ROBOMINERS

ROBOMINERS DELIVERABLE D8.4

RECOMMENDATIONS BY THE FOCUS GROUPS

Summary:
This document lists the recommendations made by internal and external experts for the current and future ROBOMINERS implementation with the vision for a future fully working system. The recommendations contained within this deliverable were collected during five Focus Groups exercises dedicated to raw materials and robotics topics alike.

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TABLE OF CONTENTS

FIGURES

TABLES

1 EXECUTIVE SUMMARY

Deliverable 8.4 – Recommendations by the Focus Groups, describes the preparation, hosting and post-processing of Focus Groups, with the ultimate goal of producing sound recommendations made by experts for the ROBOMINERS current and future implementation. The Focus Groups are an important tool to engage experts and collect their qualitative input on topics akin to ROBOMINERS implementation. Recommendations serve the ultimate purpose of driving current and future implementation of the technology with a vision to achieve a higher TRL working system.

Within Task 8.2 – Focus Groups, five Focus Groups were held in total between September 2020 and May 2021, always with online telemeetings. The following are the overall characteristics of each Focus Groups meeting:

- Focus Groups #1 - 7th September 2020 (1st meeting)
  - Number of participants: 6 internal participants
  - Topics discussed: Raw materials, Robotics & ROBOMINERS
- Focus Groups #2 - 17th March 2021 (2nd meeting)
  - Number of participants: 4 external participants
  - Topics discussed: Raw materials & ROBOMINERS
- Focus Groups #3 - 7th April 2021 (3rd meeting)
  - Number of participants: 6 external participants
  - Topics discussed: Raw materials & ROBOMINERS
- Focus Groups #4 - 30th April 2021 (4th meeting)
  - Number of participants: 5 internal and external participants
  - Topics discussed: Robotics & ROBOMINERS
- Focus Groups #5 - 4th May 2021 (5th meeting)
  - Number of participants: 4 internal and external participants
  - Topics discussed: Robotics & ROBOMINERS

Answers from the participants of each Focus Groups session to the research questions were treated and processed, resulting in Recommendations. These, as defined in this report, are divided across 1) Methodology and approach, 2) Improvements and changes, 3) Test sites, and 4) Applications. A few recommendations of interest include:

1) Methodology and approach
   a. to focus on developing very good perception and selective mining ability to move forward with ROBOMINERS development.
   b. to employ more biology-related aspects that could benefit ROBOMINERS in all aspects of implementation.
2) Improvements and changes
   a. to develop the ROBOMINERS downhole and uphole transport concept and improve self-assembling and disassembling of the robot miner.
   b. to use a Ground Penetrating Radar (GPR) on the robot miner. It is a very useful way to know densities and types of materials, which can be very critical for operations. Data from a GPR and acoustic sensor data could potentially be used together.
3) Test sites
   a. to re-scope the initial set of trials changing from harder to softer rocks (e.g. potash or coal).
4) Applications
   a. Recommendation for the project team to have and showcase different use cases with the technology. Examples include use in deep sea mining operations.

The recommendations made within this document will serve the purpose of driving the implementation of following tasks within WP8, but also aim at helping in the development and implementation of the current and future ROBOMINERS approach and concept.

2 INTRODUCTION

Focus Groups are one of the many ways to collect qualitative data for a project, product or service development and certification. A Focus Group is a method of research and data collection that works around raising discussions between a moderator and a small group of participants. They can be used with a number of goals including 1) collect background data, 2) identify barriers, bottlenecks or support for new ideas or 3) gather impressions for end-users on a concept, among others.

Within ROBOMINERS, and as part of the work of WP8 – Active Roadmapping and Clusters, Task 8.2 – Focus Groups, deals with the preparation, hosting and processing of Focus Groups dedicated to raw materials and robotics topics alike, and their entwining with ROBOMINERS' developments and implementation roadmaps.

The aim of this iterative process was to bring together experts interested in ROBOMINERS related developments to assess the current and future implementation plan of ROBOMINERS and how that plan can be improved, challenged or adapted for better and more significant impacts. Information is also helpful to help to drive future adaptations for the ROBOMINERS technology on all its intrinsic aspects such as selective mining, autonomy or control, thus helping define the project's roadmaps for 2030 and 2050. Another important aspect is to gain track for clustering and collaboration opportunities.

The Focus Groups were initially planned to being held back-to-back with periodic consortium meetings, aiming to attract experts into the project's discussions. However, due to the many restrictions imposed by the COVID-19 pandemic, the scope of the Focus Groups changed from an in-person to the online environment.

During the period September 2020-May 2021, five Focus Groups meetings were hosted, counting with the participation of 25 internal and external experts from both raw materials and robotics fields. Project/internal experts participated in the first, four and fifth meetings, while external experts participated in the remaining four. These allowed for a diverse and qualitative collection of input that fits the task's plan.

The following chapters contain more details of the preparation (chapter 3), hosting (chapter 4) and follow-up (chapter 5) of the Focus Groups. It then follows with the most relevant recommendations for the ROBOMINERS implementation and finishes with the conclusions on how the results of this deliverable will contribute to the remaining development of WP8.

