Identification of reclamation methods

for a limestone quarry using terrestrial laser scanning

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Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Abstract

Nowadays, the concept of reclamation is very pressing since the mining industry causes extensive permanent changes in the environment. Contemporary advancement of knowledge contributes to raising awareness among people and devoting special attention to the process of land reclamation, even though until the second half of the 20th century, a common practice was to leave areas degraded by the mining industry. The land rehabilitation process is a stage of mining activity that compensates for adverse changes caused by it.

The purpose of this work is to prove that laser scanning is a helpful tool in the process of determining the direction of land reclamation for quarries in after-use scenarios. As a result of research conducted in a limestone quarry in Portugal with laser scanning as the data acquisition technique, a point cloud was obtained, which was then used to determine reclamation alternatives. An important element of the land rehabilitation process is the decision concerning the appropriate landform shaping after the end of exploitation. Therefore, using the ReCap Pro software, the amount of waste material present in the research area was determined in order to use it in the process of shaping the bench slopes. Hydrogeological conditions of the study area were also analyzed, as well as its dominant surface coverage. Based on the information obtained, two concepts have been proposed. The ideas of reclamation are based on two acceptable scenarios for land reclamation, i.e. re-vegetation of the post-mining area, and giving it a new application. The obtained results support the presented thesis.

Resumo

Presentemente, o conceito de recuperação é premente uma vez que a indústria extrativa é causadora de mudanças permanentes no ambiente. O atual avanço do conhecimento contribui para o aumento da sensibilização da sociedade para o processo de recuperação de terras, embora até à segunda metade do século XX tenha sido prática comum o abandono das áreas exploradas pela indústria.

O processo de recuperação é uma das etapas da atividade extrativa, sendo a que permite compensar as alterações adversas causadas. O objetivo do presente trabalho é averiguar a capacidade do varrimento por laser (laser scanning) enquanto ferramenta útil no processo de determinação da direção da recuperação de terras de pedreiras em cenários pós-uso. Em resultado da investigação realizada numa pedreira de calcário em Portugal, onde um levantamento com varrimento por laser foi realizado, obteve-se uma nuvem de pontos que permitiu determinar alternativas para a recuperação do espaço. Um elemento importante do processo de recuperação de terras é a decisão relativa à morfologia do terreno recuperado na situação pós-uso. Assim, usando o software ReCap Pro, a quantidade de material residual presente na área em estudo foi determinada, de modo a poder ser usada no processo de modelação das vertentes. As condições hidrogeológicas da área de estudo foram igualmente consideradas, bem como as classes de uso do solo na envolvente. Com base nesta informação, foram propostas duas alternativas para a recuperação do espaço, cujos princípios se basearam em dois cenários válidos de recuperação de terras, i.e., a revegetação da área, ou a mudança para uma funcionalidade distinta. Os resultados obtidos permitem sustentar cada um dos cenários discutidos.

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1. Introduction

The exploitation of mineral resources is an ancient practice that dates back to the Stone Age. Despite the fact that stone was necessary for the creation of tools, as well as for construction, mining was carried out on a relatively small scale. Nowadays, the mining sector brings many benefits to people. There is a great economic importance in the exploitation of mineral resources, as this activity generates income for the local governments and communities, while mineral products are essential components for a vast range of everyday products. According to a 2015 World Economic Forum report, the entire mining and metals industry moves a 1 trillion dollar into economy. An indicator produced by the International Council of Mining and Metals, the 2018 Mining Contribution Index, synthesizes the significance of the mining sector contribution to national economies. The corresponding report demonstrates that for many countries there is an extreme economic dependency on the mining industry (ICMM, 2018).

The mining activity also has impacts on the environment through the damage it causes. Thanks to the development of industry and technical progress, it has become possible to exploit deposits at large depths. Therefore, the mining industry causes increasingly permanent changes in the environment. In the case of surface mining, these impacts relate to morphology, landscape, and environmental conditions (Matias and Panagopoulos, 2005). The considerable amount of former mining systems located under urbanized soils make soil protection, recovery, and reuse more important. Land consolidation and protection are necessary to prevent instability. Until the second half of the 20th century, a common practice was to leave degraded areas after the end of exploitation. However, at the turn of the 1980s and 1990s, people's awareness began to increase and the conservation and valorisation of post-mining areas began to be considered as the growth of the cultural heritage of the places they belong to (Talento et al., 2020).

Post-mining land reclamation is a stage of mining activity that compensates for adverse changes caused by this activity but also marks the beginning of a new, usually different than before, land use. The purpose of reclamation measures is to give or restore degraded areas of utility or nature value. Thanks to this, these areas can be further developed. Transformations caused by mining make reclamation a long-term process, but, at the same time, they create great opportunities to make the region attractive through the solutions applied (Correia et al., 2001).

Abandoned mining areas create a special kind of landscape in which technological heritage intertwines with ecological heritage, requiring innovative forms of environmental protection and valorisation. Nowadays, recovering abandoned quarries only by "masking" exploitation changes is inappropriate practice. There are great possibilities for the reclamation of areas affected by mining activities, and the only limitations are imagination and available technologies (Talento et al., 2020). Good knowledge of the terrain characteristics, soil properties, or expectations regarding the development of the area may determine the application of solutions that bring economic, environmental, or socio-cultural benefits. Therefore, currently, remediation activities should not be limited only to the revegetation of areas but should ensure effective land use (Gonda-Soroczyńska and Kubicka, 2016).

Reclamation processes in Portugal and Poland are governed by national law, but since the accession of both countries to the European Union in 1986 and 2004 respectively, they are subject to European legislation. Even though there are some differences in the law related to operation in both countries, national law is following applicable European standards. However, European law takes precedence over national law.

1.1. Work objective

The purpose of this work is to explore the use of laser scanning technique in the process of determining the direction of land reclamation. The concepts of reclamation of a limestone quarry, located near Fátima in central Portugal, will be proposed. Scans obtained as a result of tests carried out using the laser scanner will be used to create a point cloud in ReCap Pro software. In order to shape the slope gradient, of which the permissible value for a given reclamation direction is governed by European law, the amount of waste material available in the study area will be determined. Based on the analysis of the research area conditions carried out in a desktop geographic information system (QGIS), and considering both the results obtained from the data survey and the climate differences between both countries, it was possible to propose reclamation solutions. Within this context, the excavation outlook for individual reclamation proposals is visualized using CAD software (AutoCAD).

1.2. Thesis structure

This document is organized as follows: after the introduction (ch. 1), where the research topic is briefly presented, a literature review (ch. 2) characterizes the state of the art. Chapter 3 introduces the use of laser scanning to identify reclamation directions of a limestone quarry, used as a case study. After the discussion of the results, a summary and conclusions are presented (ch. 4).

1.3. Methodology

The process that resulted in that work, was based on the following methodology (Figure 1.3.1.).

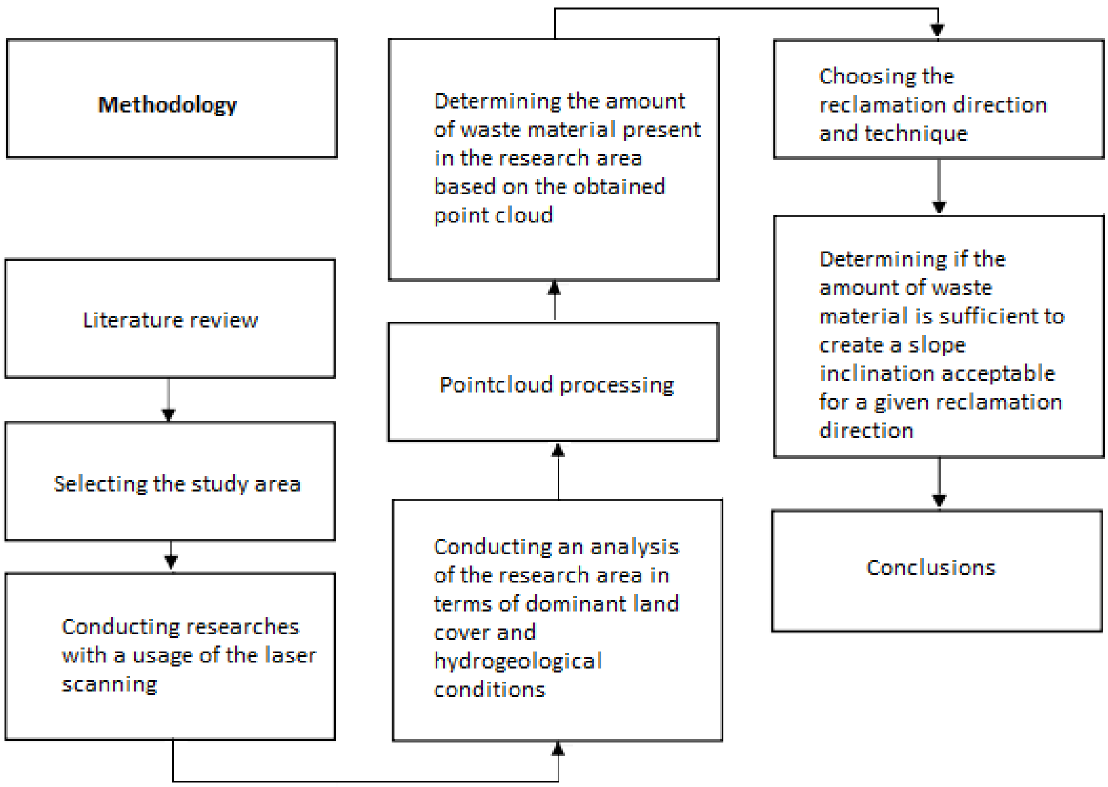

Figure 1.3.1. Master thesis methodology

2. State of the art

2.1. Mine reclamation concept

Reclamation can be defined as the process of restoring degraded areas to a productive state. The main goal of the process is a desire to restore the chemical and structural state of soils, as well as an aspiration to increase the biodiversity. An important aspect is also striving to ensure the security of the exploitation terrain and its surrounding areas, as well as to decrease the visual impact of a quarry.

