Executive Summary:
The Challenge:
Future tunnelling projects in Europe are expected to generate around 800 million tonnes of excavated material, which is usually disposed of in landfills. Efficient use and recycling of that material would substantially reduce the demand for primary mineral resources, thereby improving resource efficiency, reducing environmental impacts and sending less material to landfill. Finding a solution to this challenge is therefore of great economic and environmental interest.

The DRAGON Approach:
DRAGON (Development of Resource-efficient and Advanced Underground Technologies) aimed to solve the before mentioned challenge by developing a system for the automated bypass analysis, online classification and in-stream sorting of excavated material. All units are intended to be directly integrated into the tunnel boring machine (TBM) so that the entire processing chain from analysis to sorting takes place underground. This novel approach will maximize the use of excavated material from underground infrastructure projects in the future. The sorted material can be used as aggregates on site or in other industrial sectors such as the cement, steel, ceramic or glass industries, thus significantly increasing resource efficiency in tunnelling.

Life Cycle Assessment (LCA) and mass flow analysis were carried out to quantify and compare different scenarios of use and disposal. This will help to determine the potential environmental benefits for future European tunnelling projects and provide a sound basis for decision making by authorities.

The Benefits:
• Development of breakthrough technologies to secure innovation leadership for the European tunnelling and underground construction industry.
• Sustainable domestic supply of mineral resources within the EU by maximizing the use and recycling of excavation materials, generating an estimated direct annual value of around EUR 150 million.
• Substantial reduction in environmental pollution, CO2 emissions and land use for the disposal of excavation material by greatly reducing waste from underground construction.

The DRAGON System:
Advanced photo-optical, x-ray and microwave technologies were used to analyze the continuous mass flow of excavated material on the back-up system of the TBM.

The automated online sampling and characterization of physical, chemical and mineralogical properties provided the basis for assessing the suitability of the excavated material for different end-use options. A future downstream underground separation plant will handle the material based on the online test results and requirements for intended use.

The process steps in detail:
Excavation process: Excavation of material at the heading face by the TBM's cutting wheel, including characterization of rock properties using a disc cutter load monitoring system.
Main material flow: Discharge of the excavated material via the TBM's main belt conveyor.
Sampling: Splitting off the bypass material flow using a hammer sampler.
Elemental analysis: Material preparation by crusher and bypass belt conveyor, followed by high-precision microwave moisture measurement and online x-ray elemental analysis.
Grain size analysis: Photo-optical analysis for parallel determination of grain size distribution.
Sorting: In-stream sorting of the excavated material based on the online classification results.

Project Context and Objectives:
During the DRAGON project a system of automated online-analysis techniques as well as units for the separation and recycling of excavated materials directly on the underground construction sites was developed. The results of the project will help to reduce or even eliminate material deposits thus aiming the production of zero waste originated from underground construction sites. The performed life cycle analysis provides scientific evidence that the provided underground measures result in more resource-efficient systems and less CO2 production. 

Thus the objectives of DRAGON were to develop new techniques in order to guarantee:
• fast detection of useable mineral resources;
• immediate separation of excavation materials of varying quality already within the underground construction site;
• the processing of such excavation materials on the backup system of the TBM;
• the achievement of the economic optimum in the material management;
• the supply of valuable mineral resources to industry situated nearby the particular underground construction site; and
• minimisation of land use or landfill capacity for disposal of excavation material.

Project Results:
The most important tasks of WP1 which were dedicated to Project Management were the set-up of the different project management bodies as well as the establishment of an efficient communication and monitoring structure within the DRAGON Consortium.
In WP2 (End User Requirements) the basic characteristics of the excavation materials to be checked “on board” of the TBM were defined. In parallel work was started to set up a mineral data base, which also included the possible industrial use of the particular mineral resource. Furthermore the current legal regulations regarding the DRAGON concept where shown for numerous European countries.
In WP3 (Material Analysis Techniques) improvements of the existing online analyzing units were performed. Furthermore a pneumatic lifting system for the OXEA has been developed. Significant results have also been achieved with the novel moisture meter. Last but not least a feasibility study for a new method to determine low concentrations of heavy elements, using XRF technology has been created. One of the most important criteria for the recycling of excavated materials from TBMs is the rock strength. The approach regarding the automated online determination of the rock strength by online monitoring of the disc cutter load proved to be feasible. Therefore the development of a Disc Cutter Load Monitoring was started and successfully tested on an actual TBM drive. For the evaluation and classification of the excavated material the determination of the distribution of the grain size and shape is required. For the automated analysis of these parameters the technology from the company Haver & Boecker turned out as the most feasible method. In cooperation between Herrenknecht and InduTech the main dimensions and features of the bypass belt conveyor as a preparation for
Between 3.5 and 25 million Euros of disposal costs could be saved, depending on the negative ecological relevance of the material. Meters of disposal space and the same volume of open-cast mining with negative impacts on the environment could be reduced.

