Ref. Ares(2023)2099201 - 23/03/2023

DIGIECOQUARRY
INNOVATIVE DIGITAL SUSTAINABLE AGGREGATES SYSTEMS

Horizon 2020 research and innovation programme (Nº 101003750)

Deliverable D1.1

Requirements for improved extraction, rock mass characterisation and control report

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 101003750

Deliverable report

Deliverable No.	D1.1	Work Package No.	WP1	Task/s No.	Task 1.1
Work Package Title	Towards the digital innovative quarry - requirements for a sustainable, social, safe, resource-efficient quarrying operation				
Linked Task/s Title	Requirements for Improved extraction, rock mass characterisation and control				
Status	Final				
Dissemination level	PU	(PU-Public, PP, RE-Restricted, CO-Confidential)			
Due date deliverable	2022-03-22	Submission date	2023-03-23		
Deliverable version	6				

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Document History

Version	Date	Comment
1	2022-02-21	Draft for review
5	2022-02-28	Final Version
6	2022-03-22	First Project Review. Requested changes: Pages 9 and 15: state of the art has been incorporated in the background and VCWD sections, respectively; as a consequence a section with the reference list is added in p.33-34. Pages 13 and 28: explosives consumption expressed in kg.

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List of Abbreviations

Abbreviation	Description
ANEPLA	Associazione Nazionale Estrattori Produttori Lapidei e Affini
D & B	Drill and Blast
GA	Grant Agreement
KPI	Key Performance Indicator
KTA	Key Technology Area
MWD	Measuring-While-drilling
OEM	Original Equipment Manufacturer
UEPG	European Aggregates Association
VCWD	Virtual Coring While Drilling

1 Executive Summary

This document describes the pilot sites of the project: Valdilecha (HANSON, Madrid, Spain), Pioltello (Peschiera Borromeo - HOLCIM, Milan, Italy), Mammendorf (CRONENBERGER S.I., Saxony-Anhalt, Germany) and Alenquer (CIMPOR, Lisbon, Portugal). The report focuses on the excavation technologies and the monitoring systems in place. It outlines the developments to be carried out in each one of sites and the working and control technologies that need to be implemented for that.

2 Background

This report relates to pilot sites within DIGIECOQUARRY where rock is mined: HANSON-Valdilecha, Cronenberger-Mammendorf, CIMPOR-Alenquer and LAFARGE-HOLCIM-Pioltello. No reference is made to VICAT since no rock is mined in that site (its activity is mineral processing only) though this site might be incorporated to a revised version of this document should there be relevant issues in it related to rock excavation.

The report defines the requirements for a sustainable, safe and efficient site preparation and extraction by describing the status of rock characterisation, drilling and blasting and digging and hauling. For this, monitoring devices related with these stages are described. The resulting KPIs from these measurements are reported. The following steps are followed:

1. Actions and proposals for a sustainable management of environment protection, climate change prevention and ecological transition (related with energy, wastes, dust, gas emissions, water, land, discharges, noise, vibrations, rehabilitation).
2. Actions & proposals to optimise the management of the extraction process to increase efficiency and productivity. In terms of the extraction process, each one of the sub-phases will be analysed to propose specific tools for its improvement.
3. Assessment of all available techniques, testing and evaluation of feasible techniques:
    - Improvement of the exploration and extraction to maximise resource efficiency.
    - Improvement of the management of the rock quality in the deposit (minimisation of the mining wastes generated).
    - Optimisation of the distances covered by each mobile equipment; Coordination of the operations between related mobile equipment and, also, with stationary plants in order to increase energy efficiency, reduce the internal wear of the machines increasing their efficiency and lowering maintenance.
    - Optimise the energy consumption in the different phases of the extraction process and the global consumption.

In the last years, different tools and methods based on state-of-the-art- techniques have been specifically developed to control rock excavation and ore processing in small mines (Sanchidrián, J.A. 2018; Park and Kim 2020), which improves their feasibility, profitability and social license of these operations. Measurement-while drilling is a good example of how to assess rock mass characteristics from the response of the drill-rig while drilling (Desbrandes and Clayton, 1994). This technology provides an early information of the characteristics of the rock mass to be mined without disruption of production in terms of strength and jointing that can be used for ore grade control and blasthole chargeability assessment (Navarro et al. 2019; Navarro et al. 2021). The high initial investment of last generation drill rigs, where this technology is available from the manufacturers, difficult its penetration in quarries and make necessary the development of in-house solutions (Navarro et al. 2018). The absence of a universal formula (Fernandez et al., 2023) is another drawback that make necessary to get additional measurements of the rock mass characteristics, with in-borehole cameras or optical televiewer, to calibrate the models. These data are costly in terms of time and analysis, as an expert assessment from a geologist and massive data analysis techniques are required. The use of Artificial Intelligence techniques is playing more significant role due to its ability to solve complex nonlinear engineering problems where the physics are not fully understood or the relationships between parameters extremely complex (Jang and Topal 2014; Hosseini et al. 2022).

Another point of improvement, when drilling and blasting is employed, is the implementation of tools for Quality Assurance and Quality Control (QA/QC). Advances on Unmanned aerial vehicle (UAV) systems and algorithms for reconstruction of 3D models allows to bridge this gap and assess pre-blast conditions, including discontinuity mapping of the highwall face, and over/under excavation (Bamford et al. 2020; Stothard and Shirani Faradonbeh 2023). UAV has been also used to assess post-blasting conditions from over/under excavation to muckpile characteristics, including fragmentation (Tamir et al. 2017), where using 3D point clouds allows better particle delineations and implementation of classification algorithms (Campbell and Thurley 2017). These techniques are however, not further spread in quarries, where monitoring of the loading and hauling equipment is generally not possible despite of its advantages in terms of truck movement, fuel consumption among others. The variety of trucks and excavators from different suppliers used in a quarry make difficult to have a common fleet tracking system, being the high costs of existing systems from the machine manufacturers another drawback. In the last years, low-cost solutions have been appeared in the market (Aguirre-Jofré et al 2021) making these systems suitable for fleet management in medium size mines. In the DIGIECOQUARRY project it is planned to use the ABAUT system for that purpose and monitor the loading time of the truck which is a Key Performance Indicator of the blast performance.

