodies, and the industry to recruit professionals from other fields to fill this need. The resulting consequences are visible in the approval of low-quality projects that merely comply with legal formalities and production units operating under suboptimal technical conditions. As a result, companies see their profitability reduced, their environmental impact increased, and occupational risks worsened. All these issues have compromised the industry's image, which has been associated by the public with undesirable situations, leading to anti-mining movements in many European countries.

However, there is a risk inherent in relying on external sources of raw minerals, and the EU has been gradually becoming aware of and taking measures to minimize this problem. Nevertheless, there is a significant lack of qualified professionals necessary to boost this sector sustainably, and the sector is not very attractive to new generations.

From this context, it is essential to rethink the extractive industry in Europe by (1) increasing investment in promoting its image, (2) recruiting new talent for bachelor's and master's degrees, (3) creating curricula suitable for the needs of new generations and the sector, and (4) ensuring the quality of employment to recruit and retain the best talent.

To address these issues, the Department of Mining Engineering at the University of Porto is initiating an integrated process to better understand the problems and respond to the needs in the most structured way. This work aims to present the project and the first results of ongoing actions involving the collection of opinions through Focus Groups with students and teachers from pre-university and university education, former students, employers, and policymakers.

Corporate social responsibility: a quantitative approach for the mining sector

Marc Bascompta, Lluís Sanmiquel, Carla Vintró, Mohammad Yousefian, Hernán F. Anticoi

Polytechnic University of Catalonia, Manresa, Spain

The raw materials sector requires a holistic approach to analyse and quantify the environmental and socio-economic implications of the mining activity for all the stakeholders. Thus, it is proposed a quantitative approach to determine the corporate social responsibility (CSR) impact, applicable at the mine site and corporate levels, based on two steps: 1) a basic CSR index is obtained and 2) a correcting factor is applied, achieving the final, or corrected, CSR index.

In the first step, the system can be used at any kind of mining project and stage: prospecting and exploration, development, mining, processing, closure or rehabilitation. It consists of two dimensions, environment and socio-economic, formed by 30 elements that analyse potential positive and negative impacts. It also allows additional elements for particular conditions in each project.

The second step consists in applying some corrective factors, defining as relevant the recycling rate, the green energy transition and the regional conditions. These factors can be adapted to future changes over time regarding the supply and demand of each element or mineral.
The system proposed can be an important driver to improve the positive implications of the mining industry at all levels, as well as improve transparency, stakeholder engagement, facilitate the administrative processes and increase the returns of the mining activity in the long term.

Project management practices for developing professional skills in the mining sector

Natalia Gómez-Marín

University of León, León, Spain

The MSc Degree in Mining Engineering and Energy Resources at University of León (Spain) has a Project Management subject where an overall overview of the project management field is revised in order the student and future professional on this sector will get skills on this relevant area. The issue is that the practical knowledge is not easy to achieve if the student does not have a previous experience in the sector.

PMBOK is one of the leader institutions that represent the path to follow in project management sector. Therefore, this is the main reference for the activity. The solution passes from making a framework to the activity based on proposing specific “study cases” of existing projects in the sector, to used them as starting point and going back in the process. From them, the students in group of 3-4 simulating a real teamwork, have to proposed the project charter, the Work Breakdown Structure (WBS) and the WBS dictionary that are the main tools to start a project, following the PMBOK.

What we have found is that the student even with the theorical matter already taught find difficulties to apply the concepts, that seems to be understood at first moment. During the development of the project charter the team will be focused on a real context. They have to propose the main objectives of the projects, the main resourced needed at first point, the stakeholders involved, and the deliverables needed on each stage of the project taking into account the budget. With the WBS the students have to think on the full scheme of activities of the project, describing them and associate the deliverables needed in each part.

With these activities it is considered that the students achieve practical skills very valuable in the sector.