3 FOCUS GROUPS PREPARATION

Before hosting the Focus Groups meetings, it is necessary to do desk research and prepare said meetings. This was done during the year 2020 and in the weeks before each Focus Groups exercise. Preparation includes activities such as:

- Studying and choosing Focus Groups topics and questions:
  - Desk research and revision of ROBOMINERS topics of relevance.
- Selecting and inviting experts:
  - Selection based on experts participation on a ROBOMINERS webinar and clustering contacts;
  - Invitations sent by email with follow-up on those who replied.
- Preparation of administrative forms (GDPR, information on the Focus Groups) and the presentation with questions itself:
  - Development of a Consent Form
  - Development of a Participant Information package;
  - Creation of a PowerPoint presentation with questions to drive Focus Groups discussions.
- Arranging a date for the meeting:
  - Dates agreed amongst participants through Doodle pools.
- Setting up the meeting in an online meeting platform:
  - Go-To-Meeting was used for the Focus Groups sessions, with each meeting being recorded.

Participants were adequately informed of the Focus Groups objectives and data collection and processing activities. Consent was collected from each participant for recording the sessions and using any quotes on this report.

4 HOSTING FOCUS GROUPS

The actual Focus Groups meetings were held online during the period September 2020-May 2021, in a total of five meetings. Overall information on the Focus Groups can be seen in Table 1.

Table 1: ROBOMINERS' Focus Groups information.

Date	Number of participants (including researcher/moderator)	Nature of topics	Nature of participants
7th September 2020 (1st meeting)	7	Raw materials, Robotics & ROBOMINERS	Internal
17th March 2021 (2nd meeting)	5	Raw materials & ROBOMINERS	External
7th April 2021 (3rd meeting)	7	Raw materials & ROBOMINERS	External
30th April 2021 (4th meeting)	6	Robotics & ROBOMINERS	External + Internal
4th May 2021 (5th meeting)	5	Robotics & ROBOMINERS	External + Internal

Participant experts included:

- Raw materials experts,
  - Mining and geological engineers,
  - Geologists,
  - Petroleum technicians,
- Robotics experts,
  - Robotics engineers,
  - Software engineers,
  - Hardware engineers.

4.1 Focus Groups #1 - 7th September 2020 (1st meeting)

To kickstart data collection through Focus Groups, it was decided to host an internal Focus Group meeting among consortium participants. This coincided with a ROBOMINERS online consortium meeting in September 2020. ROBOMINERS participants in this exercise were raw materials and robotics experts, mainly constituted by partners responsible for developing relevant technological outputs for the robot: mine design, mining equipment, robot control and perception, etc.

Research questions asked varied between 1) the future of robotics and raw materials sectors on their own and their entwinement, 2) what the ROBOMINERS concept is missing or needs in critical improvement, 3) what research and technical aspects could be added to the concept, 4) what are ROBOMINERS key weaknesses and problems with development and implementation, 5) the impact ROBOMINERS can have on socio-economics and 6) how will mining look like in 2030 and 2050 and

what place can ROBOMINERS have then (Figure 1). Participants were engaged in answering 13 questions within the above topics.

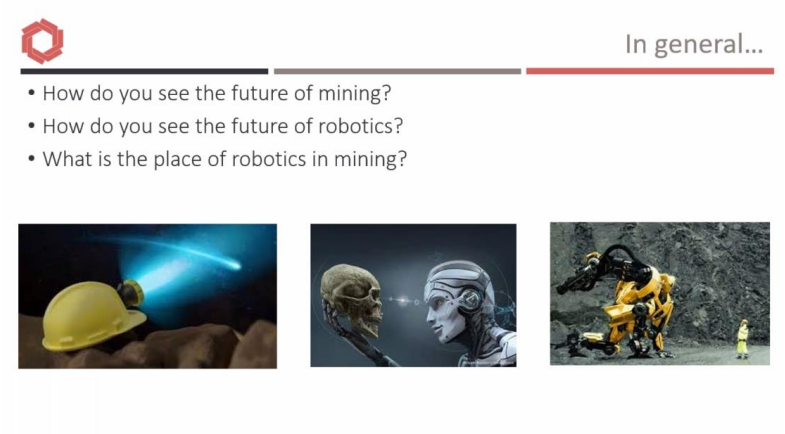

Figure 1: Driving questions example for Focus Group 1.

After the Focus Groups session, participants were invited to further contribute to the research questions (offline, based on the minutes of the Focus Groups). Below are the main points arising from the data collected:

Future of mining:

1) "Mining will be fairly automated, including many aspects related to it (e.g. processing), but never 100% through the whole cycle – e.g. mineral exploration won't be fully automated."
2) "Mining will take place in different conditions than today: reopening of closed mines for re-exploitation, mining on the moon and strong urban mining were stated as solid contenders."
3) "There will also be an incremental effort to develop new methodologies and mechanisms for mining in currently uneconomically or unfeasibly regions (e.g. deep-sea mining, deep underground mining, small deposits)."
4) Some participants showed apprehension for the future of mining in Europe due to socio-environmental constraints.

Future of robotics:

1) "More and more activities will be implemented by robotics; they will become cheaper and available to everyone."
2) "Robots, as they appear in movies, won't be a reality for 50 years."

Place of robotics in mining:

1) "Robotics will take part in mining phases (e.g. sorting and processing automation will be implemented, selective mining and processing for ore, extraction and handling of material, search and rescue in mining)."
2) "Robotics will play a crucial role in mining in extreme places and conditions with economic and technological feasibility."
3) "There is potential of zero-personnel mines, with fully automated and autonomously working robotic mining machines."

What is ROBOMINERS missing:

1) A whole-system integrating view.
2) Decision making, where to mine and how.
3) A fit-for-all approach for the concept/design.

4) "Configurability and viability in the management system of the robot to target different conditions."
5) "An adequate test site."

What should be more developed/upgraded:

1) An effective transport system for ores and waste.
2) Situational awareness.
3) Downhole and uphole transport, self-assembling and disassembling the robot.
4) Automated mine mapping and material sample analyses.
5) "Managing the stability of the borehole and the whole mining environment."