3 HANSON: Valdilecha quarry

3.1 Overview

Hanson Hispania (HANSON) is a subsidiary of HeidelbergCement, which is the leading aggregates producer in the world with around 55 000 employees at more than 3 000 production sites in more than 50 countries on the five continents. Concerning membership and clustering, HANSON is member of UEPG (European Aggregates Association), ANEFA (Spanish Aggregates Producers Association), Oficemen (Spanish cement association), Cembureau (European Cement Association), Anefhop (Spanish ready-mix concrete association), GCCA (Global Cement and Concrete Association) and, additionally, partner of BirdLife International. The core activities of HeidelbergCement include the production and distribution of cement and aggregates. Its downstream activities include mainly the production of ready-mix concrete, asphalt, and other building products.

Valdilecha Quarry located in the Southeast of Madrid province has been chosen as pilot site for Digiecoquarry among its 10 active sites, as it has been used as a testing site for many company projects in the past years. An overall view of the quarry is given in Figure 1.

Figure 1. Valdilecha quarry.

The main information of the site, such as situation, climate, extension and post-mining land use, are reported here:

- Geographical coordinates: 40º 19’ 15.6’’ N, 03º 17’ 55.0’’ O
- GoogleMaps: https://www.google.com/maps/place/40%C2%B019'15.6%22N+3%C2%B017'55.0%22W/@40.3203888,-3.3001676,17z/data=!4m5!3m4!1s0x0:0x0!8m2!3d40.3210105!4d-3.2986119
- Climate: Mediterranean climate (Köppen climate classification: Csa, BSk)
- Total surface of the site: 878 706 ha
- Surface of the extraction area: 566 902 ha (or 65% of the total surface)

- Surface of the treatment plant area: 42 956 ha (or 5% of the total surface)
- Surface of the extractive waste facilities: 0 ha
- Surface of the areas not extracted yet, still in original state (as today): 268 848 ha (or 31% of the total surface)
- Estimated surface of the rehabilitated area: 56 300 ha (or 6% of the total surface)
- Distribution of surfaces by type of final use: Mainly agricultural. Part of the site will be filled in by Industrial waste Type II as restauration.

In the last years, the company is strongly engaged in the automation and digitalization of all production activities. HANSON is both globally and locally rolling out and ambitious project AOM (Automated Operations Management) where all employees record their activities through mobile phones (start and finish times of any activity), fuel consumption and other crucial data (i.e., breakdowns, cycle time, sock management volumes, etc). More details on the parameters monitored are given in the next sections.

3.2 Geology

In terms of regional geology, the site is located in the central-eastern sector of the Meso-Tertiary Tagus Basin or Madrid Basin. The surface, in general terms, is not very rugged, except on the banks of the rivers. The Neogene is subhorizontal or slightly inclined at the edges. There is evidence of recent neotectonic activity affecting the whole of the Central System and the Meso-Tertiary Tagus Basin, with large morpho-structural alignments defined by the Henares and Jarama rivers. From a general geomorphological point of view, the following elements stand out: the calcareous high plateaus of the Páramos, high plateaus due to an exhumed intramiocene erosion surface, forms of link between the high plateaus and the fluvial network (glacis systems, escarpments in dissymmetrical valleys and gradient reliefs due to the terraces of the Henares and Jarama rivers).

In terms of local geology, the stratigraphic sequence is as follows:

- Sandstones, sands and clays with abundant feldspars and variable proportion of metamorphic elements
- Grey clays, sandstones, gypsiferous marls, gypsum, bentonites and sepiolites and crowned by carbonate levels with flints.
- Conglomerates and sandstones of the intramiocene fluvial network
- Limestones of the Páramos, which is the main rock type of the quarry site.

The limestone density is about 2 700 kg/m^3, and the uniaxial compressive strength (mean and standard deviation) from 10 samples is 111 std. 11 MPa. Los Angeles abrasion coefficient that describes the resistance to impact is ranged from 19 to 27% (low values indicates that the rock breaks difficult into fine particles) for crushed limestone of sizes 4/8 mm and 12/20 mm, respectively.

The bedding is horizontal, and the rock mass is highly jointed with presence of cavities and clay zones (see Figure 2). Clay is an important source of fines, that contaminates the run-of-mine affecting to the resulting product fractions and to the performance of the plant. The rock mass characteristics, like structural conditions or lithological changes, are not currently assessed for each blast, which prevents for instance to adapt the explosive to the rock conditions, and estimate, in a priory, the percentage of natural fines or fraction of clay in the block.

Figure 2.Example of highwall face in Valdilecha quarry

3.3 Excavation (D&B) process

The quarry has three benches, and the rock is mined by drilling and blasting. A ROC L6 down-the-hole drill rig manufactured by Epiroc is used. The blastholes are manually marked with a measuring tape. The drill rig is not equipped with a Measuring-While-drilling (MWD) system and the performance of the drill rig is not monitored. Typically, the blasts consisted of two rows of 20 blastholes each. The main characteristics of the blasts are shown in Table 1. The explosive is ANFO with a density of 800 kg/m^3. The explosive is downhole initiated with one emulsion cartridge; charging is adapted to the presence of water in the boreholes. The blastholes are delayed with non-electric detonators. Commonly 35 blasts are carried out each year to produce 1 Mt of run-of-mine. The actual blast geometry, including hole deviation and subdrill, is not measured. This leads to toe problems in some blasts, while back-break is limited. There are no complaints about vibrations, therefore they are not a concern.

The consumption of explosive and detonators used in 2020 are 160 700 000 kg of ANFO and 2 950 000 kg of emulsion; the number of detonators used are 2 711 000 kg.

Table 1. Blast design characteristics used nowadays.

Hole diameter (mm)	131
Hole length (m)	16
Hole inclination (°)	19
Bench height (m)	15
Subdrill (m)	1
N. of hole per row	20
N. of row per blast	2
Burden first and second row (m)	5.5, 6.5
Spacing (m)	6.6
Stemming (m)	3
Explosive per blast (kg)	2 000 – 5 000
Volume rock (m^3)	1 205
Powder factor (kg/m^3)	0.23
In-row and inter-row delays (ms)	42, 67

3.4 Loading & hauling (including monitoring systems in mobile equipment)

A CAT390 backhoe loader with a weight scale is used to dig the blasts into KOMATSU 605 trucks of 60 t. The average distance travelled by the trucks from face to plant feed is 765 m. A truck and a loader tracking system was installed by Abaut to monitor the performance of trucks and loaders. The trucks hauling productivity (t/h), fuel consumption, idle time, availability and breakdowns are available Key-Performance indicator. Other indicators are shown in Table 2. Once in the plant, the material is transported on different conveyors belts (see Figure 3). The produced aggregates are loaded on truck and sent to the costumer travelling for an average distance of 32 km on road.

HANSON has implemented a digitalized Preventive Maintenance Management system where all repairs and breakdowns are recorded, and all preventive maintenance activities are explained with detailed instructions. The system manages different KPIs like time and cost of corrective/preventive actions for each resource, type of defect and spares cost.