Recovery interventions have a utility and productive value, at the same time being a symbol of innovation and progress. The regenerative power of abandoned, degraded areas is a strong point of so-called "new ecology", which aims to generate new life cycles of places particularly affected by aggressive forms of degradation. This way of operating results in the creation of new ecosystems characterized by considerable complexity. Through the reclamation of post-mining areas, the site gains new opportunities in both the economic and environmental sectors. Quarries are being transformed from so-called "gray infrastructure" into "green infrastructure". The first category relates to monofunctional components (Figure 2.1.1), consisting mainly of artificial, manufactured materials. The second category includes natural or semi-natural multi-functional areas, of a rural or urban nature, which aim to improve living and environmental conditions, as well as to ensure the ecological balance of territories (Talento et al., 2020).

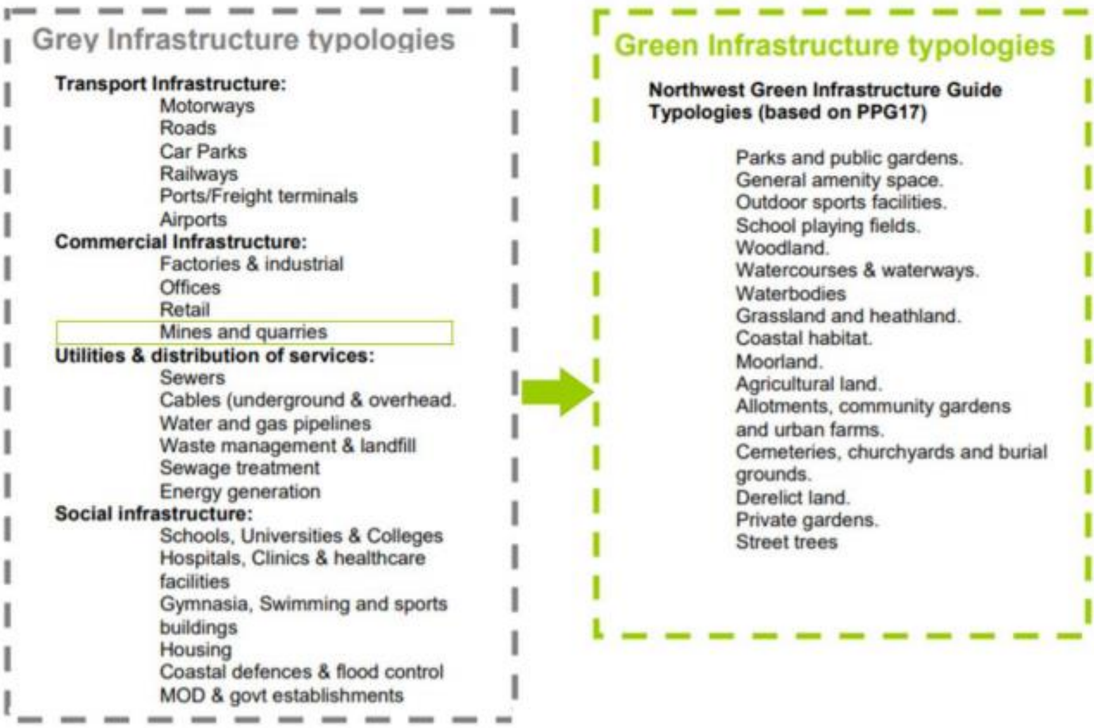

Figure 2.1.1 Components of "Grey and Green Infrastructure", adapted from Talento et al., 2020

Two main elements affect the success of the reclamation of post-mining areas – landform and vegetation.

In terms of landform, the main elements of a quarry are the quarry floor, face, and bench. Every part requires a different treatment during the reclamation process. Mostly, the quarry floor becomes the target of the intended after-use. It can remain dry or it can be flooded, depending on the depth of the water surface and the depth of extraction. It can also be modified to establish a proper surface for planting. However, the biggest challenge of the reclamation process is shaping the quarry slope. The reason is related to difficulties in ensuring safety and visual quality. Benches are attractive as a climbing place due to their height. They can also be used to provide access to various parts of the quarry during the reclamation process, as well as for recreational purposes. So there is huge potential in shaping the surface of the quarry, giving the possibility of obtaining many amenities, both environmental and social.

In the entire spectrum of the after-use quarry applications, there are places where human activity has been reduced and natural remediation has been carried out. An example that reflects this is the Miller Dale Quarry quarry in England (Figure 2.1.1). There are also cases of highly technologically advanced reclamation, where human activity had a significant impact on the development of the place. The Songjiang Hotel in China is an example of this situation (Figure 2.1.2).

Figure 2.1.2 Example of a quarry with reduced reclamation process, adapted from Legwaila et al., 2015

Figure 2.1.3 Example of a quarry after advanced reclamation process, adapted from Legwaila et al., 2015

Quarries are a hostile environment for vegetation establishment. This is mainly due to the soil quality and its insufficient quantity. The reason for that situation is also the steep slopes of quarries. Soil is a very important factor determining the success or failure of land reclamation. Sometimes it is necessary to import the soil from outside the reclamation area. A common practice is to mix topsoil with limestone dust to simulate the alkaline calcareous soil. The purpose of this treatment is to support the process of growth of calcareous vegetation and thus prevent the growth of vegetation that does not fit into the local ecosystem (Legwaila et al., 2015).

The reclamation of post-mining areas should consist of three phases, which are presented next.

1) Preparatory reclamation - includes the preparation of technical and cost estimate documentation, as well as determining the direction of reclamation and development.

2) Technical (basic) reclamation - including activities such as:

- terrain - smoothing steep slopes,
- regulation of water relations - construction of canals, drainage ditches and water reservoirs,
- soil restoration using technical methods,
- total or partial deacidification of soils,
- reconstruction of the access road network.

3) Biological remediation, which includes:

- biological housing of slopes and slopes of excavations to ensure their stability and to prevent erosion processes,
- regulation of water relations through the construction of drainage facilities and protection of waters against pollution,
- soil restoration by agrotechnical methods (Kaźmierczak and Strzałkowski, 2016).

Summary of the subsection:

The purpose of the subsection is to present the concept of reclamation, defined as the process of restoring degraded areas to a state of productivity. Two main elements affect the success of the reclamation of post-mining areas, i.e. landform and vegetation. In the case of shaping the surface of a quarry, there is enormous potential that gives a spectrum of opportunities to obtain amenities, both environmental and social. The second element affecting the success of remediation, i.e. planting vegetation, is a more complicated issue, and it is often necessary to use appropriate techniques to achieve the purpose.

2.2. Legal framework of the reclamation in Portugal and Poland

The exploitation is currently carried out according to strictly defined legal regulations and internal company rules. The control of the mining industry has helped to minimize inaccuracies related to reclamation, as well as to clarify the obligation of reclaiming degraded areas by the perpetrator of the transformations.

The term "land reclamation", according to Portuguese law, is understood as taking actions to improve the state of the environment by restoring biodiversity and ecological status of areas to the condition before mining operations or by giving them a new value of usage (Bastos and Silva, 2005). The main objectives of the reclamation are land stabilization, guaranteeing public safety, and restoring the visual conditions of the area (Direção Geral de Energia e Geologia, n/d). Act nr. 270/2001, which specifies the principles of mining in opencast mines, provides that the entrepreneur may not carry out exploitation, mine closure, or land reclamation without an approved opencast mine plan. The mine plan includes a mining plan and an environmental and landscape protection plan (PARP), indicating measures and proposed solutions for the remediation of areas. If the entrepreneur declines to operate or the license expires, the land reclamation responsibility lies with the landowner and should be carried out under the approved PARP plan (Visa Consultores, 2011).

The Polish Act nr. 16/1995 about the protection of agricultural and forest lands defines reclamation as giving functional or natural properties of degraded lands by properly shaping the terrain, improving physical and chemical properties, regulating water relations, restoring soil, strengthening slopes, and rebuilding necessary roads (Ptak and Kasztelewicz, 2014). The perpetrator of the transformations, following the Act, should carry out land reclamation within 5 years of the end of industrial activity. At the same time, the Act imposes an obligation to include reclamation at all stages of economic activity, starting from the design phase. After the reclamation, it is necessary to develop the area, understood as the implementation of targeted measures to ensure the use of reclaimed land for forest, agriculture, water storage, or other uses, either under municipal or other levels of management. It is important that land reclamation is required by those who have transformed the area, while development is voluntary and lies with the future user of the reclaimed land, which is usually a municipality or a private individual (Król, 2015).

European law, to which the national laws of Poland and Portugal are subjected, regulates the formation of post-mining areas, indicating the permissible values of the slope for a given direction of reclamation. Forest land use provides large slopes of up to 35°. A slope of more than 10° excludes arable crops, while greater than 15° excludes grass sowing. In the case of the water direction of land use, the allowed slope varies depending on the purpose of the water reservoir. For tanks with a natural function, the ratio of the slope height to the base of the terrain must be in the range 1:5 to 1:8, for tanks with a recreational function the ratio is from 1: 5 to 1:10, while for bathing areas slope must lie between 1:10 and 1:15 (Fagiewicz, 2010).

Summary of the subsection:

The purpose of the subsection is to present the legal regulations of remediation in Poland and Portugal. The person responsible for land degradation is obliged to carry out the reclamation. European law indicates the permissible values of the slope inclination for a given reclamation direction.

2.3. Main directions of reclamation in Portugal and Poland

Land reclamation assumes two possible scenarios for its implementation. The first of them assumes the creation of an ecosystem that is an alternative to the prevailing conditions. It is usually associated with the revegetation of post-mining areas. The second model of reclamation aims to give the land a new application, which is associated with the lack of obligation to re-green it (Bastos and Silva, 2005).

The process of land reclamation and giving a new application for degraded areas usually means the place transformation. These metamorphoses may require different types of intervention, from the use of minimal measures to the more significant ones (such as reforestation or creation of new constructions). Many factors decide about the possibilities of land reclamation in a given direction. Typically, these complex procedures take into account parameters such as the type of quarry, legal aspects, area security, local community preferences, and ecology (Talento et al., 2020). Some of the criteria determining the choice of the reclamation direction are decisive, while others remain less significant. Factors and criteria determining the choice of the direction of reclamation are presented in Table 1.