What should be added to ROBOMINERS:

1) Cooperation/task-sharing among robots agents.
2) Interaction robot-human.
3) Maintenance and repairing robots.
4) Specialised robots and more than one robot.
5) "A constant link to a group of experienced practical mining engineers with considerable underground experience."

Specific concerns, issues or problems:

1) All participants stated that it is still too early in the development and implementation phase of ROBOMINERS to assess this question.

"

ROBOMINERS key weaknesses:

1) The size and power of the robot.
2) The multidisciplinary of the technology and the approach.
3) "Requiring a brand new approach to mine design, which makes the concept hard to conceive and put in a sequence of real solutions."

How can ROBOMINERS guarantee social acceptance:

1) "Replacing mining with robotic mining in Europe will help with social acceptance."
2) "Guarantee positive environmental impacts."
3) "By educational work and good communication about mining. "
4) "Contraposing downsides (e.g. not providing many jobs) with upsides (e.g. mining deeper, making any mining feasible and invisible – including processing)."

How is the future of mining in 2030/2050 and the place of ROBOMINERS:

Future of mining:

1) Without people.
2) Mining taking place in extreme conditions.
3) Mining becoming invisible, with small scale mining with very small and selective machines.
4) Minimised tools and costs with maximised efficiency.
5) "Mining happens "on-demand"."
6) Views for 2030: partly automated and electrified mines with semi-autonomously working robots.
7) Views for 2050: Fully automated and electrified mines with zero personnel region and autonomous mining machines.

Place of ROBOMINERS in the future:

1) Some participants think that the concept won't change much, but rather be adapted.

2) Others think that the concept as of today will change a lot making the current robot miner unrecognisable.
3) Despite this, they all agree that ROBOMINERS can be the basis for further projects and industrial work.

4.2 Focus Groups#2 - 17th March 2021 (2nd meeting)

The second Focus Groups was held just with external experts from the mining and raw materials sectors, thus being the first exercise run solely with participants with very limited knowledge on ROBOMINERS. This aspect is rather important, since it allowed participants to give their unbiased reactions and comments on ROBOMINERS.

For this group of participants, the Focus Groups changed in tone – different presentation and questions were asked due to the external nature of the participants. Here, the questions included: 1) strengths and weaknesses of existing mining technologies, 2) shortcomings/unmet needs with these technologies, 3) new ideas, 4) factors driving the mining sector, 5) the ROBOMINERS concept and implementation (Figure 2). Participants answered to a total of 13 questions.

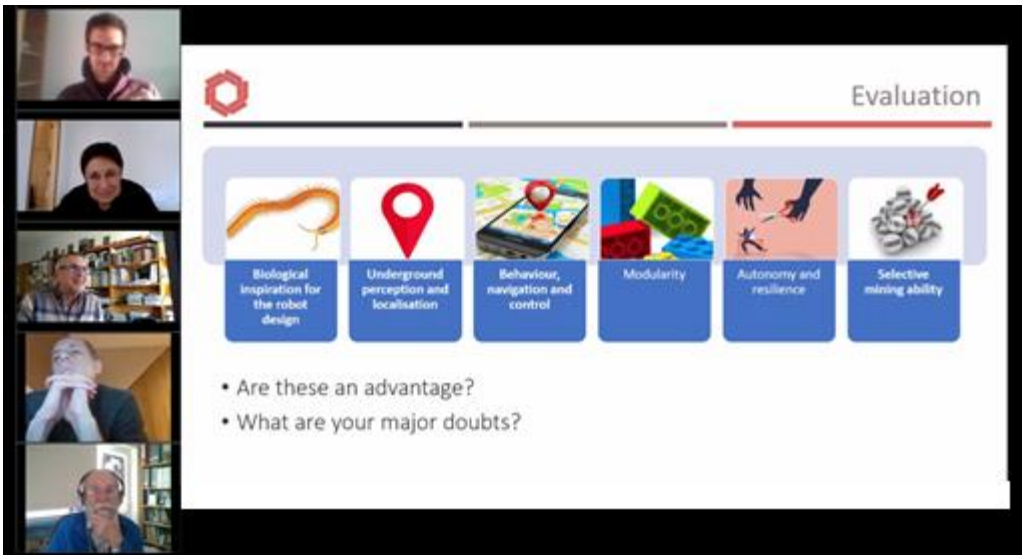

Figure 2: Driving questions example for Focus Group 2.

After the Focus Groups session, and similarly to the first group, participants were engaged to further contribute to the research questions (offline, based on the minutes of the Focus Groups). Below are the main points arising from the data collected:

Strengths and weaknesses of existing mining technologies/approaches:

Strengths

1) "Mining technologies have a huge potential and production capacity."

Weaknesses

1) Difficulty in bringing mining to harsh environments.
2) Low social acceptance of mining.
3) "The mining sector is still very traditional."
4) "Mining activities are still using too much manpower."

Problems/shortcomings/needs:

1) "The need for information, especially real-time information."

What new ideas caught the eye and/or should be implemented:

1) Rock and grades analysis in situ.
2) "An aerial mapping service that uses drones operated from underground mining shafts or galleries. The drones are scanning the underground mines in an effective way. The data goes directly to a computer and is analysed by the mining people."

What factors drive the mining sector and/or that should be applied:

1) Innovation and automation of processes.
2) Mining becoming more cost-efficient.
3) "Raise mining effectiveness and capacity to uptake new technology."

Important technological aspects for future mining :

1) Treatment of real-time information and data.
2) Use of virtual reality for mine planning and adaptation.
3) Automation of processes.
4) "Towards asteroid mining with a lot of space projects and technologies."