Table 2. Existing digging and hauling KPIs.

Machine	Parameter	Normal range
CAT390 backhoe loader	Number of passes to load truck	6,5
	Time elapsed to load truck	2,19 min
	Payload per cycle (if is there a scale in the bucket)	9,25 ton
	Idle time	10,88%
KOMATSU 605 truck	Distance travelled from bench to plant*	800
	Time elapsed from bench to plant*	2,58
	Speed*	10,84 km/h (total cycle)
	Idle time*	20,23%
	Payload (if is there a scale in the truck)	No scale

* Both distance, time, speed and idle time corresponding to the area that will be tested in the DEQ project.

Figure 3. CAT390 backhoe loader (left) and conveyor belt (right).

3.5 Summary of technologies to be developed.

Valdilecha quarry will lead to the implementation of the Key Technology Area KTA1, i.e., improved extraction, rock mass characterisation, and control. The main interest for this quarry within the project is to study and control the fines production from blasting and, if possible, to increase the production of final fractions with higher prices and minimise, at the same time, the fractions with marginal prices. For this purpose, the following parameters will be measured:

- Structural rock conditions (jointing, cavities, etc.) and lithology changes. In-borehole images and/or photogrammetric models of the highwall faces will provide direct measurements of the rock characteristics and will be used to interpret measuring-while-drilling (MWD) data. Once the model is developed, the response of the drill rig to the rock conditions will be used to identify online structural conditions (i.e., massive or heavy fractured zones) and to estimate the thickness of clay layers, from which the amount of natural fines will be calculated.
- Development of VCWD (Virtual Coring While Drilling) – virtual rock core recovery from drilling of blast holes. Literature review revealed an existing patent called "Method and system for generating a virtual core " (Bize et al 2018) for use in oil drilling with significantly differences from blasthole drillings (i.e., larger hole diameter) and its focus on hole logging procedures common in that industry such measuring resistivity. Such virtual core is a software-based representation based on resistivity measurements. Acquired data are used to generate a 2D image, that the patent described as: "may be similar to an image created photographically". The patent does not mention using a camera to take photos of the borehole wall, which is the core of the planned actions in the Digiecoquarry project. Therefore, the patent differs significantly from VCWD. To eliminate the risk of patent infringement a patent law expert was consulted.
- Geometrical characteristics of the blasts: actual collaring position of the holes (actual drill pattern), actual holes path, block geometry (pre and post blast) for volume calculations and over/under excavation analysis (not currently measured).
- Mass of charged explosive, and timing sequence used. Evaluation of the explosive performance through velocity of detonation measurements and detonation pressure records (not currently measured).

- Muckpile characterisation, including fragmentation measurements of the run-of-mine, and monitoring of rock motion (these data is not currently measured).
- Vibrations in the near field to evaluate rock damage (not currently measured).
- KPIs of digging, i.e., loading time of each truck as provided by the fleet track sensors to be installed by ABAUT that will be compared with data in Table 2.

The approach within Digiecoquarry is to link KPIs from different sources from the Mine-to-Mill to decrease the ratio of no suitable material for aggregates production, mainly fines material. These KPIs will be monitored in three field campaigns: baseline definition from 3-5 blasts made with the current techniques used nowadays to define the state zero; first campaign of blasts (15-20 blasts) to investigate the influence of the explosive energy and timing in fines production; and second campaign of blasts for validation of the techniques developed. Additionally, a dynamic image analysis system will be implemented to measure vibrations allowing a new understanding of the interaction between vibration signals and structural responses vibration monitoring for extended structures.

4 HOLCIM: Peschiera Borromeo - Pioltello quarry

4.1 Overview

Holcim Aggregati Calcestruzzi s.r.l. (HOLCIM) is a Lafarge Holcim Group company that produces aggregates (sand and gravel) for construction and road works and also for ready-mix concrete in the northern Italy market. It manages 8 quarries and 21 ready-mix concrete plants. The Company has been working in the market of aggregates and ready-mix for more than 40 years. HOLCIM has also been (for more than 100 years) one of the main players in the market of Northern Italy for cement. In terms of membership and clustering, HOLCIM is an active member of ANEPLA (Associazione Nazionale Estrattori Produttori Lapidei e Affini) and UEPG (European Aggregates Association).

HOLCIM has to date accumulated extensive experience in the production of selected aggregates (CE marking with certification level 2+) suitable for all applications in the construction sector (concrete, asphalt, precast, premix, etc.) in compliance with the specific regulations like UNI EN 12620, UNI EN 13043, UNI EN 13139 for the different intended uses.

HOLCIM has also developed experience in the design of its quarry plants, through its centralized engineering department located in Zurich. Here all aspects related to plant safety (OH&S), production efficiency, the environment and product quality are managed internally with high standards and targets.

In order to pursue the corporate objectives of customer satisfaction and continuous improvement of company performance, to create economically and environmentally sustainable solutions and, last but not least, the development of a safe working environment, the company has obtained the following certifications: UNI EN ISO 9001 - Quality management system , UNI ISO 45001/2018 - Occupational Health and Safety Management System, ISO 14001 - Environmental management system (at group level), and Organization, Management and Control Model compliant with the requirements of Italian Legislative Decree 231/2001.

Peschiera Borromeo quarry is located in Pioltello San Bovio (Milan, Italy). An aerial view of the quarry is given in Figure 4.

Figure 4. Overall view of the quarry site.

The main information of the site, including current layout and future planned extensions, are as follows:

- Geographical coordinates: 45°4707 / 9°3315
- GoogleMaps: https://www.google.com/maps/place/45%C2%B028'14.5%22N+9%C2%B019'53.4%22E/@45.4701063,9.3282961,15.7z/data=!4m5!3m4!1s0x0:0x0!8m2!3d45.4707!4d9.3315
- Climate area: Moderately continental (Köppen climate classification: Cfb).
- Total surface of the site: 815 000 ha.
- Surface of the extraction area: 101 500 ha (or 12.5 % of the total surface).
- Surface of the treatment plant area: 42 800 ha (or 5.3 % of the total surface).
- Surface of the extractive waste facilities: 17 000 ha (or 2.1 % of the total surface).
- Surface of the areas not extracted yet, still in original state: 201 500 ha (or 24.7 % of the total surface).
- Surface of the rehabilitated area: 363 000 ha (or 44.5 % of the total surface).
- Distribution of surfaces by type of final use: 67% quarry lake (243 800 m^2) and 33% vegetation (119 200 m^2).