Table 1 -Factors influencing the choice of the reclamation way in Portugal and Poland

Factors	Example criteria
Economic	Reclamation and development costs of the post-mining area Maintenance costs of the developed area and facilities Operation costs Profitability of investments and payback period for commercial projects
Legal	Factors resulting from legal provisions on the protection of nature or monuments
Technical	Excavation type Shape, depth, surface and permeability of the area Type of rocks Service distance Available recovery techniques Slope and slope stability
Hydrological	The presence or absence of water in the excavation Water quality Depth of the groundwater table Thickness of impervious layers
Cultural	Occurrence in the vicinity of spiritual goods (tombs, extermination camps, cemeteries) or material goods (mines, smelters, as well as technical products related to these places)
Spatial	Distance from built-up areas Distance from industrial plants Access by own means of transport or public transport
Social	Demography Impact on local emigration / immigration Changes in the quality of life of society Wealth of society Possibility of employment in new workplaces Tradition and customs Social needs
Environmental	Geology Landscape quality Climate Topography Native vegetation Soil type Natural habitats Contamination of water, soil

During the process of determining the possibilities of degraded areas transformation, mining areas should be classified in terms of their future use. In connection with the future purpose of areas, it is possible to distinguish the naturalistic and recreational reclamation direction, as well as the cultural, educational, and productive direction (Talento et al., 2020). In the case of surface mining, the most common directions of reclamation are forest and agricultural (Ostręga and Uberman, 2010). In a reclamation of Polish calcareous excavation areas, forest and water directions are mostly used (Kacprzak and Bruchal, 2011). It can be concluded that methods of reclamation and development are basically unlimited, however, to determine these directions in documents and decisions, their classification becomes useful, as presented below.

Reclamation in a natural direction

Natural quarry reclamation is a set of methods aimed at restoring vegetation in areas affected by mining excavation. This operation ensures the creation or restoration of natural conditions in order to enable the continuity of the ecosystem with surrounding areas. The purpose of this type of remediation is also to limit the negative morphological effect caused by excavations. This rehabilitation category requires an advanced ecological analysis of the territory to support appropriate technical and vegetative choices. Two subgroups can be distinguished in that group of reclamation methods, i.e. forest and nature remediation (Talento et al., 2020).

Forest direction

The forest reclamation direction, both in Poland and Portugal, is most widely used. This type of land rehabilitation involves adapting the areas for their future use as forests, plantations, or wooded areas.

This method can be used in the case of areas over 25 ha. Soils do not need to be characterized by high fertility, but the slope gradient, for which a maximum value may be 35°, is a limitation. To develop the forest area, techniques such as the addition of organic material or nutrients are often used to enrich the soil. A very important issue is also the proper formation of the soil layer responsible for the proper vegetation of plants. The right selection of tree and shrub species that have a major impact on the success of biological reclamation at the initial stage of reclamation is also of great importance (Ostręga et al., 2011).

The species used for planting in Portugal are often eucalyptus (Eucalyptus globulus), and in the case of reclamation of calcareous lands, they are native tree species such as the Aleppo pine (Pinus halepensis), stone pine (Pinus pinea), carob plant (Ceratonia siliqua), rush broom(S. junceum) as well as olive trees (Olea europaea), (Fontes Vicente, 2016).

In Poland mainly calcareous tree species are planted, such as black locust (Robinia pseudoacacia), silver birch (Betula verrucosa), white poplar (Populus alba), european larch (Larix decidua), maple (Acer sp.), rowan (Sorbus aucuparia), or gray alder (Alnus incana), (Kacprzak and Bruchal, 2011). Figure 2.3.1 presents the Polish quarry in Górażdże, which conducts a reclamation in water direction.

Figure 2.3.1 Example of forest reclamation direction in Poland (Górażdze quarry), adapted from https://www.quarrylifeaward.com

Creating a nature protection reserve

This direction of land reclamation requires a suitable substrate that will be able to allow the growth of naturally occurring vegetation. Post-mining areas, although usually associated only with the devastation of the environment, often after the finishing of mining activities are covered by various forms of nature protection. The reason for this phenomenon is natural succession or exploration of interesting geological phenomena during exploitation (Ostręga et al., 2011).

An example in Poland is the creation of the "Bonarka" Inanimate Nature Reserve in a closed terrain of a marl excavation, as a result of an interesting rock exposure (Figure 2.3.2).

Figure 2.3.2 ”Bonarka” Nature Protection Reserve in Poland, adapted from https://www.agh.edu.pl/

Reclamation in a water direction

Reclamation in a water direction includes the preparation of a recreational, breeding, or ecological water reservoir in the degraded area. Hydrological and hydrogeological conditions are decisive factors in the process of choosing this reclamation direction. Suitable excavations for water management are irrigated excavations, where extraction takes place from below the water level, as well as drained excavations and excavations whose bottom and slopes are made of poorly permeable material. If the exploitation is carried out from under a water mirror, after stopping drainage, the excavation will be filled with water. Then it is natural to adapt the irrigated excavations to various water functions, such as:

• recreational - bathing, water sports

• households - retention tanks, drinking water tanks

• fishing - breeding ponds

• nature - water reservoirs as an element of the landscape (Ostręga and Uberman, 2010).

An example of water reclamation direction in Poland is a water reservoir "Sosina" in Jaworzno (Figure 2.3.3).

Figure 2.3.3 Example of water reclamation direction in Poland (water reservoir "Sosina"), adapted from http://geoportal.pgi.gov.pl/

Reclamation in a recreation direction

Recreation rehabilitation is aimed at developing space to give it a recreational function. Land reclamation in this direction can perform the following functions:

• Leisure and tourism - beaches, sports and recreation facilities, accommodation bases (camping and camping sites, summer houses, hotels, guesthouses)

• Sports - ski slopes, bicycle routes

• Cultural - theaters and amphitheaters, concert halls

This method of land reclamation, similarly to the previous one, requires stability of the slope and location near the city center or village. For the educational use of land, the land must have an area exceeding 10 ha. A common practice of preparing land for land reclamation in this particular direction is to redevelop the land to correct the slope to enable its use for a specific purpose (Ostręga and Uberman, 2010).

As an example in Portugal, the recreation area on a river in Sintra, created from the site of the once-existing open-cast mine, can be adduced (Fontes Vicente, 2016).

A Polish example of this particular direction of land reclamation is the sport and recreation center with ski slopes in the Bełchatów - Góra Kamieńsk area (Figure 2.3.4), or the Kadzielnia amphitheater in Kielce built in a closed limestone quarry (Ostręga et al., 2011).

Figure 2.3.4 Example of recreation reclamation direction in Poland (Góra Kamieńsk), adapted from https://pgegiek.pl/

Reclamation in a cultural direction

This direction consists of using the reclaimed space of former mines to commemorate local historical events. As an example for Poland, the tragic history of exploitation areas associated primarily with World War II, during which the establishment of labor camps in mines was a common phenomenon, can be paradigmatic. In this case, turning the reclaimed space as a memorial is the only acceptable way of developing it. The reclamation will be limited only to tidying up the area and securing mining excavations and remains of the camp facilities and infrastructure.

In Poland, examples of such a solution for land reclamation and development are the Penal Labor Camp "Treblinka I" and the Extermination Camp – Treblinka II at the gravel pit and the Labor Camp transformed into the "Płaszów" concentration camp (Figure 2.3.5) at the terrain of limestone quarries in Krzemionki Podgórskie in Krakow (Ostręga et al., 2011).

Figure 2.3.5 Example of cultural reclamation direction in Poland, adapted from https://muzeumtreblinka.eu/

Productive reclamation

Productive reclamation includes agricultural and industrial reclamation. The goal of the agricultural reclamation is to restore the original or create a new ecosystem, as well as to prepare the land for agricultural production. The second subgroup of productive reclamation aims at adapting the areas to perform various economic functions. In both cases, it is necessary to conduct a morphological analysis of the area in order to take appropriate reclamation measures (Talento et al., 2020).

Agricultural direction

Agricultural reclamation is designed to prepare the area for agricultural use and production (for arable land, meadows and pastures, gardens, orchards, bush plantations), (Talento et al., 2020). The decision of agricultural reclamation is made on the basis of morphology (small slopes required), soil and water conditions, soil-forming properties, and the demand for agricultural land in surrounding areas. At the initial stage of rehabilitation, special expenditures are needed due to the preparation of fully productive soil with appropriate chemical (soil acidity/alkalinity) and physical properties. The latter limitations are related to the degree of stony nature of the area (crops are possible when the stony value is less than 15%), the availability of water, as well as the risk of erosion. Common practices necessary for agricultural reclamation are the addition of organic material, acidity correction, soil fertilization, slope reduction, and drainage work (Ostręga and Uberman, 2010).

In Portugal, flower-tolerant soil species with moderate levels of nutrients and moisture are often used, i.e. peony (Paeonia broteri), species of the Scilla fenus, and friar's cowl (Arisarum vulgare), (Fontes Vicente, 2016).

In Poland, examples of species planted are corn (Zeamays), cereals (for example rye, Secale cereale), sunflower (of the Helianthus genus), or beet (Beta vulgaris), (Ostręga and Uberman, 2010). Figure 2.3.6 presents the Open Pit Mine "Ostrowite", which carried out a reclamation in agricultural direction.

Figure 2.3.6 Example of agricultural reclamation direction in Poland (Open Pit Mine “Ostrowite”), adapted from https://www.lafarge.pl/

Industrial direction

This direction consists of the adaptation of areas for various economic functions of an industrial, service, or communal character. Industrial areas are often located within cities and are well connected with other urban centers, therefore their adaptation to new functions is easier. In the case of implementation of the industrial direction, the reclamation process will be limited to technical activities consisting of the appropriate preparation of areas and excavations and securing technical infrastructure facilities. A very common practice is reducing the slope to ensure its stability in future land use.

This direction of land reclamation may include the creation of industrial parks, warehouses, shopping centers, car parks, and municipal solid waste landfills, of which a landfill in Seixal, south of Lisbon, is an example.

A popular Portuguese example of the direction of this type of reclamation is the Municipal Stadium of Braga (Figure 2.3.7), a football stadium in a former quarry carved in the side of a hill in the city of Braga, northwest of Portugal, which was a venue during the UEFA Euro 2004 championship. The space of a former open-pit mine was also developed in Lousal, in southwest Portugal, by building hotels and restaurants, as well as by creating a historic mining museum. Additionally, in 2010, a science education center was opened, in partnership with local authorities, Portuguese universities, and the Science and Education ministries (Fontes Vicente, 2016).