What do you think about the ROBOMINERS approach and concept:

Plus

1) "Very ambitious."
2) "Interesting."
3) "Possibility of bringing zero life loss."
4) "Zero accidents in mining."
5) "Feasible."

Minus/Concerns

1) "The sites chosen for trials are not totally adequate."
2) "Uncertainty when drilling."
3) "Possible uses for robot miners and "generic vs unique" approach."
4) "How is mine planning done."
5) "How to characterise resources."
6) "Perception and selective mining will be difficult."
7) "Knowing where to mine and how."
8) "Difficulty in planning exploitation in advance. "

What could be added later on and or missing:

1) "A much smaller scale designed to be able to target even smaller and more precise deposits."
2) "A robot that goes over the mine wall and collects the mineralogy of relevance."
3) "In situ analysis and testing to know what is happening and being able to plan."
4) "Handling waste, including toxic or radioactive waste."
5) "Use other transport ore mechanisms besides slurry, which might not be possible in all conditions."
6) "Employ more possibilities for production tools."

4.3 Focus Groups #3 – 7th April 2021 (3rd meeting)

Similarly to the previous iteration, the third Focus Groups was held just with external experts from the raw materials sector. A similar scope was involved in the definition of this exercise, with questions being identical to the second Focus Groups Figure 3). A total of 12 research questions were asked.

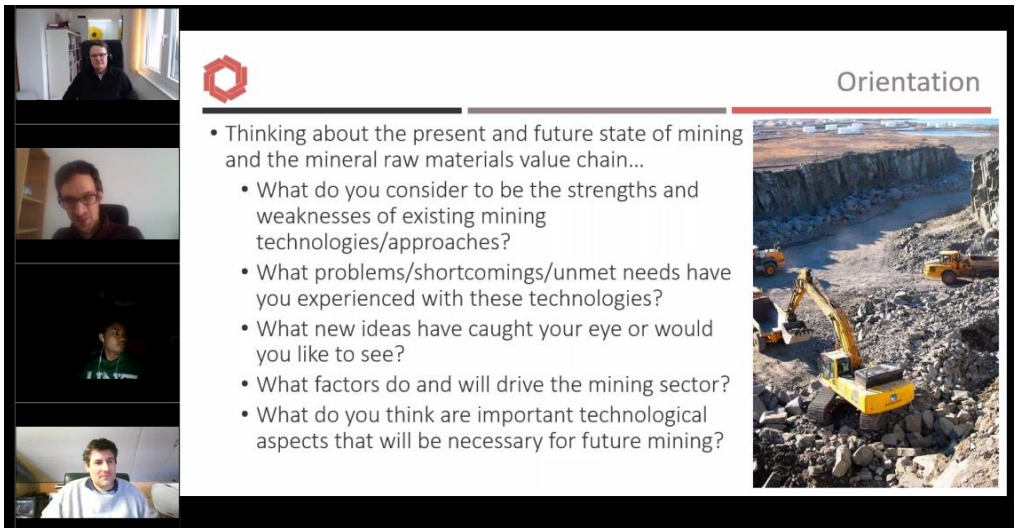

Figure 3: Driving questions example for Focus Group 3.

After the Focus Groups session, and similarly to the first group, participants were engaged to further contribute to the research questions (offline, based on the minutes of the Focus Groups). Below are the main points arising from the data collected:

Weaknesses of existing mining technologies/approaches & Problems/shortcomings/needs:

1) High costs of the mining industry.
2) Big amounts of waste materials still produced.
3) Misconceptions on Net Present Value of mining.
4) Short/lacking orebody intelligence.
5) "The low social acceptance of mining operations (especially in Europe)."
6) "Easy to access deposits are less and less common, meaning there is the need to mine in different conditions such as remote areas, go deeper, etc."
7) "Mining still very traditional and not digitalised enough when compared to other sectors and its potential."

What new ideas caught the eye and/or should be implemented:

1) "Mine and production planning with recent upgrades in surveying and remote sensing and other technologies."
2) "Extractive technologies (from routine maintenance to predictive maintenance; remote and autonomous mining fleets; online controlling, infrared and x-ray on conveyor belts for real-time decision making)."
3) "Have a replica of the mine online and use big data to make decisions – optimise extraction efficiency, resource usage, minimising impact, etc."

What factors drive the mining sector:

1) "Money and competition."
2) "Shortage of skills in the mining sector and market."
3) "Geographical/Political forces and drivers."
4) "Policies – fostering employment, environmental regulations, etc."

Important technological aspects for future mining:

1) "Development of mining companies to be efficient and economically viable, plus community involvement (Social License to Operate), try to use fewer resources (water, energy, reducing emissions plus become safer, reducing the number of people in mining operations)."

2) “Advance machines and robotics will need to be more reliable.”
3) “There needs to happen a significant development in how to do condition monitoring before machines break down, preventing machines from getting stuck and creating problems.”
4) “New technological improvements in the way minerals are leached / “digested”/ broken will be much developed.”
5) “An effective way to sort ore and waste.”
6) “Artificial intelligence, the industrial internet of things, sensors, etc.”