The main efforts will be focused on automation, control and optimization of the treatment plant (KTA 3.1 and KTA 2.2). This aims to reduce noise and to decrease the consumption of energy and of primary and recycled water (500 000 L /day).

4.2 Geology

In terms of regional geology, only the deposits related to the recent Fluvioglacial (Würm pp-Riss) outcrops are discussed here. These derive from the fundamental level of the plain that come from the dismantling of the morainic circles located to the north and occurred during the Würm. They consist of gravels and sands in a silty matrix with local and limited clayey lenses. Within them, a variation from the coarser to the finer terms can be seen moving southwards. On the surface, there is an anthropized layer about 1 m thick. Under this alteration layer there are gravels, silty sands, and clays for a thickness of about 100 meters. At a depth of about 100 m below ground level there is a layer of clay at least 15 m thick, that constitutes the base level of the main aquifer.

In terms of local geology, a geognostic survey carried out in the quarry area, up to a depth of 50 meters, identified the following lithological units:

- 0–1 m: no results (anthropized layer).
- 1–3 m: prevailing fine sand, gray colour, and rare gravel.
- 3–11 m: prevalence of sandy gravel deposits, with a good size distribution, sometimes richer in gravel. There are also two silty levels (5-7 m and 10-11 m).
- 11–40 m: prevalence of gravelly deposits with small gravel and, to a minimum extent, sand. Single clayey level of limited thickness (less than 1 m) at a depth of about 35 m.
- 40–50 m: mainly made up of clay and silt. Levels with peat and wood have been found locally.

From the hydrogeological point of view at the regional level, the units described above are home to the first aquifer or "water table" which, in the quarry area, is located at a depth of 3-5 meters. The main rock types of the quarry site within the alluvial deposit are granite, quartzite, metamorphic rocks (gneiss), and carbonate (rare); see Figure 5. The bulk density is on average 1.9 - 2.0 gr/cm^3.

Before initiating excavation of the deposit, the overburden (about 1 m thick) was previously removed and deposited in a dedicated area. This soil will ultimately be used at the end of the excavation for the restoration of the quarry.

The material extracted from the dredge is delivered (by conveyor belt) to the process plant (crushing and screening) for the production of all finished materials (sand and gravel over a range of granulometry) ready for sale.

In the selection phases, the natural material (sand and gravel) is washed using water although the crushing (secondary and tertiary) section operates dry. At the end of the screening and washing processes of the materials, the used water contains the finest particles (fine sands - silt) which are not retained by either the sorting equipment or the cyclones. These turbid waters are sent to the clarifier (static) which separates a suspension of solids from clarified water.

The solid suspension is sent to the settling pond while the clarified water is sent to the storage tank and used again in the washing cycle (around 80% of water usage is recycled).

The thickened solids that accumulate in the settling pond consists of a plastic mixture of clayey-silty or, at most, silty-sandy fractions, with a composition directly attributable to that of the processed material.

The amount of suspended material at the entrance to the settling tank is variable and directly connected with the granulometric characteristics of the part of the deposit under cultivation. Considering the characteristics of the deposit and the historical data of the plant, it is possible to estimate the average silt production, obtained from the washing process of the quarried material, to be approximately 2.5 - 3% of the excavation plus other 3 – 4 % derived from crushing section.

Figure 5. Extracted material in Peschiera Borromeo - Pioltello quarry.

4.3 Extraction from water environment (including monitoring tools currently used)

Due the depth of the aquifer with respect to the deposit, an underwater dredge is used to extract the rock. An image of the dredge is shown in Figure 6.

The actual dredge is a Rohr RS 8,0/32 that is currently working at a maximum depth of 42 meters below the surface. The bucket capacity is 8 cubic meters, and the dredge is operating with double shift (4 people) for a total of 15 working hours. The average dredge production is currently 2 200 – 2 300 tons/day with an average of 11-15 bucket cycle/hour.

The dredge is equipped with 2 electrical engines 160kW each (for the winch) and a combination of automatic and manual excavation is performed via a PLC.

There are sensors that provide:

- Rotations of the machine drum that is converted to length in meters (excavation depth)
- Number of bucket cycles (in nominal ton/hour)
- Time of opening/closure of the bucket
- Amperage of the winch engines

There is no Ethernet connection (Lan or Wi-Fi) from the dredge to the quarry plant, hence all the data are manually reported daily to the management system of the quarry.

The optimal bucket cycle is 2 minutes at 24 m depth. The currently conveyors speed is 2,2 meters/second for a maximum nominal capacity of 300 t/hour. The current KPI's are summarised in Table 3.

The quantities of processed material for the year 2019 was 490 000 t, more details are shown in Table 4.

Table 3. Current KPIs of the rock extraction.

Parameter	Normal range
Bucket cycle	20 cycles/hour (24 m depth)
Bucket cycle	11 – 15 cycles/hour (35-40 m depth)
Production	2 200 – 2 300 t/day
Bucket capacity	8 m^3
Conveyors speed	2,2 m/s

Figure 6. Underwater dredge for alluvial deposit extraction.

Table 4. Ends product year 2019 in Peschiera Borromeo quarry.

Product	Crushed natural aggregates	Not crushed natural aggregates
4 mm < Coarse aggregate < 32 mm	40 000 t	235 000 t
Sand < 4 mm	25 000 t	158 000 t
Mineral waste	32 000 t	

The dredged aggregates are moved by conveyor belts to the crushing/screening plant over a distance of approximately 850 m. From there, the final products are loaded on trucks and sent to the costumers by road over an average distance of 40 km.

The fresh water used for washing of the crushed/screened aggregates is obtained from a borehole and the water drained from the aggregate is sent to the recycling / decanter plant to be integrated with the recycled water derived from the static decanter process.

One aim of the project is to reduce the freshwater consumption by approximately 5% by focusing on both the processing part (increasing washing efficiency) and the water recycling part. The freshwater withdrawal during the reference year of 2019 was 75 497 cubic meters. The reference ratio for the fresh water is 154 litres/ton representing 10% of the total water circulation of 8 000 litres/minute. The total ratio (recycling water + fresh water) is 1 500 litres/ton.

4.4 Summary of technologies to be developed.

Peschiera Borromeo - Pioltello quarry will lead to the implementation of the Key Technology KTA2.2 (Models for crushing and screening optimization), and KTA3.1 (Devices for automation of treatment plants). No position sensors (GPS) are nowadays installed in the dredge and for the deposit (rock characterisation, etc), the water table and batimetric survey data are collected by campaigns. The technologies to be developed in this pilot site are mainly connected with the optimization of the crushing, screening, and washing processes related to the production of sand and gravel (alluvial deposit) as well the project aims to increase the efficiency of the aggregates plant with the reduction of electrical consumption and fresh water per t/h produced (gross). To achieve these specific goals, the project counts on the plant site with the right management of the SCADA system combined with all the sensors positioned in the several machines in the plant. The DEQ project foresees for the Pioltello quarry the installation of new sensors and devices focused on the project’s KPIs.