Advantage of approximately 50 million Euros. The aspired reduction of the disposed material to 20% would save 3.5 to 7 million cubic pigments and others. Austria for example plans to build 200 km of tunnels during the next decade. About 35 millions of tons of DRAGON is also to achieve valuable minerals which could be used for construction materials, steel production, ceramics, electronics, and productivity. The DRAGON Consortium provided sufficient experience and scientific excellence in order to guarantee the successful implementation of the DRAGON project on a European level. The DRAGON project aimed to contribute to the general European strategy and integration of different resource-efficient environmental technologies strongly depend on the ability to cope with the inherent complexity of technologies and environments in order to boost organisational, national, international as well as individual performance and productivity. The DRAGON Consortium provided sufficient experience and scientific excellence in order to guarantee the successful implementation of the DRAGON project on a European level. The DRAGON project aimed to contribute to the general European strategy of a) preventing waste, b) minimising waste and c) re-using it as a new valuable raw material. Besides that the business area of environmental and resource-efficient technologies is one of the fast growing economic sectors in Europe and quite important for the pioneering role of Europe in relation with an environmental-friendly policy. The technologies developed in DRAGON in order to reuse the excavation material will have (in the future) a fundamental impact on:

- sustainable management of limited mineral resources;
- higher resource efficiency through a recovery process and related decrease of EU dependency on resource imports;
- lower environmental impact e.g. by slowing down other environmentally critical mining processes;
- more competitiveness of all underground construction related companies/organisations;
- new resource-efficient environmental technologies.

The rate of utilization of excavated materials from tunnelling will be significantly increased. Besides increasing this rate the goal of DRAGON is also to achieve valuable minerals which could be used for construction materials, steel production, ceramics, electronics, pigments and others. Austria for example plans to build 200 km of tunnels during the next decade. About 35 millions of tons of excavation materials will be excavated. An increase of valuable utilizations for example up to 30% would already mean an economical advantage of approximately 50 million Euros. The aspired reduction of the disposed material to 20% would save 3.5 to 7 million cubic meters of disposal space and the same volume of open-cast mining with negative impacts on the environment could be reduced. Between 3.5 and 25 million Euros of disposal costs could be saved, depending on the negative ecological relevance of the material.
Transferring this situation to entire Europe these economic and ecological advantages could be multiplied with a factor ten to twenty. So the total impact for Europe is expected to be between 500 million and 1,5 billion Euros.

Scientific Impact

DRAGON aimed in a multidisciplinary way at the optimization of the research outcome and commercial exploitation of its results by mobilising the critical mass of scientific knowledge as well as eco-environmental application skills. Most of that expertise was already based on previous funded national projects & initiatives, in which some of the partners have been involved (e.g. one Austrian project (funded by FFG) which was dealing with the re-use of tunnelling excavation material and another German project (funded by DBU) which aimed at the development of an innovative separation technology for bentonite).

Novel and absolutely innovative technologies within DRAGON are:

Control of a tunnel boring machine by the fragmentation of the excavated rock which led to an optimisation of the machine operation. Scientific challenges in the DRAGON approach were the combination of optical particle size measurements on a continuous sample and its evaluation with respect to the natural breakage characteristics.

Therefore the connected scientific impact embraced technologies a) which allowed online-analyses considering grain size, grain shape, etc. under outstanding underground conditions as well as b) which allowed new separation processes and c) which facilitated recycling technologies of underground excavation materials under very limited space conditions.

Reducing the pressure on primary raw materials/preserving the environment/reducing pollution

The Domestic Material Consumption of the EU-27 as a whole is increasing. The biggest part consists of non-metallic minerals, especially sand and gravel. The exploitation of minerals is usually affected by conflicts between the economic interests of the extractive industries or the construction sector and environmental protection concerns, but also declining sizes of natural stocks have an influence. To overcome such problems new ways of making minerals available on a regional and local level through tunnel excavation projects is a possible solution. The excavation close to the users is very important because it will also help to reduce the consumption of fossil fuels for production, processing and transport.

Additionally DRAGON contributed to the European concepts to tackle the challenges in commodity markets and on raw materials (EC Raw Materials Initiative strategy document, Feb. 2010) by helping to make Europe more independent from the markets in terms of metallic minerals, industrial minerals and construction materials.

Fostering the use of secondary raw material

The European economy heavily relies on resource imports and has a risky dependency on countries with difficult political, social and environmental circumstances especially when it comes to high-tech metals.

The substitution of such sources for primary raw materials by tunnel excavation materials was a new and innovative way to foster the use of secondary raw materials.