An evaluation of the feasibility of the use of electrostatic separation for physical soil washing

Xabier Corres[1], Diego Baragaño[1,2], Juan María Menéndez-Aguado[3], José R. Gallego[1], Carlos Sierra[4]

[1]Universidad de Oviedo, Mieres, Asturias, Spain
[2]Czech University of Life Sciences Prague, Prague – Suchdol, Czech Republic
[3]Escuela Politécnica de Mieres, Mieres, Asturias, Spain
[4]University of León, Campus de Vegazana, León, Spain

Here we firstly apply electrostatic separation as a novel tool for soil washing. It is a technology widely used in mineral processing and other industries, but it has not been applied to soil decontamination. For this study, a single-phase high-tension roll separator was used in the separation processes, operated at different voltages (17.5 kV-41.5 kV). The efficiency of this equipment to separate pollutants in soil was exemplified with samples from the mining district of Linares (southern Spain), an area severely affected by past industrial (metallurgy) and mining activities where soils contaminated with Potentially Toxic Trace Elements (PTEs) have been profusely described. This is the case of "La Cruz" smelter surroundings, where high concentrations of Cu, Zn, As, Pb, Ni, and Cr were identified. Due to the warm climate of the zone, the sandy loam soil of this area is completely dry, making it a perfect sample to test the physical soil washing via electrostatic separation. The obtained results provided yield values ranging from 0.69% to 9%. Recovery values were notable for Zn (83.25%), Cu (77.65%), and Mo (81.01%) and significant for Sb, Pb, As, Ni, Cr, and Cd (45-60%). The less efficient element to be removed was Hg, with 25.88% as its highest recovery. Moreover, electron microscope revealed the mineralogy of the PTEs-bearing particles. Furthermore, the application of the attributed analyses was used to select the optimal concentration conditions that corresponds to 41.5 kV. All things considered, we conclude that an electrostatic separation can be a valuable tool for the decontamination of post-mining soils, especially in dry climate sites, as well as for the potential recovery of critical elements in the framework of the circular economy.

Geochemistry of the precipitation profile in a passive treatment plant for acid mine drainage

Ainara Rodrigo, Rafael León, José Miguel Nieto

University of Huelva, Campus “El Carmen”, Huelva, Spain

The Iberian Pyrite Belt (IPB) is one of the metallogenic provinces with higher concentrations of polymetallic massive sulfide deposits in the world. After more than 4,500 years of almost continuous mining, large volumes of mining waste such as dumps, flooded galleries and open pits have originated in the region. This has resulted in severe environmental pollution due to the exposure of sulfides to atmospheric agents, leading to the oxidation of pyrite in a phenomenon called Acid Mine Drainage (AMD). Among all existing remediation methods for AMD, the one that has proven to be the most viable and effective in the IPB is the passive treatment using Dispersed Alkaline Substrate (DAS). DAS technology enables the removal of large amounts of acidity and metals from AMD-affected waters. A full-scale example of DAS system application is the passive treatment plant of Mina Esperanza (Almonaster La Real, Huelva).

In this work, a preliminary geochemical and mineralogical study of the precipitation profile inside the treatment plant is carried out. The different precipitation fronts inside one of the plant reactors are characterized, and the metallic load associated to each front is estimated. For this purpose, a 2-meter trench was dug in the reactive substrate after two years of plant operation, and 19 samples were taken every 10 cm along the profile.

The study shows a high retention of metals inside the treatment reactor. Four main precipitation fronts have been distinguished, to which are associated metal phases with variable geochemical behavior. While some elements (e.g. Cu, V, As) show a defined behavior along the profile, others such as Y and REE are anomalously distributed at depth. Likewise, the results obtained show the great effectiveness of passive DAS type treatment, which allows concentrating high quantities of critical raw materials of economic interest.