5 CRONENBERGER Steinindustrie: Mammendorf quarry

5.1 Overview

Cronenberger Steinindustrie Franz Triches GmbH & Co.KG (CSI) is a subsidiary of Pescher Beteiligungen GmbH & Co.KG, which is a fifth-generation family business that runs quarries in Germany and Nigeria for 109 years. Main products in all quarries have been aggregates for road construction (asphalt, concrete) with special focus on high quality aggregates used in top layers of roads, railroad ballast, armourstones for waterway construction and materials for production of concrete precast parts such as railway sleepers. Currently the group employs 150 people in three quarries in Germany and one recycling plant, the production is about 3 million t/year.

CSI operates Mammendorf quarry (Sachsen-Anhalt, Germany) that is located in Germany's most northern hardrock formation. Since 1998, the quarry extracts and processes 1.2 million t/pear year (on average) of a volcanic hard rock (andesite).Table 5 shows the quantities of natural aggregates produced. To extract the rock, about 0.6 million t/per year of gravel and sand material have to be removed, this yields to an overall production of 1.8 million t/pear year (on average). An overall view of the quarry is shown in Figure 7.

The rock is mined through drill & blast method, after this, the material is moved by several excavators, quarry trucks, trucks, wheel loaders and other mobile machinery. The hard rock is then crushed, screened and processed in a fully automated processing plant. Products are sold all around the North of Germany, where the quarry is a leading market player. CSI represents the large group of small-medium enterprises that operate quarries in Europe, which have special needs in terms of possibilities of allocation of resources (personnel, money, etc.) in optimization of processes.

Table 5. Production per year in Mammendorf quarry.

Product	Mass (t)
Armourstone	10 000
Railway Ballast	50 000
Coarse aggregate (> 32 mm)	70 000
Aggregate (2/32 mm)	900 000
Sand (< 2 mm)	160 000
Filler (< 0.0363 mm)	10 000

Figure 7. Quarry site.

CSI is a member of VERO association (advisory board), MIRO Gesteinsverband (member of several expert groups), Deutscher Asphalt Verband, VSVI-Vereinigung der Straßenbau- und Verkehrsingenieure, Baustoffüberwachungsverein NRW, Hessen, Rheinland-Pfalz and International Chamber of Commerce (member of expert group industry and environment). It is also member and participant in expert group Forschungsgesellschaft Straßen und Verkehrswesen. CSI takes part in an energy efficiency network by the German Government share knowledge and, projects for energy efficiency improvements and CO_2 reduction.

The main geographical information of the site, as situation and extension, is here reported:

- Geographical coordinates: 52°10'34.7"N 11°26'13.6"E.
- GoogleMaps: https://www.google.es/maps/place/52%C2%B010'34.7%22N+11%C2%B026'13.6%22E/@52.1770452,11.4354795,1 025m/data=!3m1!1e3!4m5!3m4!1s0x0:0x0!8m2!3d52.1763111!4d11.4371105
- Climate area: Temperate oceanic climate zone (Köppen climate classification: Cfb).
- Access: the quarry is directly situated at a state road. Close Highway access.
- Total surface of the site: 51 ha.
- Surface of the extraction area: 25 ha (or 50% of the total surface).
- Surface of the treatment plant area: 1.5 ha (or 3% of the total surface).
- Surface of the extractive waste facilities: 0.
- Surface of the areas not extracted yet, still in original state: 8 ha (or 16% of the total surface).

  Surface of the rehabilitated area inside the quarry: 0%, the entire area is in usage as extraction, plant or storage area.
- Distribution of surfaces by type of final use: mixture of agricultural, lake, ruderal areas, hedges, biotope network areas. These areas that have been rehabilitated are outside the limits of the quarry.

5.2 Geology (including current practices to assess rock quality)

In terms of regional geology, the area is located in the "Flechtinger Höhenzug", which is dominated by geologically old rock types, a mix from sediments and volcanic stones. This area is one of the northern solid stone occurrences in Germany. The deposit has been assessed through the analysis of more than 60 drill cores and drilling dust samples, this was combined with an extensive geophysical evaluation that gave solid information about the deposit, its characteristics, and the geological development of the site. The geology of the deposit presents different layers of materials of different geological origin and thus with different technical properties; however, the main rock type of the quarry site is andesite.

In terms of local geology, andesite is covered by mother soil, boulder clay, sandstone and tuff. Below the valuable stone the deposit is limited by Greywacke. Figure 8 shows the structure of the geologic formation and its current use by CSI.