What do you think about the ROBOMINERS approach & What do you like and do not like:

1) “Good approach/concept but only conceivable in 30-50 years’ time.”
2) “Many individual ideas that are particularly good. If implemented in stages/steps could be very useful for advancing the possibilities of mining.”
3) “Use an existing mining approach together with some of these concepts would be already a huge step towards the ROBOMINERS final concept (implemented in the relatively short term).”
4) “As a roadmap and vision for “what we would like to mine in 50 years”, it is a very good concept. In terms of practicability on what the project can achieve, there is a 50-year development and many stages in-between, where individual approaches of the whole technology could be employed at different stages, paving the way for the evolution of the entire system.”
5) “Consider the possibility to invest in the crushing rock + transport to surface approach at this stage of development.”
6) “Many different geological conditions can be present in the working environment, which will probably require other machines/solutions to address different exploitation scenarios.”

Doubts about ROBOMINERS implementation:

1) Methods to access the rock.
2) Hard rock and soft rock require different mining approaches.
3) How to implement in existing mines (for South African standards this would be difficult to work).
4) “Different rock types are also very important: to mine hard rock you need high power, force and that typically translates into big machines. From a machine perspective, it is a very challenging approach, challenging on the design.”
5) “Doubts on mining and extraction aspects (producing a slurry and making as much processing as possible underground would be the best way to do it, finishing in the surface.).”
6) “Sensing the ores (the concept won’t be able to apply the same technology to all mineralogy. Perhaps start by targeting only few mines and be able to analyse those minerals and then proceed to more diversification).”
7) “Good approach and concept to “go smaller” and focus on the relevant areas to mine, with less waste produced.“

What could be added later on and or missing:

1) “Possibility to employ laser technology, comparing to drilling - but perhaps there will be technological challenges. Another technology to vaporise the waste and leave the minerals to be exploited could also work.”
2) “Perhaps lichens could be investigated as biological inspiration for dissolving minerals. As a project, try to understand better how organisms do it. Maybe there is a means of selective extraction through a digestive slurry.”
3) “Many of the technologies planned already exist and could readily be used. Perhaps resize them to an adequate size for the robot miner and use it. To have rapid technology advancements, start using existing technologies and combining them in a new visionary way.”

4) "There are new concepts such as using jet fuel to cut rock far quicker than existing means, that could be added to ROBOMINERS."

Is the ROBOMINERS technology a "yes", "no" or "maybe"?

1) "For me, ROBOMINERS is "a maybe". I can certainly see aspects of the concept, that if developed, could be an advancement in mining technology in general which could lead to a new product – not the robot miners necessarily. I think that robot miners could be ready in 50 years. What might be missing from your side is a manageable and realistic roadmap."
2) "Even with a very unfinished robot miner, you would already be pushing the boundaries of what can be achievable in such a short timeframe. I can see many aspects of robot miners being useful to develop, and there are many companies developing these items. Perhaps it would be better to pack them together and make a non-optimal machine that can work."
3) "Once you have such a general/gross looking machine, you can start at scaling the size and components down. The biggest hurdle is "how are you going to get over the mechanical means of cutting rock."
4) "Any new development starts with a crazy idea. It is this crazy idea that pushes people to come with something new. In my view, you are at this stage. It is early to answer this yet. By 2023, we will be able to answer this question, together with the help of the roadmaps for the future."

4.4 Focus Groups #4 – 30th April 2021 (4th meeting)

The fourth Focus Groups was held with external and internal experts from the robotics sector and was the first Focus Groups dedicated explicitly to robotics aspects of ROBOMINERS.

For this group of participants, the Focus Groups changed in relevant topics – a different presentation and questions were asked due to the expertise and nature of the participants. Here, the questions included: 1) strengths and weaknesses of current technologies, 2) new ideas for general implementation, 3) factors driving robotics developments and implementation, 4) the ROBOMINERS concept and implementation towards robotics aspects (Figure 4). A total of 10 questions were made.

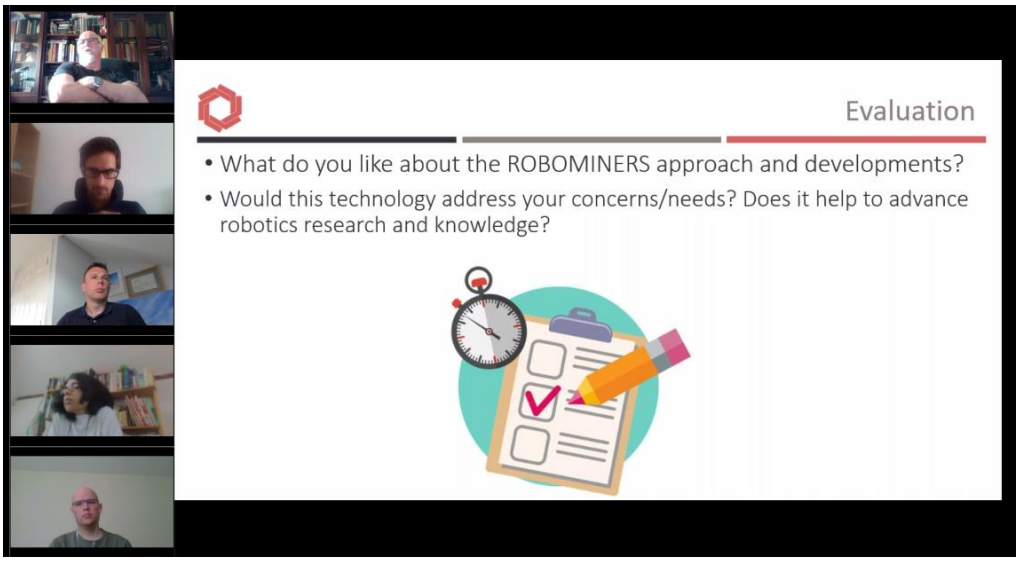

Figure 4: Driving questions example for Focus Group 4.