Interactive and parametrized exercises in engineering education at Aalto University

Lauri Uotinen, Mateusz Janiszewski, Mikael Rinne

Aalto University, Espoo, Finland

The Finnish technical universities aim to increase student intake by 30% while undergoing cost-saving measures. To achieve this, Aalto University implemented interactive and parametrized exercises in the Foundations of Solid Mechanics bachelor level 5 ECTS course. The course consists of weekly exercises that tackle common mechanics problems, including stress and strain and extracting stress components. Based on student feedback, lecture diaries, and comparison of exercise and exam performance, two main problems were identified: copying and lack of motivation.

To address the copying problem, a quarter of the exercises were rewritten into parametrized problems that were dependent on student numbers and automatically checkable. Half of these problems were included in midexams to reduce copying and improve students' ability to solve problems independently. To address the lack of motivation, open-ended problems with multiple correct solutions were designed, along with a semi-structured FEM solver interface constructed using Comsol Server. Students were instructed to solve each problem using simplified controls, such as sliders. Feedback was collected, and similar problems were included in midexams to evaluate the effect on learning outcomes.

Both methods were found to be effective in improving engineering education. The parametrized problems reduced copying and improved students' ability to solve problems independently, as evidenced by exercise and exam scores. The open-ended problems with simplified FEM solver interfaces addressed the lack of motivation by providing students with real-life problems and allowing them to solve complex problems with multiple correct solutions. The feedback collected from students supported the effectiveness of both methods. Overall, these methods provide a model for improving engineering education that could be adapted and implemented by other universities facing similar challenges.

Teaching mining engineers with interactive virtual reality scenarios

Julian Lassen, Nils Schlatter, Yannick Feldmann, Bernd G. Lottermoser, Jan-Niklas Bender

RWTH Aachen University, Aachen, Germany

Hands-on experience is a critical part of mining engineering education. In addition, field trips are an essential pedagogical tool. They address active learning, problem-based activities and real-world contexts. On the other hand, field trips are expensive, time consuming and complex to organise. Also, due to the number of participants, access to extractive industry sites cannot always be guaranteed. As a result, there is a need for teaching methods that allow students to experience the content of lectures in a hands-on way. By using a VR environment, these challenges can be overcome and most of the benefits of a real field trip can be retained. At the Institute of Mineral Resources Engineering (MRE), a virtual reality (VR) underground mine was created using Unity Game Engine and further developed in three projects. The VR mine allows students to experience an underground mine that is modelled on a real mine in Mittersill, Austria. Students can choose from a variety of scenarios ranging from mine safety and ventilation to drilling and blasting. The use of VR enhances the student's motivation to learn, improves three-dimensional understanding, strengthens process-oriented learning and leads to better linking of different topics through visualisation. As a result, the VR-Mine has been successfully used in university teaching since 2021, with highly positive feedback from the students. The VR mine also won the Silver Award in the field of Immersive Experiential Learning by the Wharton School of the University of Pennsylvania. This shows that the topic is up to date and highly innovative.

Realisation of a digital platform for standardised and uniform data management for SMEs in the German quarrying industry

Julian Lassen[1], Jonas Müller [2], Gerrit Hoeborn[2], Bernd G. Lottermoser[1]

[1]RWTH Aachen University, Aachen, Germany
[2]FIR e. V. an der RWTH Aachen, Aachen, Germany

The use of digital data in combination with platform solutions have the potential to increase the competitiveness of companies by successfully meeting the challenges of a rapidly changing market through more efficient business processes. In the German quarrying industry, digital transformation is only taking place to a limited extent. Compared to other sectors, SMEs in the industry are significantly behind in digitisation. It is still common practice to document key indicators with pen on paper. Currently, internal optimisation of process steps and capacity utilisation is only possible to a limited extent due to insufficient data management. In the research project PROmining (IGF project no. 21480 N), a platform solution was realised for the German quarrying industry, which enables SMEs to improve their data management, to optimally utilise their resources and equipment and thus to react more effectively to fluctuations in demand. The developed platform enables users to digitally document internal data on operating equipment, personnel as well as production in a standardised, uniform manner and without high technical hurdles. Relative key performance indicators are visualised on the platform's dashboard. This enables companies, especially those that have been poorly digitised so far, to monitor and plan site-specific capacities. The platform serves as a decision-making instrument for equipment and personnel planning, as well as for monitoring the company´s process chain. The web-based platform was successfully tested in three companies of the project committee and is available at https://promining-tool.fir.de/.