DRAGON also supported the third pillar of the EC Raw Materials Initiative by boosting resource efficiency and promoting recycling. By transforming underground construction projects into a kind of new and innovative mining places to gain new raw materials DRAGON fits well to the framework of the Europe 2020 flagship initiative on resource efficiency, which was presented by the Commission in 2011.

Building up on more sustainable consumption and production patterns

Resource efficiency also in the underground construction area is an important driver of innovation and a key element for achieving sustainable development and hence also sustainable consumption and production. The DRAGON project contributed to the idea that the most valuable material is already separated (within the underground construction area) from less valuable or even hazardous substances in order to re-use that material with the highest quality as possible and to immediately re-use/transfer the material into other industrial production cycles (either directly on the underground construction side and/or in other industrial sectors such as cement, brick, ceramic, glass, steel and other industries).

From the organisational side that have very positive effects on the future workflow in the underground construction industry area itself because the excavation material is directly processed and separated into different process streams according to the corresponding quality and does not need to be stored temporarily outside of the underground construction site. The missing space in the portal areas of underground construction sites is one of the main reasons why most of the excavation material is disposed instead of it is brought into other industrial production cycles.

Increasing the role of SMEs as end users and developers of green technologies

The Consortium featured major participation of SMEs. That means that more than 50% of funding was dedicated to the SME partners which were experts in a number of underground construction areas and active in so called niche markets. Their roles can be
summarized as follows:

- Development of various high performance online analysis techniques.
- Development of new and innovative materials management concepts as well as setting-up models for the optimal transportation, storage and handling/processing of the excavation material (= valuable raw material within other industrial production cycles).
- Analysis of environmental performance and life cycle assessment (LCA).

Those fields of operation which were vital for DRAGON required a high degree of flexibility, innovation and expertise, properties which could be provided by the DRAGON SME partners.

The SMEs helped to disseminate the results among authorities and infrastructure operators for whom they normally work as independent underground construction experts. The knowledge they achieved through DRAGON will enhance their significance in their own projects and will provide new tasks for them in managing the material streams in a more sustainable and also in a more economical way. This kind of know how will strengthen their position in the national and international underground construction field. The cooperation with the industrial parties like HK and PORR enabled those SME partners to widen their business contacts and to enter new markets.

Impact on Society & Environmental Impact

One of the main objectives of the DRAGON project was to contribute to the natural resource conservation within the European Union. The reduction of solid waste volume in a range of about 300 Million m³ going to the landfill was a desired impact of the project.

Depending on the geological composition of the material it is possible to recycle up to 100% of the excavated material. The reduction of transport ways, the diminution of pollutants as well as the re-use of the excavation material possess a large environmental protection potential.

Besides that another important impact was related to a significant reduction of the use of new raw materials (primary resources) which have an impact on global warming, on the acidification and eutrophication potential, on the stratospheric ozone depletion and on the Photochemical Ozone Creation potential.

The main expected outcome of the LCA (life cycle analysis) was to provide scientific evidence that the re-use of excavated tunneling material results in more resource-efficient and more closed-loop related systems (even in the industry-related economy) in Europe.

Contribution to standards & relationship to important stakeholders

The DRAGON Consortium aimed to establish a close relationship to the external surroundings (national environmental authorities; standardisation bodies etc.) of the project in order to implement and integrate the project results/findings quite smoothly within the specific regional, national and/or international environment.

Main target of the DRAGON project was to act as Best Practise Case how underground excavation material can be re-used as valuable material in diverse industrial processes and sectors. In that connection the DRAGON Consortium got in close contact with diverse national & European stakeholders (some of them were already part of the Advisory Board) and tried to influence the diverse directives in order to guarantee the re-use of underground extraction material as new valuable input material for other industrial processes and industries. Beside that ISO Standards: 14040/14044 for Environmental management – Life cycle assessment were used in order to include “life cycle thinking into the project”.

Why the project required a European approach?

Statutory regulations concerning environmental technologies and waste management are currently governed by national authorities and are therefore completely inhomogeneous. The basic European vision towards finding a solution for the re-use of tunnelling excavation material is very well in line with the idea to set-up international standards and to solve such a problem on an international level.

The European Commission is one of the predominant drivers for introducing sustainable resource management as well as innovative environmental technologies/solutions and to strengthen the position of Europe in the global market of environmental technologies. The European level is therefore the right “ecosystem” in terms of stipulating support from the national environmental authorities and to provide adequate visibility of those efforts.

The present approach needed many competencies from many different scientific, technological, environmental and geological fields. So for example in order to develop new solutions which allowed the re-use of excavation material – the various underground conditions in Europe had to be examined. These embraced clay in London, which was the main geology at the huge underground project Cross Rail in UK to Alpine geological conditions, for example in the huge tunnel project Lyon-Turin between France and Italy. DRAGON intended to use especially the above mentioned underground construction projects as valuable case studies.

List of Websites:

Webpage: www.dragonproject.eu
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