After the Focus Groups session, participants were engaged to further contribute to the research questions (offline, based on the minutes of the Focus Groups). Below are the main points arising from the data collected:

Weaknesses of existing technologies/approaches:

1) Lack of robustness and adaptability of robotic systems.
2) The embodiment of solutions.
3) "Interaction with reality, in the sense that it is not predefined and pre-controlled."
4) "The flexibility of the control systems to manage open-ended situations."
5) "Systems not well equipped to deal with novelty and with ambiguity."
6) "Problems in miniaturisation arise because the actuators do not have a good combination of physical power, energy to deliver the power, and cooling/ventilation."
7) "Stakeholders are also a weakness in robotics implementation (hate the flexibility and want safety)."
8) "There is a mismatch between the ambition in robotics and the needs of industry."
9)

What new ideas caught the eye and/or should be implemented:

1) "Modularity, being able to change."
2) "Compatibility."
3) "Open source and results sharing amongst different teams."
4) "Standardisation for collaborative approaches."
5) "Defining the concept of task."
6) "More biologically driven ideas."

What factors do and will drive robotics developments:

1) "Development of greener energy and conservation."
2) "Money and funding (environment, government, jobs, etc.)."
3) "Robots adaptability, resilience, usefulness."
4) "Investment in space robotics as a big driver."
5) "Fabrication of robots."
6) "Robotics applications as a multidimensional implementation goal."
7) "Physical interaction in a mission-oriented level, between the robot and the physical system."

What do you think are important technological aspects that will be necessary for further robotics implementation in human activities:

1) Communications.
2) Cybersecurity.
3) Miniaturisation, fabrication challenges and battery power.
4) Alignment of human and robot conceptualisations.

Major doubts on ROBOMINERS approach and concept:

1) "If the vision is to be fully autonomous, the robot would need to establish themselves, correct for their faults. Furthermore, the team will need to be able to pull the robots out, dismantle robots, etc. The steps of going into the mine with the robot, e.g. modularity, needs to be such that you can cope with failure. If the robot fails in a key place and you can't let anybody in, need to take robots apart, etc. In the future, you need to take these failure possibilities into account. Autonomy is very advantageous to take humans out of mines."
2) "You can go into the surface of the rock, but going into the rock will be really difficult".
3) "Very specific targeting, then you really need to worry about the structural stability of your environment."

4) "How to provide support for the mine operations, structural stability and keeping open the paths for movement."
5) "The problem of pumping out the slurry."
6) "Rock hardness can become a limitation to the technology."

Needs development/missing:

1) Robustness of the robots/system.
2) "Perception and selective mining ability (essential to prove short term operation)."
3) "Autonomy, flexibility, resilience and sustainability (for longer-term operation)."
4) "Reduce the size of the robots to have even more selective mining."
5) "Have full 3D dimensional sensing."

What do you like about the ROBOMINERS approach and developments &
Would this technology address your concerns/needs &
Does it help to advance robotics research and knowledge:

Advance robotics research and knowledge in:

1) Sensing without vision.
2) 3D behaviour.
3) Sensoring coping with the environment.
4) Different designs of locomotion.
5) "Control in environments that change and that robots need to adapt to."
6) "Autonomy presents issues with generalised ability. You can only train based on what you have seen. But then you need the robot to deal with the unforeseen, unknown. You are working on a problem that you cannot solve. It is too challenging to solve in the next 2-3-4 years, right? You can make advances, but the most you can do is produce a prototype to address some of these specifications. My point is: we can get further by working together, especially on the low TRL stuff. It would help if we work together on the conceptualisation, standardisation and even on sharing bits of science. We can move on to things that we see as main challenges."

What would you like to see added or changed to the robot miner &
What do you think it is missing &
What could be added later on?

1) Alternative use cases.
2) Multi-tasking robots.
3) Better ways to moving the waste.
   "Interaction with humans.
4) Tasking and human safety.
5) Collaboration and coping with other systems that are not the robot.

4.5 Focus Groups #5 - 4th May 2021 (5th meeting)

Similarly to the previous iteration, the fifth Focus Groups was held with experts from the robotics sector. A similar scope was involved in the definition of this exercise, with questions being the same as in the fourth Focus Groups (Figure 5). In total, 10 research questions were posed to the participants.

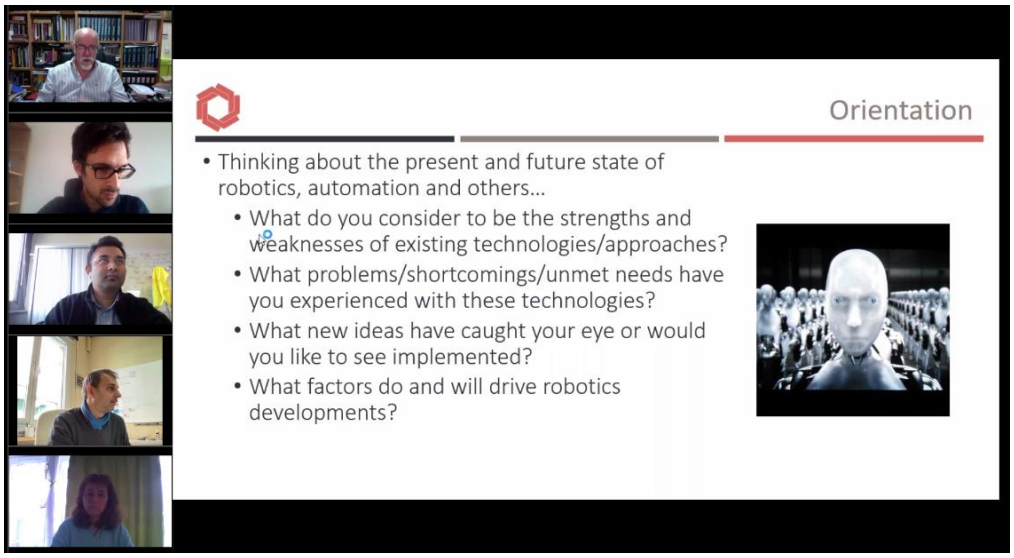

Figure 5: Driving questions example for Focus Group 5.