3D multi-user hologram tables for future-oriented teaching in mineral resources science and medicine

Max Weber, Bernd G. Lottermoser

RWTH Aachen University, Aachen, Germany

A major challenge in higher education is, that especially for STEM subjects and (dental) medicine, spatial understanding of complex 3D structures is a central requirement. Traditional teaching methods have their limitations in this respect. Common mixed reality media can partially solve the problem, but social interaction and collaboration are restricted, image quality (resolution, "realness") is limited, and virtual reality glasses can cause discomfort. Multi-user hologram tables offer a solution here to overcome these limitations and effectively promote spatial understanding. The Holo-4-Edu project aims to improve the skill acquisition of spatial understanding of complex 3D structures from a frustrating challenge to an interactive, and collaborative learning experience. By combining multiple projectors, it is possible to project complex, high-resolution 3D models onto the table surface, which are then visualized in 3D with the help of holo-glasses and a motion-tracking system. Several users can interact simultaneously with the holograms and analyze, discuss and comprehend the displayed content holistically in a collaborative learning process. The consortium consisting of the Institute of Mineral Resources Engineering (MRE), the Audiovisual Media Center (AVMZ) and the Institute of Information Management in Mechanical Engineering (IMA) will develop solutions to establish a hologram table for future-oriented university education. The development, testing, evaluation and curricular anchoring of didactically detailed and interactive multi-user hologram modules will be carried out. These modules will be implemented for selected courses of various geo- and mineral resource sciences and medical courses.

Satellite remote sensing and ground truth data acquisition of European mine waste repositories – SatMine

Nina M. Küpper, Jan-Niklas Sander, Bernd G. Lottermoser

RWTH Aachen University, Aachen, Germany

The European raw material sector stands as the second largest waste-producing economic sector. However, the documentation of this waste varies across European countries, leading to inconsistencies and variations within existing national databases. Consequently, there is a lack of a comprehensive transnational database that uniformly records mineral waste with all essential information. This poses a significant obstacle to the European Union's efforts to transition its mineral resources and mining sectors towards a sustainable and closed-loop circular economy.

To address this challenge, it is imperative to create a standardized database that encompasses mining residue throughout Europe. This database should contain comprehensive information regarding their location, quantity, as well as physical, chemical, and mineralogical characteristics. To accomplish this objective, the SatMine project is developing a uniform, efficient, and economical methodology for the documentation of mining residues. This innovative approach utilizes a novel, multivariate technique that integrates data sets from automated, multi-, and hyperspectral satellite remote sensing with measurement data obtained from portable instruments such as pXRF and pLIBS. By streamlining the documentation process, this methodology aims to save both time and resources.

Pilot studies are underway in Greece and Slovenia to develop and optimize the methodology. The selected mining residues sites for these studies are those that have significant economic demand for a sustainable and secure European raw material supply or those that pose potential environmental hazards.

Achieving the research goal of a Europe-wide database of mining residues necessitates the collaboration of an international consortium. Therefore, the European SatMine Consortium has been established, with plans for future expansion to include additional European members. The overarching objective of the European SatMine Consortium is to create a sustainable, international research network.