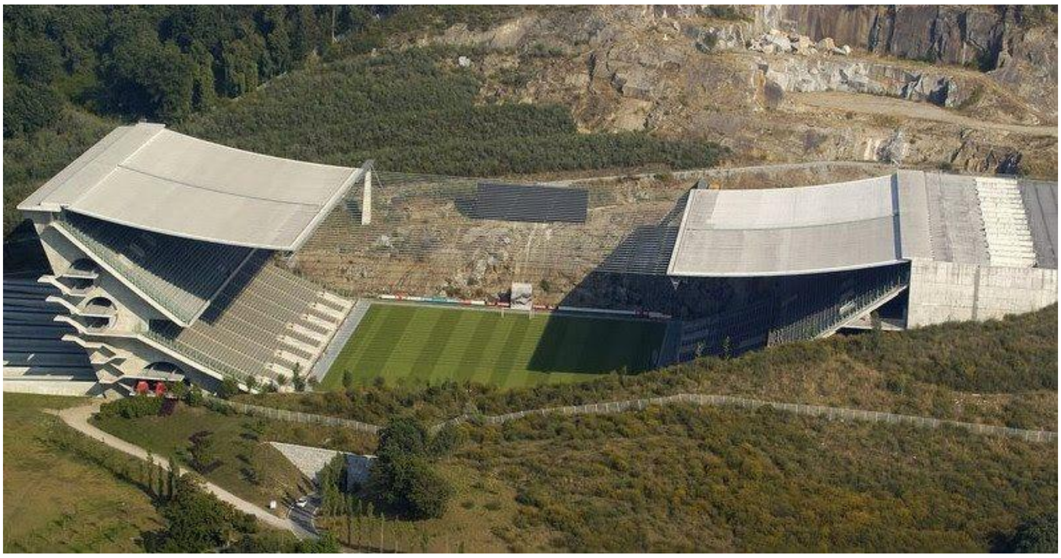

Figure 2.3.7 Example of industrial reclamation direction in Portugal (stadium in Braga), adapted from https://www.cm-braga.pt/

Figure 2.3.8 presents other examples of places where specific directions of land reclamation were used.

Naturalistic	Recreational	Cultural	Productive	Facilities
Karsdorf Vineyard (Germany) Vineyard and afforestation in limestone quarries.	**Brick Pit Ring** (Australia) Recreational Park that promotes the biodiversity with the presence of rare species.	**Montraker** (Croatia) International summer school of sculpture located in an active and Vrasar stone quarry.	**Portel winery** (France) Winery and quarry museum in a gypsum quarry.	**Beinheim port** (France) River port on the Rhine for barges and boats boats in a sand and gravel quarry.
Rheinelbe (Germany) Naturalistic Park with garden school, seat of IBA Emscher Park, in a coal mine.	**Rordal Lake Park** (Denmark) Park for aquatic sports with open-air theatre in a gypsum quarry.	**Crazannes** (France) Rest area La Pierre de Crazannes with open-air museum in a marble quarry.	**Landschaftskunst Goitzsche** (Germany) Recovery of lignite mines for touristic-bathing purposes, near Bitterfeld and Pouch.	**Hidrarchy Project** (Italy) The quarries became reservoirs to mitigate hydric system variations.
Zanderij Quarry (Holland) Terraced Park with botanical collections in an aggregates quarry.	**Bois-le-Roi** (France) Public Park with bathing area in a sand quarry.	**Westpark** (Germany) Urban Park in Munich suburb with show rooms, exhibition spaces, greenhouses and amphitheater in gravel quarries.	**Druridge Bay** (UK) Territorial Park with lakes, seaside resort and naturalistic oasis in a coal quarry in Cresswell.	**Memory Forest** (Sweden) Cemetery Park in Enskede in a gravel quarry.
Blue Circle (UK) Wooded areas and golf course in clay quarries.	**Firminy** (France) Stadium and Youth and Culture Home in a coal quarry designed by Le Corbusier.	**Moray Sacred Valley** (USAN) Opencast agronomic laboratory.	**Blue Water** (UK) Shopping Center in a limestone quarry in Greenhithe.	**Igualada cemetery** (Spain) Cemetery Park, place to rest and reflect in the solitude.
Vulcano Croscat (Spain) Natural park with geological, botanical, faunistic, and landscape value.	**Cergy Ponds** (France) Lakes for aquatic sports, swimming pool, tennis golf courts, equestrian trails and naturalistic areas in a sand quarry.	**Broken Circle and Spiral Hill** (Holland) Land art pieces in a sand quarry in Emmen.	**Denia Mountain** (Spain) Commercial and touristic center in a limestone quarry, with hotel, auditorium, parking and terraced gardens.	**Chicago deep Tunnel** (USA) Biggest quarries in the world, transformed in a stormwater and linked, through channels and tunnels.
La Mortella Gardens (Italy) Gardens in a trachyte quarry in Ischia, spaces for artistic manifestations and concerts.	**Emscherbruch** (Germany) Landscaped park with recreational areas (skating rink, mountain bike) in coal mines.	**Eden Project** (UK) Thematic Park in a kaolin quarry, with greenhouse, experimental gardens and open-air amphitheater	**Isola Giarola Quarry** (Italy) Area for recreational, naturalistic and productive (fish farming) purposes in a sand quarry near Piacenza.	**Spiral Hill** (Netherlands) Sand dock revolving around a rock.
Isola Giarola Quarry (Italy) Area for recreational, naturalistic and productive purposes in a sand quarry.	**Braga Stadium** (Portugal) Stadium in a stone quarry on the north side of the Monte Castro in Braga.	**Field of sculptures** (Romania) Open-air ethnographic museum in a limestone quarry in Măgura	**Ca' Trebbia** (Italy) Agricultural recovery in a gravel quarry near Piacenza.	**Skogskyrkogarden** (Sweden) Cemetery Park and masterpiece of the recycled places.
Luneo Quarry (Italy) Oasis WWF in a clay quarry with spontaneous renaturalization.	**Blue Circle** (UK) Wooded areas and golf course in clay quarries	**Fossar de la Pedrera** (Spain) Memorial Park in a stone quarry in Barcelona	**Quarries Hotel** (Italy) Tourist settlement in white tuff quarries in Favignana.	
Lignite Quarry (Germany) Renaturalization in the Lusatia Region.	**Henry Palmisano Park** (USA) Recreational Park conceived in a multifunctional and adaptive manner; it also serves as a buffer in flooding situations.	**Tindaya Mountain** (Spain) Exhibition space and land art intervention in a marble quarry of Tindaya Mountain.	**Pierre et Vacances Costa Plana** (France) Tourist settlement in the French quarries.	
Las Medulas (Spain) Spontaneous renaturalization in the former golden mines.	**Isola Giarola Quarry** (Italy) Area for recreational, naturalistic and productive (fish farming) purposes in a sand quarry near Piacenza.	**La Mortella Gardens** (Italy) Gardens in a trachyte quarry in Ischia, spaces for artistic manifestations and concerts.	**Intercontinental Hotel** (China) Tourist building constructed and attached to the vertical wall of the quarry.	
Zanderij Crailoo (Holland) Natural reserve, close to the Dutch railway.	**Gym Free climbing** (Italy) Rock Gym in a stone quarry in Rome	**Rubbio Quarry** (Italy) Studio and artistic laboratory with open-air amphitheater near Vicenza.	**Hotel in a quarry** (China) Tourist building suspended on the quarry surfaces.	
Musital Quarry (Switzerland) Naturalistic recovering of a limestone quarry.	**Lignite Quarry** (Germany) Natural Park with lakes for acquatic sports and recreational activity.	**Geo-mining Park** (Italy) In Cagliari, Saregna.	**Dionyssos Quarry** (Greece) Touristic park to see the industrial memories.	
	Dalhalla Theatre (Sweden) Recreational activities, concerts and events during all the summer season	**Royal botanic gardens Victoria** (Australia) Educational purposes to show the different Australian micro-landscapes.	**Quarry Botanic Garden** (China) Touristic space for visitors approaching natural landscape and experiencing the culture of quarrying industry.	
	Atlanta's Westside Park (USA) Recreational Park water reserve container .	**Negev Phosphate Works** (Israel) Gigantic environmental sculpture Park.		
	Hedeland (Denmark) Regional park with natural areas, sports facilities, amphitheater and other equipment in a former gravel and clay quarries.	**La Palomba Park** (Italy) Sculptural Park in the Matera archaeological Park of rock churches.		

Figure 2.3.8 Other examples of specific directions application, adapted from Talento et al., 2020

Summary of the subsection

There are several directions of reclamation for post-use open-pit mining sites. The choice of the remediation way can be determined by a wide range of factors - from geological conditions in case of agricultural direction to the local history of the area in case of cultural and contemplative direction. The land development is also influenced by factors such as a desire to merge the reclaimed area with the native ecosystem (forest direction). Often, the choice of remediation direction is also determined by technical or social factors, as in the case of the sport and recreation direction, where the terrain is used to create a museum or sports field.

2.4. Reclamation techniques

Factors presented in the previous section influence the type of reclamation techniques that can be used in a given case, as well as the final appearance of the quarry. Patterns of the reclamation process should be consistent with the principles of landscape design. Importantly, to achieve a success of the reclamation process, projects must also comply with the theories and principles applicable to the intended after-use of the terrain. Several reclamation techniques can be used to reduce the visual impact of quarries and provide biodiversity potential. These techniques contribute to the more effective achievement of a functional, aesthetic, and sustainable landscape. They can be used independently or combined to prevent monotony in the landscaping process.

Enabling the natural succession process was a commonly used form of reclamation. Nowadays, although rare, it can also have the desired effect. Despite the fact that vegetation reduces the quarry visual impact on the landscape, this is not appropriate practice for large-scale mines. However, natural succession can be a part of the recovery plan for small mining companies.

Very often, the effectiveness of remediation methods can be significantly increased by using a combination of techniques to achieve the intended result. A very important factor affecting the choice of one or a combination of techniques is the nature of the surrounding landscape, as well as the availability of waste material, useful in the process of shaping the surface of post-mining areas. The choice of a technique will also be determined by future land use of the terrain and economic factors (Legwaila et al., 2015).

The categories of land transformation are subdivided into two macro groups:

• Remodelling: this includes operations of filling, modification, and insertion.

•Not-remodelling: this does not entail substantial alterations of the excavation and includes the small intervention method, attached method and natural succession (Talento et al., 2020).

Remodelling land transformations

Filling methods

Filling operations, as the first subgroup of remodeling transformations, varies depending on the material used. In the case, when water is the filling material, there are possible configurations typical for lakes, reservoirs, and wetlands, where the flat surfaces predominate. In other situations, when solid material, such as a ground, is the filling matter, the possibilities of terrain reshaping are expanded. A building can also be considered as filling material. In this case, degraded areas are reconstructed, and an empty space is developed to perform specific functions, such as a car park or hotel.