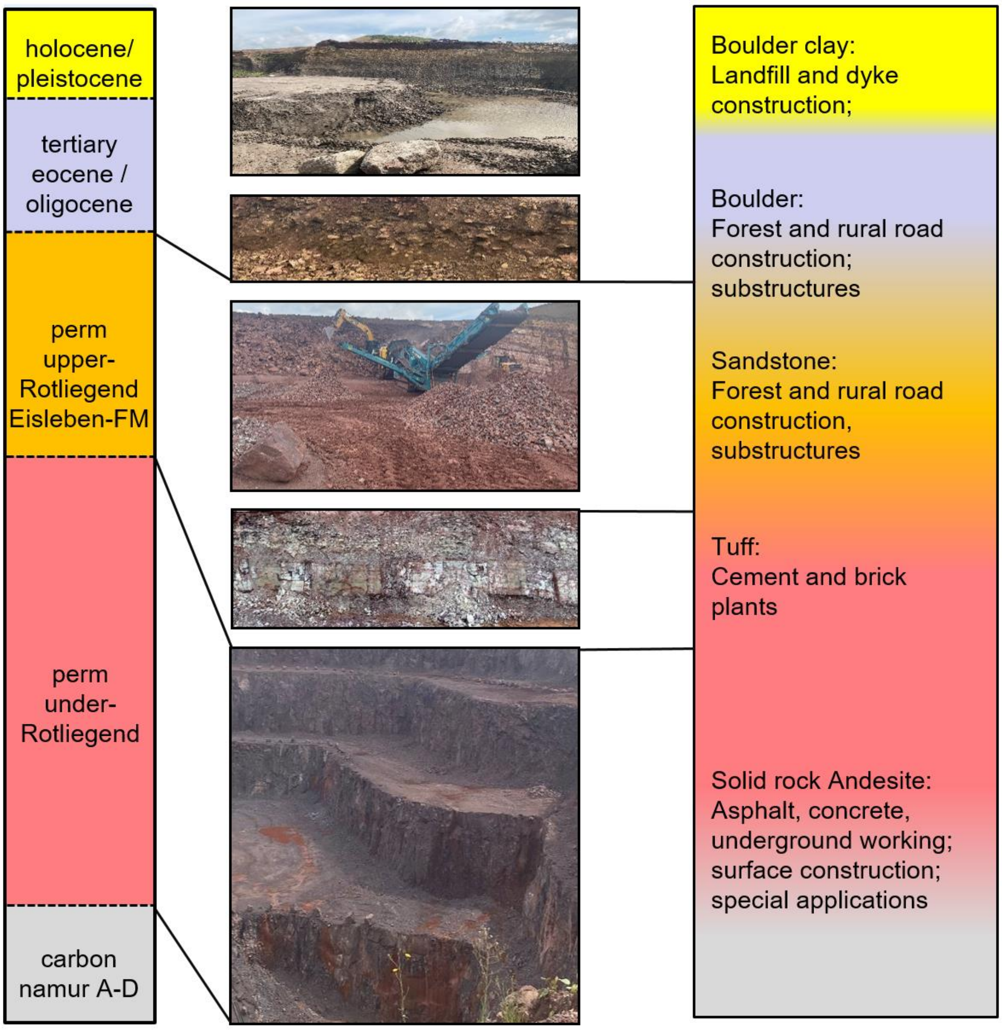

Figure 8. Structure of the geologic formation and its current use by CSI.

As shown in Figure 8, not only the hard rock andesite is used for production, but also adjacent rock layers such as sandstone layers and even the overburden materials, such as boulder clay. Sales of the boulder clay differ between 100 000 to/year and 300 000 to/year, so that between 16% and 28% of total material extracted is transported to the internal dump site.

The density of andesite rock is 2,75 to/m³, and aggregates produced from this rock type achieve an LA-Work Index of 11 and a high Polished Stone Value of 56, which make the products fit for all asphalt applications. The hard rock causes no alkali silicic acid reaction in combination with cement and salt that makes it fit for usage in all concrete applications, such as top layer highway concrete surfaces. The quality of the rock and the products are assessed through a management system of internal and external controls guided by the norm TL Gestein StB 04/18. Products are produced according to *DIN EN 13043, DIN EN 12620, DIN EN 13381, DIN EN 13450, DIN EN 13242, DIN EN 13285*. The production management system is certified so that the products present CE-certificates. Next to the "qualified" products CSI also produces unqualified materials. In total, about 45 different products are produced and sold.

5.3 Excavation (D&B) process

The quarry presents seven benches and a total depth of 75. The planning and the blasting operations are internally controlled and managed by the personal of CSI. Georeferenced laser scans are used to create a 3D plan of the drilling grid; from this, a subcontractor (with 45 years of working experience in quarries of the Pescher-Group) performs the drilling operations with through an Atlas Copco drilling machine equipped with GPS based position and angle control (the diameter of the holes is 102 mm). After drilling each hole is checked with a georeferenced sensor, to check deviations and correct positioning with respect to the intended grid plan.

Blastholes are charged with help of suppliers of explosives. Due to the high amount of water in the rock, mostly emulsion and gelatinous explosives are used in combination with non-electric blasting systems. Each blasting is videotaped and measured through a measuring station, these measurements are evaluated according to DIN 4150-3 and the results are constantly used to optimize the blasting system. Advancing with the mining of the deposit, the blast vibrations reduce respectively, since the blasting operations move away from the nearest village.

5.4 Loading & hauling (including monitoring systems in mobile equipment and other information like distances travelled, downtime and fuel consumption)

The site machinery is from different manufacturers and includes: 5 excavators, 5-wheel loaders, 6 trucks, 4 quarry trucks and 1 bulldozer. The machinery is used to transport material to the plant, to the dump site, and from the plant to 90 stockpiles. The currently installed monitoring systems are:

- Geoposition:
    - Some mobile machines are fitted with geo position in their OEM (original equipment manufacturer) online systems. Often the on-board GPS is not precise enough, and the geoposition data is sent in long intervals so that data cannot be used.
    - A TomTom system is installed on each truck, but the evaluation of these data is difficult because the precision is low. This system is developed for road trucks and bases on Google maps.
    - Automatic truck scaling: three quarry trucks are fitted with an internal Original Equipment Manufacturer (OEM) or after-market scale to optimize average loading/transport amounts.
- Excavator scaling: two excavators are fitted with internal scales to optimize loading of internal and customer trucks.
- Automatic fuel consumption measurement: the site's fuel station and the internal fuel truck are fitted with a measurement and evaluation software Pandora, that yields machine and driver specific consumption data. Table 6 shows the fuel consumption per year.
- Nowadays production measurement method: combination of weight-scale data (on mobile machinery, on conveyer belts, outbound weight-bridge), and cycle-numbers.
- All trucks and all wheel loaders are equipped with a tire pressure monitor system, this allows to reduce the fuel consumption and extend the tires life.

Table 6. Existing KPIs of the digging and hauling process.

Parameter	Normal range
Transported tons of overburden	1 000 - 5 000 t/day
Transported tons of production	0 - 8 000 t/day

The travelled distances and external transport method of the aggregates to customers are here listed:

- Road: 5-500 km.
- Train: 100-250 km.
- Boat: 200-500 km.

5.5 Summary of technologies to be developed.

Since the amount of internally transported material per year is very high, internal transport through mobile equipment stands for the largest amount of CO_2 emissions of this quarry operation as a whole. Existing data on mobile equipment usage derives from different sources that make it difficult to practically use this information for process improvement. To tackle this problem, it would be interesting to develop a system that integrates all existing data in one platform. This would make possible to assess process improvements on real time. This aims to decrease fuel consumption, CO2 emissions and decrease downtime and repairs.

The focus during the Digiecoquarry project will be working on KTA 3.3 “Mobile equipment digitalization” (including GPS, RTK, acceleration and data logger on the existing mobile-equipment like wheel loaders, dump-trucks and excavators of different brands/manufacturers) taking into account real time and modeling data. Finally, different KPIs can be measured and organized on a regular and consistent basis. This can then be used for better management and improvement of the quarry mobile equipment fleet usage.

6 CIMPOR: Alenquer quarry

6.1 Overview

AGREPOR is a Portuguese aggregates producer with 10 active quarries and owned by CIMPOR the major Portuguese cement producer. Furthermore, CIMPOR is member of ANIET (National Association of Extractive and Manufacturing Industry).