Advanced characterisation of graphite ores using computed tomography

Leonard T. Krebbers, Bernd G. Lottermoser

RWTH Aachen University, Aachen, Germany

Graphite, an allotrope of carbon and a Critical Raw Material in the EU and other major economies, possesses exceptional physical and chemical properties that make it indispensable for a wide range of industrial applications. Advanced applications, such as lithium-ion batteries, impose stringent criteria on the mineral's properties like flake size, shape, and purity to ensure optimal performance. To meet the demanding requirements of these applications, a comprehensive assessment of graphite's mineralogical properties is crucial throughout the manufacturing process. This examination extends to graphite ores, as diverse graphite ore types are linked to different product uses. Traditional mineralogical characterisation methods such as scanning electron microscopy coupled with energy dispersive X-ray spectroscopy, optical microscopy, and X-ray diffraction play a vital role in providing valuable information on graphite properties. However, they often require careful sample preparation and have limitations in terms of dimensionality. Moreover, they may be subject to the stereological error that can adversely affect the quality of the analysis. X-ray micro-computed tomography (CT) is a non-invasive imaging technique allowing for 3D visualisation and quantitative analysis of solid materials such as ores and rocks. The present study explored the added value of CT for the characterisation of graphite ores. CT was employed along with conventional mineralogical methods to examine a flake graphite ore. By developing acquisition protocols and advanced image processing strategies, the authors were able to extract quantitative information on key microstructural properties such as flake size, flake size distribution, shape and purity. This information is currently unattainable through other analytical tools. Despite current limitations including the need for prior knowledge of the samples' mineralogy and operator expertise to obtain viable results, CT shows great potential to become a routine characterisation tool to improve resource efficiency.

On-site screening of mine water chemistry using portable laser-induced breakdown spectroscopy

Nils Schlatter, Bernd G. Lottermoser

RWTH Aachen University, Aachen, Germany

Laser-induced breakdown spectroscopy (LIBS) is a quantitative atomic spectroscopy technique that has proven reliable in the laboratory for the analysis of inorganic water chemistry down to the ppt range for a wide range of elements. In theory, LIBS can analyse any element in the periodic table. Nevertheless, it leads a rather niche existence in the analysis of aqueous samples compared to IC, AAS and ICP-MS. However, the use of portable LIBS (pLIBS), could overcome the classical standard procedure of water testing. Rather than taking a few selected samples, transporting them refrigerated to the laboratory, and then analysing them, which is usually time-consuming and costly, direct screening of the mine water chemistry could be carried out on site. Though, some physical constraints hamper the analysis of liquids with LIBS. It is therefore necessary to resort to certain measurement setups, some of which are not easy to implement in the field. Though, it has been shown that a liquid to solid conversion of a small droplet on a surface enhanced aluminium foil is a reliable solution that can be adapted to a pLIBS. Liquid to solid conversion not only circumvents the physical issues, but also lowers detection limits by preconcentrating in the form of an evaporation residue. Very low detection limits have already been achieved for Li, Na, and K in single element standard solutions. The same method has now also been used to calibrate Cr, Ni, Cu, Se, Cd, Zn, Pb, and As. Good correlations have been obtained between prepared and predicted concentrations of these elements in standard solutions. The detection limits, some of which are very low, combined with the wide measurement range are very promising. In the future, it may be possible to pre-screen mine waters for potentially toxic elements and analyse them quantitatively.

Innovative, digital media in the education of mining engineers

Nils Schlatter, Bernd G. Lottermoser, Johannes Emontsbotz, Maximilian Weber, Yannick Feldmann, Julian Lassen, Johannes Sieger, Alexander Hennig