A specific example of terrain transformation using the filling methods is the backfilling technique (Talento et al., 2020). The backfilling technique is a process of partially (or completely) filling avoid quarry with soil or waste material from the exploitation process to restore the original or give a new landform. This method depends on the availability of filling material. In the situation of insufficient material quantity, it is necessary to supply from an external source, which can generate costs. The advantage of the method is the fact that it minimizes the possibility of potential rock falls, which contributes to increasing the safety of the reclaimed area. That results in the possibility of establishing vegetation anywhere on the site after the landform shaping process (Legwaila et al., 2015). Image 2.4.3 presents the backfilling technique application.

Modification methods

The second subcategory of remodeling methods is “modification”, which can be divided into “new form”, “emphasizing”, and “camouflage”. The first one aims to give new aesthetic, visual, and ecological values for the land, reducing the degradation through land movement or rock reshaping. The “emphasizing” method refers to actions of sculptural remodelling, adapting cuts and bevels and the goal of “camouflage” is to hide undesired surfaces or substances through technological solutions.

Two specific techniques – rollover slopes and restoration blasting – can be presented as an example of modification methods (Talento et al., 2020).

Figure 2.4.1 Rollover slopes technique example, adapted from Legwaila et al., 2015

The rollover slopes technique consists of tipping and pushing material over the upper edge of the quarry and spreading it on the benches, forming gentle slopes. It is often used in well-visible parts of the quarry, although the surface smoothness may not resemble the natural shape of the terrain. This technique contributes to reduce the risk of land instability, increasing the conditions of safety within the quarry. The disadvantage of the method is the possibility of steep slopes presence, which may limit the land after-use possibilities, as well as making the highest parts of the quarry less accessible. Figure 2.4.1 presents the rollover slopes technique application.

The restoration blasting technique, presented in Figure 2.4.2, aims to use the final phase of blasting of the quarry faces in order to simulate landforms occurring in the area. The technique is mostly used in the visually intrusive parts of the quarry, allowing blending the quarry area with its surroundings. The method is a technical undertaking that requires geotechnical knowledge, enabling the implementation of a specialized explosion. This method is often economically unprofitable because, in the case of unstable quarry walls, it is necessary to provide professional protection and implement measures to prevent the falling of rocks (Legwaila et al., 2015).

Figure 2.4.2 Restoration blasting technique example, adapted from Legwaila et al., 2015

Insertion methods

The "insertion" is the last subgroup of the remodelling transformations. It comprises new constructions inserted, partially, in the quarry void, causing excavations of subtraction and adaptation (Talento et al., 2020).

Not-remodeling land transformations

The second group refers to the "not remodelling" transformations. One of the subcategories are methods with small interventions performed, aiming to secure excavation areas. As a "small intervention" method, a bench planting technique can be presented.

Small intervention methods

The bench planting technique (Figure 2.4.4) involves placing soil and waste material on benches to create a planting surface. The main purpose of the method is to allow the establishment of vegetation on benches, which can eventually cause complete coverage of rock walls. The method's limitation is often soil instability and insufficient soil amount for planting large, deep-rooted trees.

However, using the proper type of plants, this technique can minimize the amount of exposed rock surface, thereby improving the visual quality of a quarry. An important advantage is the fact of a relatively small amount of the fill material required to carry out the process (Legwaila et al., 2015).

Figure 2.4.3 Backfilling technique example, adapted from Legwaila et al., 2015

Figure 2.4.4 Bench planting technique example, adapted from Legwaila et al., 2015

Attached method

There can be distinguished also the "attached" subgroup, which is declined in three variants: "attached horizontally", "attached vertically", and "suspended". These measures adopt the construction of buildings, paths, and facilities to resolve the transformation of a quarry (Talento et al., 2020).

Natural succession

The last subcategory of not-remodeling: transformations is the natural succession, which is a concurrent method with all artificial interventions. This method exalts the power of nature to destroy any form of degradation. Natural succession is a process in which the re-vegetation is based on the presence of seeds and roots in the soil. This occurs at various stages, called primary and secondary succession (Talento et al., 2020). The technique is recommended to use as a cheap alternative for the reclamation of abandoned quarries, but it can also be used in quarries that have undergone the closure process. Depending on the soil quality and the number of seeds, this process is very time-consuming. Also, succession may be associated, especially in the early stages, with land instability.

The advantage of the process, however, is the fact that there is a wide range of possibilities for the creation of various ecosystems, which minimize the negative visual impact of the quarry on the surrounding areas (Legwaila et al., 2015). Figure 2.4.5 presents the natural succession technique.

Figure 2.4.2 Natural succession example, adapted from Legwaila et al., 2015

Summary of the subsection

Land transformation methods consist of two main groups – remodelling and not-remodelling methods. The aim of these methods is to reduce the visual impact of quarries and provide biodiversity potential. They also contribute to a more effective achievement of a functional, aesthetic, and sustainable landscape. Transformation methods can be used independently or combined to prevent monotony in the landscaping process. Such specific reclamation techniques can be distinguished as examples of land transformation methods: rollover slopes, backfilling, bench planting, restoration blasting, and natural succession. Each method is appropriate for different environmental, economic, and visual conditions.

2.5. Laser scanning

3D laser scanning is a measuring technique that results in the acquisition of spatial data of an examined area or object. It belongs to a group of active remote sensing systems that use electromagnetic radiation of laser beams emitted by a measuring device, called a rangefinder, which measures the sensor to target distances, scanning over a predefined directional and distance range and capturing what is in its field of view (Kuznetsowa et al., 2014).

There are aerial, satellite, and terrestrial laser scanning, classified by the type of support the scanner is based in. In this work, terrestrial laser scanning (TLS) was used, as it was possible *in situ* data acquisition (Marshal and Stutz, 2012).

The history of the measuring technique began in 1993. At that time, the LIDAR (Light Detection and Ranging) systems and techniques covered only the aerial laser scanning (ALS) in the form of aircraft-mounted devices. However, the turning point was in 1998, when the world's first terrestrial laser scanning (TLS) device was created (Gu and Xie, 2013).

A laser scanner usually consists of:

• a transmitter (diode) generating laser light,

• a system of rotating mirrors that evenly spread the laser beam over a given surface,

• an optical telescope that collects reflected laser signals,

• a detector that converts light energy into a ready-to-save form in the registration module (HDD, memory card),

• the control unit to which the transmitter and detector are subjected (Kuznetsowa et al., 2014).

Figure 2.5.1 shows the working principle of laser scanning measurements.

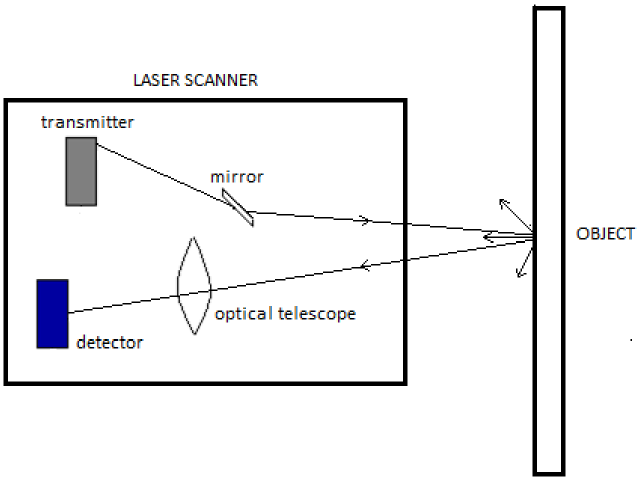

Figure 2.5.1 Laser scanning operation method

The basic classification of TLS scanners is based on distance measurement technology. There are pulse (TOF) and continuous wave (CW) scanners, called also phase scanners. For pulse scanners, the function of the time, which takes the beam to reach a whole distance from the object and back, is distance. The phase laser signal is modulated by a suitable sinusoidal or exponential function. TOF scanners are characterized by a lower data acquisition speed compared to phase scanners, as well as lower measuring accuracy. Their advantage is the large measuring range. The first of the discussed group of scanners is therefore intended for the registration of objects and processes in the field of geomorphology or geology, landscape monitoring, as well as topographic and mining works. On the other hand, continuous wave scanners are used primarily in the architecture, construction, and engineering field (Xie and Jia, 2010).

The most important features of terrestrial laser scanners are:

• high acquisition speed (hundreds of thousands to millions of points per second)

• complete independence of measurements from lighting conditions, as these devices can work in total darkness

• significant independence of measurements from air transparency – only the range is reduced, not the measurement accuracy

• significant automation of data acquisition – this feature minimizes the possibility of measuring errors

• possibility of immediate registration of the object's condition - complete independence from the availability of external data

• no direct costs associated with data acquisition (Ahamad and Ojha, 2015).

All laser scanners, belonging to the group of active remote sensing systems, work on a similar principle - they are based on measuring the distance of the device from the tested object. This is possible thanks to measuring and recording the time that elapses from the moment the laser beam is sent to its return to the detector after reflection from the target surface. The known value of the speed of the propagating electromagnetic wave and the measured time make it possible to calculate the distance of the object from the scanner (Gu and Xie, 2013).

Faro Focus S70 was used as a measurement tool during the research. This device is a high-speed three-dimensional laser scanner for the detailed measurement and documentation of large object spaces and buildings. It is perfectly suitable for short-term measurements up to 70m. The speed of the laser scanner used during testing reaches up to 976.000 points per second, and its range is up to 350 m. The device also records the angle at which the laser beam is sent. The device used in the measurements has an ability to cover a 360° horizontal plane and approximately 330° vertical plane (does not cover angles near the nadir as it is out of the field of view). The measured time and the beam deflection angle allow the determination of local X, Y, Z coordinates, which can be converted into a real-world coordinate reference system. Several millions of these coordinates give a fully three-dimensional image of the environment.

Then, computer software must be used to combine individual scans through point set registration and to create a consistent, coherent, and usable spatial data model. In this work, Autodesk ReCap Pro was used for this task (User Manual for the Faro Focus M and S Series, 2019).

Figure 2.5.2 illustrates the used laser scanner during a data capture operation. The device, after the configuration of a job, can aim its laser beam in a wide horizontal and vertical range: its head rotates horizontally, while a mirror tilts vertically. The laser beam is used to measure the distance to the first object on its path, within the predefined distance set by the operator.