AGREPOR has a wide variety of quarries (granite, limestone, dolomite and gypsum) and supplies a wide variety of public and private customers that operate for instance in public works, RMC, fertilizers, lime production, cement, concrete, ballast, mortar, etc. AGREPOR will pilot and validate the proposal in one of its limestone quarries located in Alenquer (Lisbon district, central region of Portugal). A view of the quarry and the processing plant is given in Figure 9.

The main geographical information of the site, as situation and extension, is here reported:

Figure 9. General view of Alenquer quarry

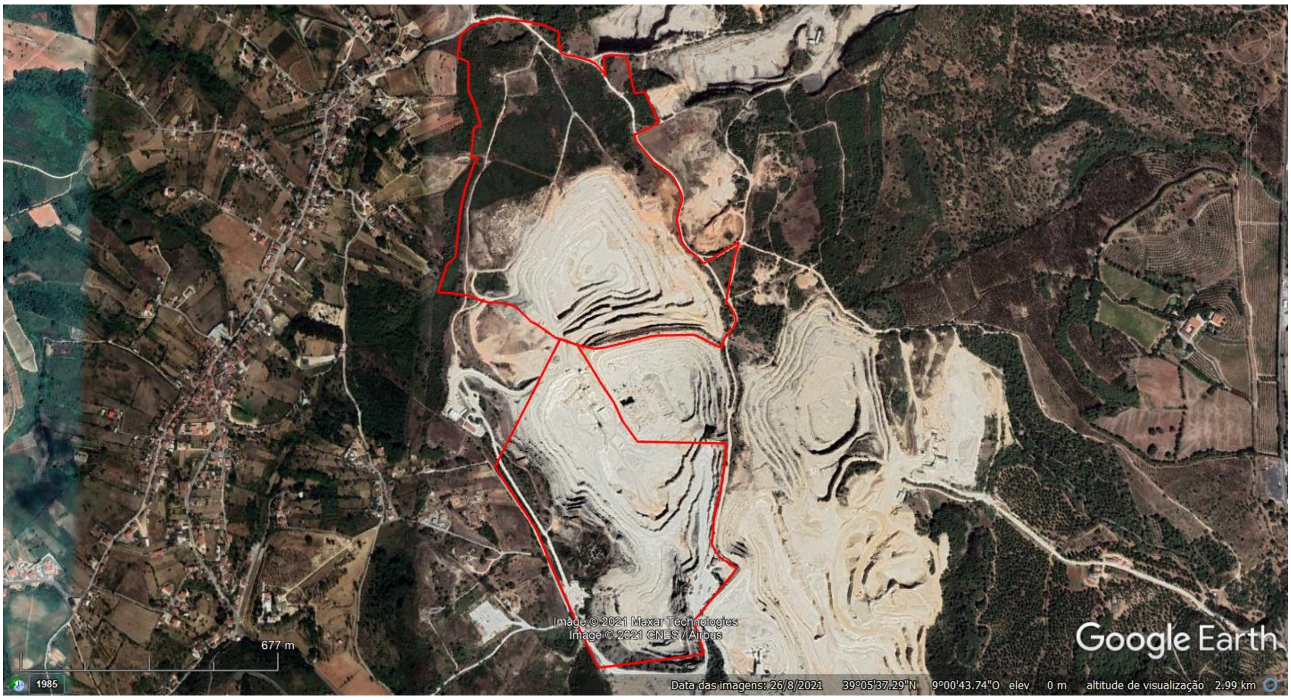

Figure 10. Google earth view of Alenquer quarry and urban perimeter (Image date 26/8/2021).

- Geographical coordinates: 39^{o}05'27.6'' N, 09^{o}01'02.9'' O.
- Google Maps: https://goo.gl/maps/HcbskXZ5ki7XNSpQ9
- Climate area: The summer is hot, dry and with an almost cloudless sky. Winter is cool, with precipitation, strong winds and partially overcast skies (Köppen climate classification: Csa).
- Access: The quarry is located on top of a hill. To access it, a road must be taken along which some houses as well as other quarries can be found. The urban perimeter is just a few hundred meters away from the quarry and is expected to shorten in the future (see Figure 10).
- Total surface of the site: 77 ha.
- Surface of the extraction area: 38.9 ha (or 50.52 % of the total surface).
- Surface of the treatment plant area: 1.2 ha (or 1.56% of the total surface).
- Surface of the extractive waste facilities: 2.4 ha outside the extracting area (or 3.12% of the total surface).
- Surface of the areas not extracted yet, still in original state: 31 ha (or 40.26% of the total surface).
- Surface of the rehabilitated area: 15 ha (or 19.48% of the total surface).
- Distribution of surfaces (%) by type of final use: 100% forest.

Crushed natural aggregates are the main product. These are armourstone, coarse aggregate (4/32 mm and >32 mm), sand (<4 mm). The annual production and the energy and explosive consumption are shown in Table 7.

The main challenge of the quarry, considering the significant input of energy and resources, is the reduction of energy consumption, whether diesel or electricity, while improving the productivity and efficiency of the equipment.

Any improvement that is achieved in this area has immediate and measurable effects on the environmental impact of the activity, thus making the activity more sustainable and with the possibility of extrapolating the measures implemented to the rest of the sector.

In parallel with this challenge, considering that it is a risk activity, the opportunity to use monitoring tools and AI (Artificial intelligence) to reduce this risk not only has immediate benefits but will also improve the public perception of the activity.

Table 7. Key indicators

		unit	Total value 2021
Produced		t	1 632 445
Electricity		kWh	1 534 372
Explosive		kg	179 500
Fuel		l	466 598

6.2 Geology (including current practices to assess rock quality)

The main rock type of the quarry site is limestone. In terms of local geology, the deposit formed during the ages of Jurassic J3-4. Most of the extracted material is sold, and only less than 3 % is a waste aside for restoration purposes or dumped in landfill. An overview of the quarry benches and limestone stratification is shown in Figure 11.