After the Focus Groups session, participants were engaged to further contribute to the research questions (offline, based on the minutes of the Focus Groups). Below are the main points arising from the data collected:

Weaknesses of existing technologies/approaches & problems/shortcomings with them:

1) Autonomy of robots.
2) Capability to understand missions, situations, goals and possibilities.
3) The resilience of systems.
4) "Controllers are too rigid and incapable of dealing with uncertainty and change – how to handle the unexpected and the unknown are problems."
5) "Solutions that are trustworthy dealing with multiple heterogeneous types of sensor data – current approaches can process such data to a certain extent, but now there are even more challenges related to big data: volume, velocity, variety, etc."
6) "Autonomy that has more to do with planning (online, reacting, perception level, etc.)."
7) "Descriptions are high-level in text and, in the end, there is a significant gap/lack of formality in the analysis of these capabilities."
8) "Lacklustre interaction between elements."

What new ideas caught the eye and/or should be implemented:

1) More formality and rigour.
2) How much can be quantified with autonomous robots.
3) Uncertainty aware methods and explainable AI.
4) General robustness of solutions.
5) "More formality in the definition of system and environment, and characterising the properties being searched for."
6) "Opportunistic science, very high-level autonomy, where the robot chooses its own goals; not in a set of predefined goals, but can define new goals by itself."
7) "Having multiagent systems working as well as they can, cooperating, collaborating, well-coordinated, and to have real use cases where these work."

What factors do and will drive robotics developments:

1) User needs.
2) Real societal/political will or pull from the market or society.

3) Robust robots.
4) Different levels of autonomy will drive robotics.
5) “Money from public bodies to fund research and money from customers/end-users that need robotics applications.”
6) “Another point is that robots are there to replace humans - acceptance by the industry of the technology.”

What do you think are important technological aspects that will be necessary for further robotics implementation in human activities:

1) Cybersecurity.
2) Communications (new ways of communicating).

Advantages of ROBOMINERS approach/concept:

1) “Advantages are many: can see many applications, from space to drill exploration wells, somewhere to find mineral seams, low costs exploration, taking samples and retrieving them, especially for minerals. Oil and gas also. Even for inspection on fracking sites. Reach areas where humans cannot reach.”
2) “The concept of the ROBOMINERS project can be applied to different areas, and this is one of the project strengths.”

Doubts on ROBOMINERS approach/concept:

1) “In any new concept like this, there will be unforeseen challenges. Specially drilling through hard rock. If the robot is down the mine and gets stuck, retrieving it can be difficult. You need to think about some robust and simple mechanism that can bring the system back to the surface if you cannot lose it. You will need to find a way to free the system if it gets stuck. With the modules, this can be a way to at least save some equipment.”
2) “The environment of operation is very challenging. If it is dusty, sensors are much less useful, you need to deal with this too. If it is underwater or muddy, also the same, almost no vision.”
3) “Going underground is one of the biggest problems. For demonstration sites, and if the rock is too hard, then there might not be enough power to dig, but if the rock is too soft, there is a risk of collapse.”

What would you like to see added or changed to the robot miner &
What do you think it is missing &
And what could be added later on?

1) More money/funding directed for production tools.
2) Multi-robot miners.
3) “Try to use Ground Penetrating Radar.”
4) “Data from a Ground Penetrating Radar and acoustic sensor data could potentially be used together.”
5) “Collaboration - having many robots and having robots interacting with humans and collaborate with humans, collaborate with heterogeneous robots.”
6) “More robustness and adaptability of solutions.”
7) “A follow-up project would indeed give the opportunity to explore not only how multiple robots would solve the task but also new types of sensors, a combination of wireless networks and the existing sensors.”
8) “A robot that is tolerant to failure is a very difficult task, but having a few of them that can help each other, could be a much easier problem to solve. “

5 FOCUS GROUPS FOLLOW UP

To further contribute and adapt views, participants were contacted *a posteri* of each exercise to have the chance to re-answer the questions posed. This also allowed interested parties who could not attend the online activities (due to time constraints or other commitments) to provide their views. Follow-up was done within a week of the respective Group exercise, with results received in a five days period.

With all the necessary information gained from each session (and their follow-ups), one report per session was produced. These reports are internal documents that helped in the creation of this deliverable and its recommendations. They contain administrative information as well as the processed replies of the participants to each question. They will only be shared within the ROBOMINERS consortium and be used for the implementation of other Tasks under WP8 or even the project itself. These internal documents, which contain participants' replies, got their consent for this purpose.

6 RECOMMENDATIONS MADE BY THE FOCUS GROUPS

The objective of task 8.2 is to collect recommendations made by experts from Focus Groups exercises. This was done considering the exercises themselves as well as the follow-up approach. The internal documents produced for each Focus Group session were used for this purpose. Recommendations made by the Focus Groups hereby presented span from direct project implementation aspects to more transversal and supporting ones. Recommendations are divided amongst four categories: 1) Methodology and approach, 2) Improvements and changes, 3) Test sites, and 4) Applications.

6.1 Methodology & Approach - recommendations and comments

During ROBOMINERS:

#1: better definition and creation of mine planning and resource characterisation, especially in the unknown environments that are new mines.