Figure 2.5.2 FARO laser scanner in operation, author photo

With the spread of this measuring method, new applications are constantly emerging. Laser scanning can usually be used to create 3D models of various surfaces. Examples of areas of application of 3D laser scanning are inventory of objects, 3D visualizations of cities and buildings, or virtual tours. Measurements using a laser scanner have also been used in mining, as shown below:

• Generating 3D mine models. This application can be used to analyze rock properties or to determine the volume of resources drawn

• Specifying object dimensions. It can be useful in the process of monitoring the deformations of mine elements over time.

• Surface research, especially useful in the process of monitoring the subsidence in mining areas.

• Data acquisition in a process of planning the post-mining land reclamation

• Landslide monitoring, particularly useful in the analysis of landslide hazards in surface mining

• Monitoring of deformation of the underground mining area

• Measurement of earth masses in heaps (Kędzierski et al., 2010).

There are also other methods of measuring terrains and objects, including the method of using a scanning total station or a photogrammetric method.

A scanning total station is a device equipped with a specular rangefinder that allows distance measurement without signaling the endpoint of the measured length. This feature makes scanning total stations similar to laser scanners, but only in the way of obtaining data. These instruments differ in the design of the transceiver system, and the visible effect is the speed of data acquisition, which in the case of scanning total stations is up to 25 points per second. Despite obtaining a much smaller density of points for the same measurement time, the main advantage of a scanning total station is its range of about 600 m - 1000 m (Wagner, 2016).

Photogrammetry is a measuring technique based on photogrammetric photos (photograms). Thanks to photographic exposure and then - photogrammetric processing, a model of the object being developed is obtained. It is used in many branches of the economy. Aerial (aerophotogrammetry) and terrestrial (ground photogrammetry) processes can be distinguished. The purpose of ground photogrammetry is to obtain photos and measurements that will allow the development of a map or obtain data on the photographed object. Photogrammetry is also used, among others in geology to search for mineral resources, in architecture for the inventory of monuments, and even in medicine (Mancini and Salvini, 2020).

There is a technique, which combines the airborne lidar, aerophotogrammetry and the analysis of historical topographic maps in order to carry out the detection and geometrical characterization of a buried landfill. As a result of the methods connection, multi-temporal topographic datasets are obtained, which provide a base for further direct investigations, monitoring strategies and assessment of environmental hazards associated with buried landfills. The analysis of historical aerial photographs and topographic maps provides an effective tool for a rapid identification of buried landfill sites and associated anthropogenic landforms. This connection of measurement methods can be applied for the identification of unknown landfills, the analysis of their historical evolution and to carry out the quantitative assessment of their volume and geometry (Esposito et al., 2018).

Summary of the subsection

The purpose of the subchapter is to present laser scanning as a measurement technique. All laser scanners work on a similar principle - they are based on measuring the distance of the device from the tested object. Faro Focus S70 was used as a measurement tool during the research. This device, perfectly suitable for short-term measurements up to 70m, is a high-speed three-dimensional laser scanner for the detailed measurement and documentation. The fields of application of laser scanners are very wide. In the field of mining, there can be distinguished, among others, applications such as generating 3D models, specifying object dimensions, and monitoring of deformation of the underground mining area.

3. Application of laser scanning to identify reclamation directions in a limestone quarry

3.1. Description of the study area

Measurements using the FARO laser scanner described in the section 2.5. were carried out at the Filstone Natural limestone quarry in Casal Farto, near Fátima, Portugal. The company is located in the Maciço Calcário Estremenho (limestone massif of Estremadura) limestone region, very close to the Serras de Aire e Candeeiros nature park.

The location of the opencast mine is shown below (Figure 3.1.1).

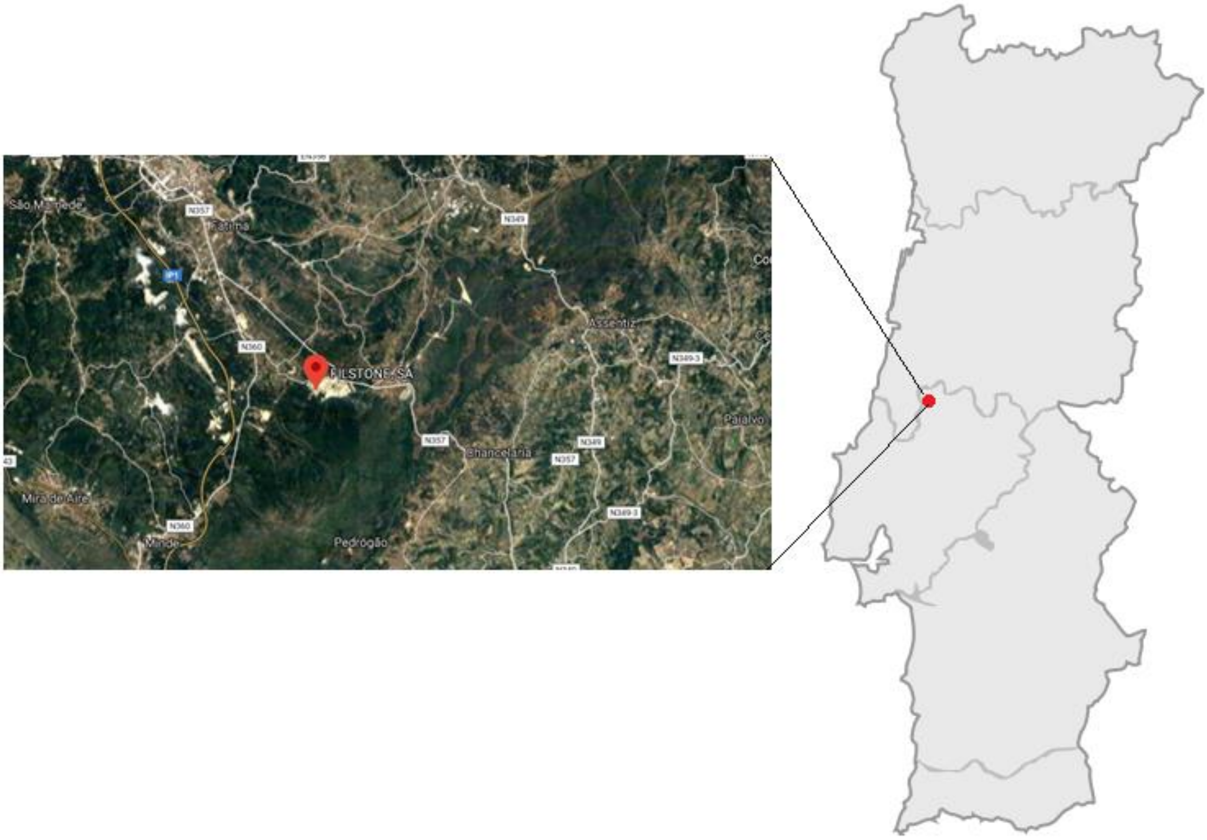

Figure 3.1.1 Location of the Filstone Natural quarry in Portugal. Image in detail extracted from Google Maps

The mine, located 6 km southeast from Fátima, annually extracts 30,000 m^3 of limestone with several beige to whitish hues and finishings. Major applications of this product are stone cladding, as well as facade coverings, general masonry, and stonework. Filstone Natural conducts mining cooperation in this area together with two other companies - Pedra Alva and Extrastone.

Figure 3.1.2 presents the layout of the quarry. The approximate dimensions of the area are 1440 m by 611 m. The red point indicates the exact place, where the measurements were taken.

Figure 3.1.2 Layout of the quarry, adapted from Google Earth

To allow the determination of the characteristics of the areas surrounding the Filstone Natural mine, an analysis of the study area was performed. The analysis was carried out using a collection of spatial data layers described below.

Figure 3.1.3 shows the quarry and surrounding areas on the current OpenStreetMap basemap. The Filstone Natural quarry area is marked with the rectangle.

Figure 3.1.3 Quarry and surrounding areas in the OpenStreetMap dataset (approximate area: 1440 m by 611 m)

The analysis of terrain changes was based on the official Portuguese land cover/land use reference maps from 1995, 2010, 2015, and 2018, produced by DGT (Direção-Geral do Território, the Portuguese national mapping agency). These datasets, named COS ("Carta de Ocupação do Solo"– "Soil Occupation Map") are available as polygon shapefiles (a widely used spatial data vector format) in DGT's website and are the product of image classification, using the minimum mapping unit of 1 ha (0,01 km^2). They were obtained by the visual interpretation of detailed orthophoto maps (pixel size of 25 cm) and other ancillary data, using a rigid hierarchical nomenclature up to various levels. The single land cover/land use code assigned to each polygon in each of the COS yearly datasets is selected from the most detailed nomenclature level, according to a minimum occupation within the delimited area.

As an example, the COS 2018 land cover/land use map has 83 classes in the most detailed refinement (fourth level of detail), which can be aggregated up to a generalized level containing 9 LCLU mega classes: artificialized/built-up areas, agriculture, pastures, agroforestry space, forests, open spaces or with sparse vegetation, wetlands, and surface water bodies. Four classes of terrain were distinguished in 1995, 2010 and 2015: Class 1 for built-up areas; Class 2 for agricultural areas; Class 3 mainly for forest areas; Class 4 for wet areas; and Class 5 for permanent water bodies. In 2018, additional terrain classes were specified, resulting in the distinct 9 mega classes listed above.

A desktop geographical information system (GIS) software (QGIS) enabled to process the spatial data on the vegetation in the studied region, using the COS datasets mentioned before. The most common types of forest class plant complexes include cork oak forests (Quercus suber L.), eucalyptus forests (Eucalyptus L'Hér.) and pine forests (Pinus pinaster Aiton and Pinus pinea L.).

The following figures were obtained in QGIS using the various COS land cover/land use datasets. Figure 3.1.4 shows the area of the Filstone Natural mine and its surroundings in 1995, 2010, 2015 and 2018 respectively. The Filstone Natural quarry area is marked in yellow.