AGREPOR ensures the production of aggregates, in compliance with European regulation (EU) No. 305/2011 of the European Parliament and Council of March 9, 2011 (Construction Products Regulation – RPC), of construction products as certified number 0866-CPR-2004/CE.0020. The product characteristics are shown in Table 8 and Table 9The company complies with a test plan for the final product, with the frequency based on the normative guidelines:

AG - Granulometric Analysis and Fines Content - EN 933-1

EA - Sand Equivalent - EN 933-8

IA - Flattening Index - EN 933-3

LA - Fragmentation Resistance (Los Angeles) - EN 1097-2

MVAA - Actual Volume and Water Absorption - EN 1097-6

RAS - Alkali Silica Reactivity - ASTM C 1260

RpS - Drying Shrinkage - EN 1367-4

TC - Chloride Content - EN 1744-1

TH - Humus Content - EN 1744-1

TE - Total Sulfur Content - EN 1744-1

PET - Petrographic Analysis - EN 932-3

PRT - Proctor - EN 13286

MD - Micro-Deval - EN 1097-1

Figure 11. Limestone quarry

Table 8. Simplified description of the product

Structure	Solid
Texture	Solid
Alteration	Sane little changed (W1 a W2).
Surface	Rough
Porosity	Mean
Shape	Angular
Irregularity	-------------
Anisotropy	Anisotropic
Vesicularity	Does not present
Other verified properties	Whitish in color. Reacts with hydrochloric acid

Table 9. Geological classification of the product

Minerals present and respective dimensions	Calcite and others. Dimensions less than 1 mm.
Geological age	-------------
Geological classification	Chemogenic sedimentary rock - Limestone.

6.3 Excavation (D&B) process (including monitoring tools currently used)

Considering that the quarry mines a hard rock, the extraction process starts with drilling and blasting. Drilling is done with an Atlas Copco F9CR hydraulic driller according to the drilling pattern suitable to the bench condition. The drilling machine is equipped with a drilling control system that allows specifying and controlling effectively the depth and inclination of the hole. The machine has a de-dusting system that through filtration avoids the dispersion of the drilling dust to the environment. The operator does the positioning of the machine according to the drill pattern. Table 10 shows the average blast characteristics for 2021.

The explosives used are emulsion and bulk ANFO, which are loaded manually. For safety reasons non-electric detonators are used. Although there is a standard blasting pattern special attention is given by the technical staff and workers to adapt this to the specific conditions of the benches to avoid environmental problems and assure that the blast result is suited to the mobile equipment and crushing plant. Through this constant attention is possible to have controlled blast results. The ground vibration monitoring is done frequently according to the requirements of the permit.

All the relevant information needed to access the D&B performance is registered in MS Excel, SAP and other reporting tool, KoboToolbox.

The purchase, transport and use of explosives is done under a strict control of the police authorities and under the European directives a tracking system for the delivery and use of explosives is done, through the use of QR code readers to identify the explosive application. This information is accessed via internet and available to the company and also police authorities.

Table 10. Blast design characteristics (average 2021).

Hole diameter (mm)	105
Hole length (m)[a]	14
Hole inclination (°)	15
Bench height (m)	13
Subdrill (m)	1
N. of hole per row	11
N. of row per blast	1
Burden (m)	3,9
Spacing (m)	4,3
Stemming (m)	3
Explosive per blast (kg)	630
Volume rock per blast (m^3)	2230
Powder factor (kg/m^3)	0,282
In-row delay (ms)	25

6.4 Loading & hauling

Considering the adequate blast results and fragment size distribution achieved in this quarry, the loading is done by wheel loaders and transported to the crusher by rigid dump trucks. The loading machines are changed according to the company needs since there is mobility between quarries, but usually the loading and hauling is done with a set of two-wheel loaders and four rigid dump-trucks, namely one Volvo L350F, one CAT 988G one CAT775D and three Komatsu HD465.

The average distance from the quarry face to the plant crusher is 500 m and the dump trucks either travel uphill loaded or downhill.

Considering that some of these equipment, although in good working conditions, are old and that there is no possibility of obtaining the working data remotely directly from them, the company implemented a set of reporting tools in KoboToolBox to compile data. With this information and other obtained from different sources it is possible to have KPI. The expected range of some of these KPIs is shown in Table 11.

The produced aggregates are directly loaded from silos or by wheel loaders form stockpiles. All the dispatched aggregates are weighted in scales and the data integrated automatically in SAP system. The machines in use for loading the trucks are two Volvo L150E and one Volvo L150H.

AGREPOR does not have an own fleet of trucks to deliver aggregates to his customers. For such service, the company has a set of suppliers that work on its behalf. The estimated average distance of transport to the costumer is 26 km.

Table 11. Existing KPIs of the digging and hauling process.

KPI	Normal range
Productivity of mobile equipment (produced t/engine hours)	88-98
Labour productivity (produced t/working hours)	36-40
Fuel consumption (l/engine hours)	0.26-0.32

6.5 Summary of technologies to be developed.

In CIMPOR's site, the autonomous and intelligent system for aggregates transportation from crushing to stock, storage, and external transport traceability (KTA3.1&3.2) will be implemented with the focus on rationalising energy consumption and using equipment. Main areas monitored will be levels of the silos, analysis of the stock zone for prioritisation on transport, remote and autonomous interpretation of storage locations.

The installation of technologies that enable an autonomous management will allow prioritising the aggregates to be transported, optimising routes, transport speed and deposition sites with all security safeguards, validating and demonstrating these DIGIECOQUARRY solutions. For external transport, the validation of the technologies that enable full traceability from the quarry to the customer will be demonstrated by ensuring route optimisation in terms of the best possible route that minimises transportation time and fuel consumption, estimated time of arrival (ETA) and communication to customer and quarry (dispatch), sharing of inter-fleet information to adjust the travel speed and to guarantee just-in-time in congested unloading sites. Other aspects that will be validated in terms of storage to external transport connection will be the correct identification of the aggregate to be loaded, silo discharge control, correct truck positioning without spilling and cargo viability and communication to driver. Health and Safety, and Environmental technologies will also be implemented.

7 Conclusions

This report provides the main information from the DIGIECOQUARRY sites where rock is mined: HANSON (Valdilecha quarry), LAFARGE-HOLCIM (Peschiera Borromeo quarry), CRONENBERGER S.I. (Mammendorf quarry), and CIMPOR (Alenquer quarry). A general overview of the sites includes location and production of each company (including problems and main interests of the quarry). A general geological characterisation is done, detailing the main rock type and describing both the local and regional geology. The excavation process is described in terms of utilized machinery and logistics in the quarry site. The products and subproducts obtained are specified, the quantities of explosives consumption are also included. The loading and hauling operations and the relative monitoring systems are reported, the consumption of fuel and the machinery adopted in this phase are explained. A resume of the technologies to be developed in the DIGIECOQUARRY project is done; in this case, each company focusses on one or more crucial aspects to improve the production, safety, and quality of its site. Finally, most of the main KPIs are already being measured with the currently installed technologies. Once the interpretation of the outputs thus measured has been verified, it will form the baseline for the development and evaluation of the new, more advanced technologies.

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