RWTH Aachen University, Aachen, Germany

Innovative digital media such as Virtual Reality (VR), Mixed Reality (MR), training simulators, interactive videos, 360° videos and virtual excursions are increasingly enriching university teaching by enhancing practical experience. At the Institute of Mineral Resources Engineering (MRE), a digital showcase collection of minerals, ores and rocks, a hologram table, a virtual mine, mixed reality handbooks and training simulators have already been used for some time in the teaching of mining engineering students. On the one hand, the use of these innovative, digital media in the training of mining engineers promotes the student´s motivation to learn. On the other hand, complex topics can be mastered more quickly through three-dimensional representation and correlations can be understood more comprehensively through process-oriented learning. Furthermore, experimental learning can be promoted through self-determined scenario-based exercises and practical experience can be increased through realistic applications. The additional effort involved in implementing such media forms in teaching is usually compensated for by the simplified reusability of the teaching materials in subsequent years. Overall, this results in a clear advantage over conventional teaching and learning methods. The use of innovative, digital media in the training of raw materials engineers is an important cornerstone of modern teaching adapted to the development and needs of the industry. This not only promotes the students' motivation to learn, but also offers clear advantages in terms of learning outcomes compared to conventional teaching and learning methods.

Field trials evaluating the potential of biopolymers as dust suppressants on mine soils

Johannes L. Sieger, Bernd G. Lottermoser, Justus Freer

RWTH Aachen University, Aachen, Germany

Mine dust from exposed surfaces, such as overburden and waste dumps or tailings storage facilities, can affect local ecosystems and the health of workers and communities. Applying dust suppressants is an established dust control method, but many traditional suppressants, such as salt brines or petroleum-based products, can have adverse environmental effects or are fossil-based. Recent laboratory studies have shown that biopolymers, which are bio-based and considered environmentally benign, have potential to act as dust suppressants. However, large-scale field trials are needed to examine their effectiveness under real field conditions. In this study, field trials were conducted to investigate the effectiveness of selected biopolymers (corn starch, xanthan gum, and fava bean protein concentrate) as dust suppressants. A field sprayer was used to spray low doses of the biopolymers on designated trial areas on the overburden dump of the Inden lignite mine (Germany) and tested repeatedly over the subsequent weeks. The test programme included measurements of dust emissions from soil plots exposed to the airflow of an electric fan, visual inspections, and penetrometer tests. Results show that all biopolymer treatments effectively suppressed dust emissions in the short-term, up to 8 days after application. After day 8, rainfall leached the water-soluble biopolymers from the soil surface, reducing the effectiveness of the treatments, with results suggesting that the treatments would have lasted longer under dry conditions. Thus, the field trials demonstrate that biopolymers can be effectively used for the short-term suppression of dust emissions from exposed mine soils and, thus, can be considered a bio-based, environmentally friendly alternative to traditional dust suppressants.

Shock wave fragmentation of electric arc furnace slags: observations from CT-scanning

Theodor Steller, Bernd G. Lottermoser

RWTH Aachen University, Aachen, Germany

Electric arc furnace (EAF) slags are essential by-products during steelmaking. With the beginning transition from coke-based steel production in blast furnaces to using hydrogen-based directly reduced iron (DRI) in EAFs to reduce the industry's carbon emissions, EAF slag production is anticipated to increase. While EAF slags can be recycled as aggregates for road construction, the market conditions are becoming increasingly challenging. Additionally, they contain high metal contents that cannot be effectively recovered using conventional processing techniques due to poor metal-rock-separation, and their high toughness leads to significant machinery wear and dust emissions, demonstrating the need for innovative processing methods to conserve primary resources and maintain the industry's international competitiveness. This study aims to explore the potential of using electrohydraulic shock wave technology to process EAF slag. Here, shock waves are generated in a liquid medium using electrohydraulic effects, offering a contactless method to achieve effective fragmentation and separation of materials at mechanical weak points and boundary surfaces while minimizing possible contaminations and equipment wear. To validate the viability of this technique for EAF slag processing, a comprehensive analytical study is indispensable. Alongside X-ray diffraction, X-ray fluorescence and mineral liberation analysis, computed tomography will play a key role in gathering detailed information about the slags' chemical, mineralogical and physical properties in 3-dimensional space down to the µm-level. The collected data is expected to enhance the understanding of the process flows involved in shock wave fragmentation, optimize configuration settings for the best possible material separation and metal yield, and contribute to more sustainable steel production processes by managing valuable resources in a circular economy.