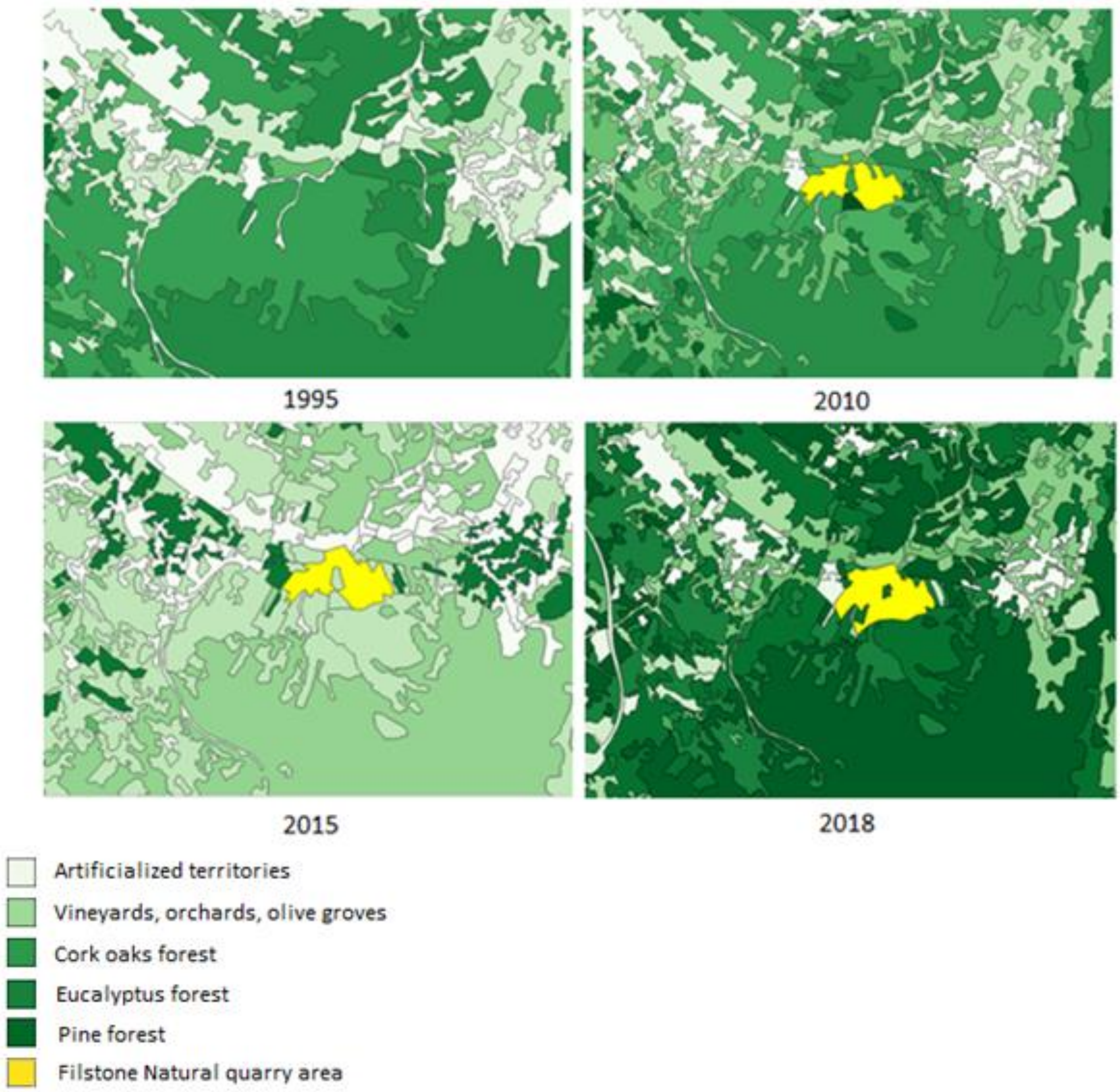

Figure 3.1.4 Area of the quarry and surroundings in 1995, 2010, 2015 and 2018

Based on the analysis of the research area over the years, it can be concluded that forest areas dominate the site surrounding area. Figure 3.1.5 shows forest areas around the mine in 2018. They are marked in yellow.

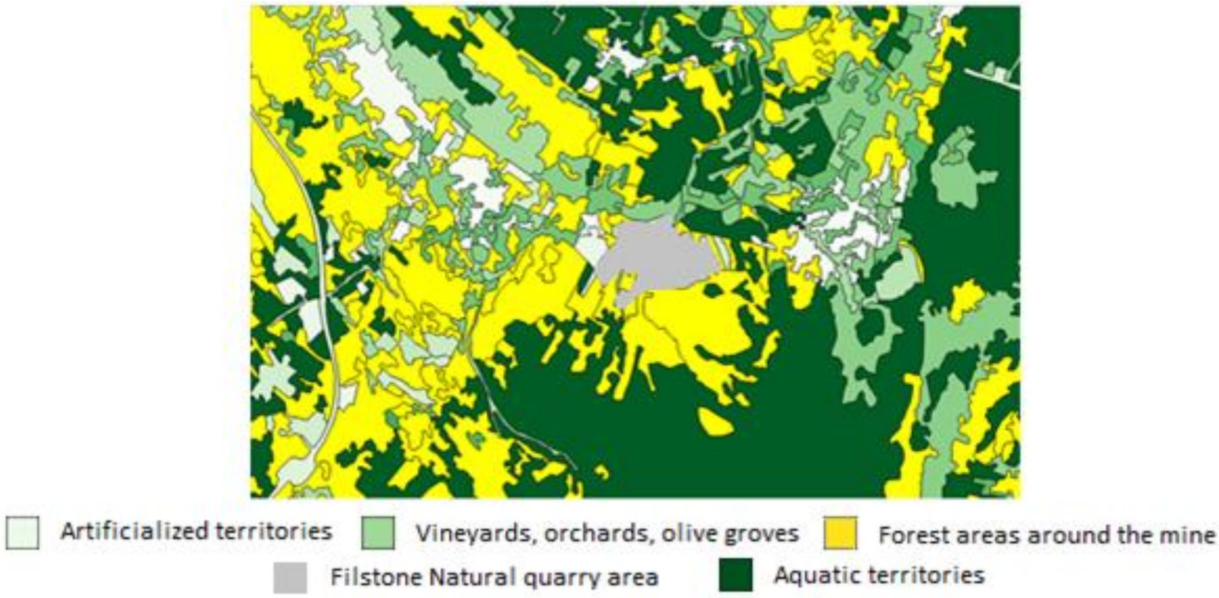

Figure 3.1.5 Forest areas nearby quarry in 2018

To obtain as much data as possible, the research area was also analyzed in terms of hydrogeological conditions. The Hydrogeological Map of Europe shows that the mine area is located in the region of moderate and highly productive fractured aquifers. Image 3.1.6 illustrates the hydrogeological conditions near the town of Casal Farto, which is marked in yellow.

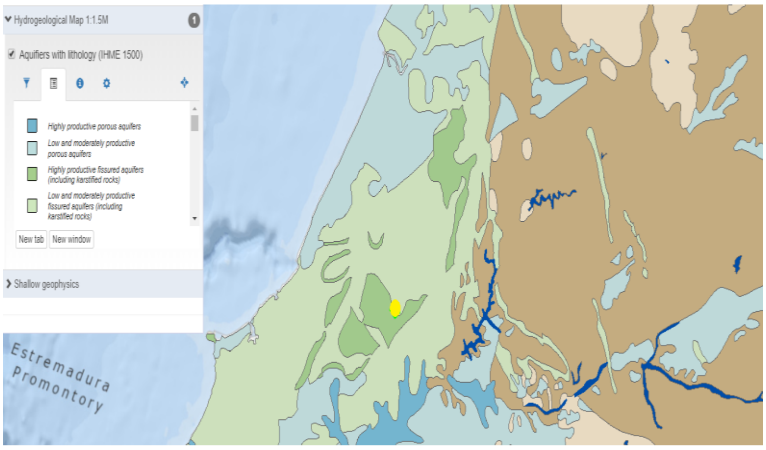

Figure 3.1.6 Hydrological conditions nearby quarry area, adapted from Hydrogeological Map of Europe

3.2. Specification of the software

In this work, ReCap Pro software was used to create a global point cloud. ReCap Pro is a program provided by Autodesk with a one-year educational license available for students, educators, and institutions. It is used for creating 3D models from imported laser scans and photographs. Program settings allow to open received point clouds and then process them in a specific direction. The program allows removing unnecessary points, measuring distances between specific points, marking, and combining scans.

There are three ways to import point clouds into the software. The first, used during that research, directly imports scans that come from a laser scanner. This type of file has an FLS format. The next option is to load the point cloud from a mobile device. The last one creates an image using photos. The software allows users to open and combine previously prepared files and also to import additional scans to a previously created project. That results in an automatic or manual connection of models. The program offers many functions. One of them is the ability to remove unnecessary points by using the "Delete" function. Figure 3.2.1 – Figure 3.2.4. show ReCap Pro software functions.

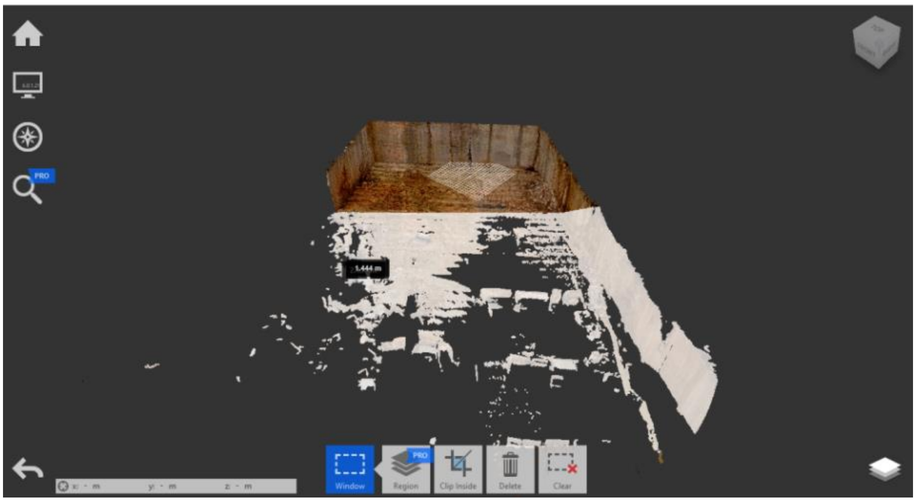

Figure 3.2.1 ReCap Pro software operation- “Delete” function

Concerning the marked surface, the program additionally gives the possibility to create a new point cloud by separating it from the original. The "Clip Outside" function leaves the selected surface, while "Clip Inside" removes it.

Software features such as "Elevation", "Intensity", "Normal", "Scan Location" and "RGB" allows to view the model in terms of height, intensity of points, plane differentiation, laser scanner location and default view respectively. In many cases, these functions can facilitate work in the program.