#2: develop and implement mine mapping and material sample analyses adequate methodologies that can improve on the preliminary geological knowledge.

#3: consider other options for production tools in order to have more available options, also depending on different mine layouts.

#4: implement individual approaches of the whole technology that can be employed in at different stages of ROBOMINERS development, paving way for evolution of the whole system at incremental steps.

#5: focus on developing perception and selective mining abilities, essential to move forward with ROBOMINERS development.

#6: employ more biology-related aspects that could benefit ROBOMINERS in all aspects of implementation.

#7: do technology transfer and clustering with space mining companies and projects, that can lead to the adaptation of the ROBOMINERS concept on Earth and extend it to Space.

#8: showcase the social-economic potential impacts of the ROBOMINERS mining approach. This is an essential step for any new mining application to be successful.

After ROBOMINERS:

#9: invest in the collaboration between robotic agents, robots interacting with humans and collaborate with humans, which is currently missing.

#10: conceptualise and develop different robot miners for different exploitation scenarios, extending the ROBOMINERS application opportunities to different conditions.

6.2 Improvements & Changes - recommendations and comments

During ROBOMINERS:

#1: develop the ROBOMINERS downhole and uphole transport concept and improve self-assembling and disassembling of the robot miner.

#2: study the possibility of using leaching as a mining method, in a novel way to extract targeted minerals.

#3: use Ground Penetrating Radar (GPR) on the robot miner. It is a very useful way to know densities and types of materials, which can be very critical for operations. Data from a GPR and acoustic sensor data could potentially be used together.

#4: develop and implement ways to have stability and managing the stability of the borehole as a critical aspect for operations.

After ROBOMINERS:
#5: improve the decision-making processes – where to mine and how – of the robot miner.
#6: consider the implementation of new production and transport methods in new robot miners approaches.
#7: consider the development of a new robot miner design for the future. A new design would be one that would address the main trends for mining in the future:

- Mining in extreme conditions (deep temperatures and pressure; space)
- "Invisible" mining
- Small-scale mining with very small machines and very selective mining
- Minimised tools and costs with maximized efficiency
- Combining biological activity with machines (Using bacterias together with nanorobotics)
- Mining on demand, i.e. a smart control of the whole supply chain, allowing rapid reaction on raw material demands by putting in/out modular units of robotic mines within short notice.
- 2050: Fully automated and electrified mines with zero personnel region and autonomous mining machines. Difficult to automate maintenance and utility work.

#8: have more specific robot miners than a fit-for-all robot miner, translating into better results and in more applicability of the technology.

6.3 Test sites - recommendations and comments

During ROBOMINERS:
#1: re-scope the initial set of trials changing from harder to softer rocks (e.g. potash or coal), in order to prove the concept and change to harder rocks further down the line with a higher Technology Readiness Level.
#2: have a test-mine, where components and prototypes of the robot miner could be investigated and probed in near-real conditions. Also suggesting that this test-mine could be near-surface.

After ROBOMINERS:
#3: Regarding test-sites, experts commented that a 'Kupferschiefer' formation target (as defined in the ROBOMINERS proposal as an example of Ultra-depth possibility) for testing the robot miner is a good approach, but this would need the robot to be adapted to higher temperatures.

6.4 Application - recommendations and comments

During ROBOMINERS:
#1: use the robot miner in the fringe of operating mines (where there are still economically feasible resources but which are difficult to reach with current mining technology.
#2: showcase different uses for the technology. Examples include use in deep sea mining operations.

After ROBOMINERS:
#3: change the actual robot miner concept to have a new miner able to mine even deeper (e.g. that could be used in South African mines).

7 CONCLUSIONS

The Focus Groups were a qualitative method to collect data on topic akin to ROBOMINERS – raw materials & robotics – from where experts' impressions and views were processed to generate recommendations for implementation of the ROBOMINERS project now and in the future.

During the period September 2020-May 2021, five Focus Groups meetings were hosted, counting with the participation of 25 internal and external experts from both raw materials and robotics fields. Project/internal experts participated in the first, four and fifth meetings, while external experts participated in the remaining four. These allowed for a diverse and qualitative collection of input that fits the task's plan.

Recommendations collected are divided among four main groups of actions (during and after the ROBOMINERS funding period):

1. Methodology and approach
    - 10 recommendations
2. Improvements and changes
    - 8 recommendations
3. Test sites
    - 3 recommendations
4. Applications
    - 3 recommendations

The Focus Groups exercises, also served as a means to study and understand experts perception on the use of ROBOMINERS. Some key strengths were identified by them (e.g. the real possibility of bringing zero life loss as well as zero accidents in mining; application of the technology in other areas), but also some weaknesses were pinpointed (e.g. the limiting size and power of the robot; requiring a brand new approach to mine design). A few constraints of implementation, which the consortium should act upon, include the not adequate selection of test sites (i.e. hard rocks) or necessity to improve on the production and transport of the ore from the mine to the surface.

Most of the recommendations by the Focus Groups experts involve changes – some of them internally identified during the project already - to the initial ROBOMINERS approach since these recommendations are based on implementation knowledge derived from the first stages of the project. These recommendations expand the project scope and expected impacts to a bigger array of application environment (e.g. more mines).

The recommendations contained within this document are now shared with the ROBOMINERS team to be screened for direct implementation. Besides this, the recommendations, as well as the data collected during the Focus Groups sessions, will allow the development and implementation of upcoming tasks within WP8, namely Task 8.3 - Horizon Scanning & Visions and Task 8.5 – Roadmapping.