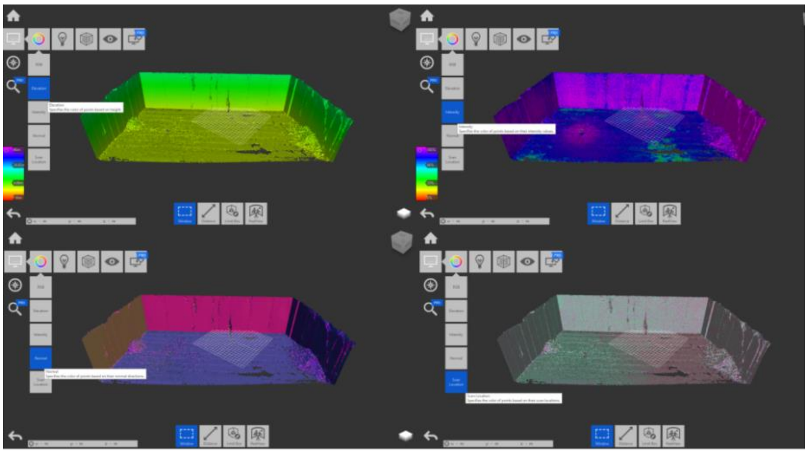

Figure 3.2.2 ReCap Pro software operation – “Elevation”, “Intensity”, “Normal”, “Scan Location” functions

The "Point Display" function offered by the program allows changing the shape and size of the points of the model. This option especially facilitates work when there is a large accumulation of scan points.

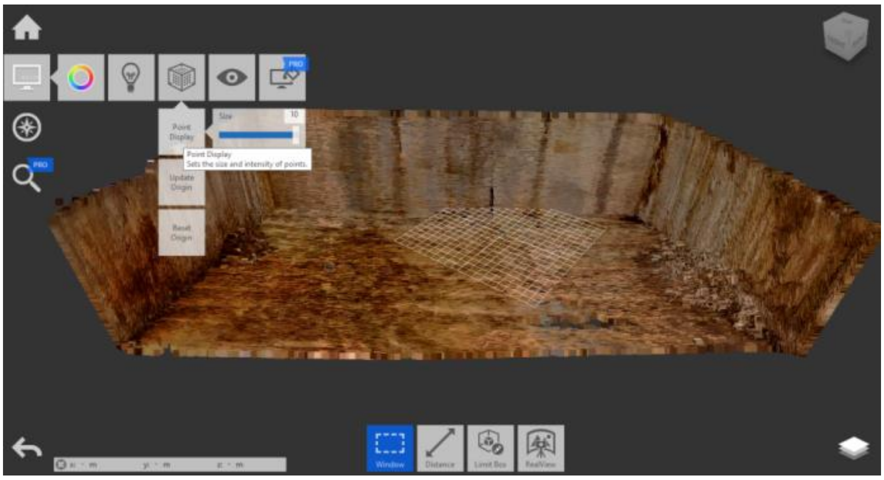

Figure 3.2.3 ReCap Pro software operation- “Point Display” function

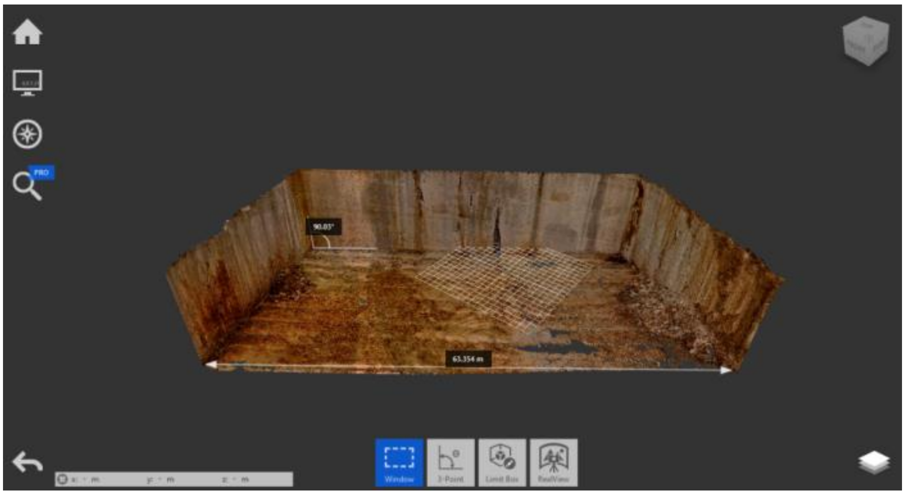

Figure 3.2.4 ReCap Pro software operation- “Distance” function

The functions located at the bottom of the main panel allows to control the visible area, write text, or switch to the function of spherical images. A very useful feature is also the "Distance" option, which allows specifying the distance or angles between specific scan points. The software allows saving files in two formats - RCS or RCP. The first one contains the actual point cloud data, while the second one has additional information, such as scanning areas, recorded distances, and annotations.

3.3. Description of the measurement method and obtained scans

Measurements took place during the visit to the limestone opencast Filstone Natural mine on March 3rd, 2020. They consisted of obtaining scans of the selected study area using the FARO laser scanner described before. The research was carried out at a section of the mine on which no further extractive activity will be made. After analyzing the mine structure and the exploitation works in the mine area, it was decided to carry out measurements in the west wing of the quarry, in a section where exploration was finished. Scans were selected in order to illustrate the appearance of the excavation area. The position of the laser scanner and the range of individual scans were taken into account. Measurements were made from three different locations. Therefore, three scans were selected in such a way as to most accurately reflect the appearance of the study area and the waste material present there. The quality of scans does not play a significant role in the topic of that work, so other scan configurations were not considered. The corresponding point clouds and the parameters assigned to them in the initial phase of the measurements are presented in this section, detailing each of the steps.

Figure 3.3.1 presents the excavation area where the measurements were carried out and the Figure 3.3.2 shows the operator configuring the laser scanner before the survey.

Figure 3.3.1 Area of measurements

Figure 3.3.2 Setting up the laser scanner

First scan

Figure 3.3.3 presents the first scan point cloud. Figure 3.3.4 presents the photography obtained as a result of the measurement with the parameters indicated in Table 2.

Table 2 First scan parameters

Selected Profile	Outdoor >20m
Resolution	1/4
Quality	4x
Point Distance	6,1 mm/10 m
Scan Range	360°
Scan Duration	779 s

Figure 3.3.3 1st scan point cloud

Figure 3.3.4 Photography obtained during the 1st Scan

Second scan

Table 3 presents the parameters applied for the second scan.

Table 3 Second scan parameters

Selected Profile	Outdoor >20m
Resolution	1/4
Quality	4x
Point Distance	6,9mm/10m
Scan Range	360°
Scan Duration	668 s

Below (Figure 3.3.5.and Figure 3.3.6.), the scan and the photography obtained as a result of the measurement with the parameters indicated in Table 3 are presented.

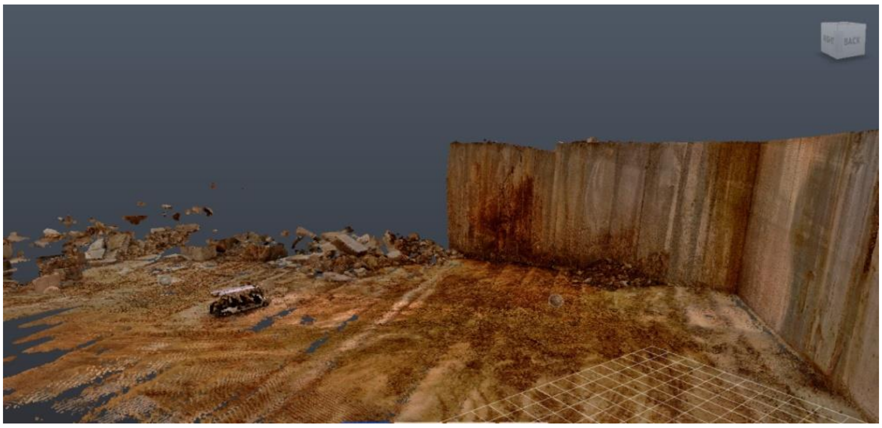

Figure 3.3.5 2nd scan point cloud

Figure 3.3.6 Photography obtained during the 2nd scan

Third scan

Table 4 presents the parameters of the third scan.

Table 4 Third scan parameters

Selected Profile	Outdoor >20m
Resolution	1/5
Quality	3x
Point Distance	7,7mm/10m
Scan Range	360°
Scan Duration	422 s

Figure 3.3.7 presents the scan and Figure 3.3.8 shows the photography obtained as a result of the measurement with the parameters indicated in Table 4.

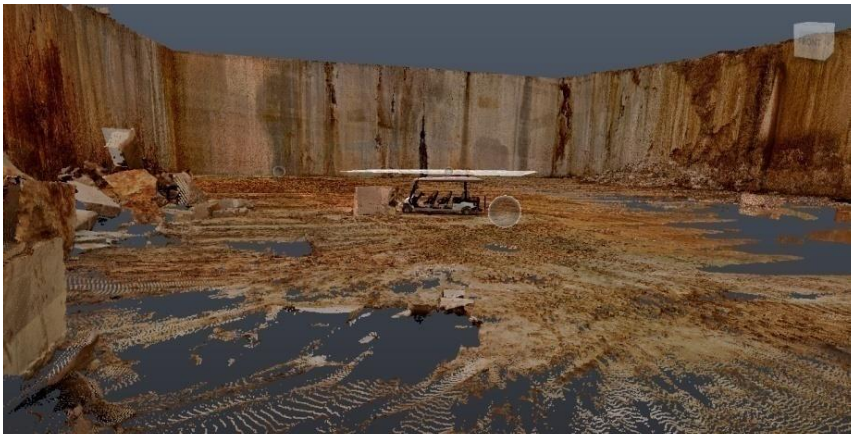

Figure 3.3.7 Third scan

Figure 3.3.8 Photography obtained during 3rd scan

3.4. Global point cloud processing

As mentioned in the previous section, Autodesk ReCap Pro software was used to open the obtained scans and, as a result of their connection, create the global point cloud. The obtained global point cloud, shown in Figure 3.4.1 and Figure 3.4.2, covers the area of the mining wall and the surrounding areas where the limestone waste material is located.

Figure 3.4.1 Obtained Point Cloud resulting from the connection of obtained individual scans – front view

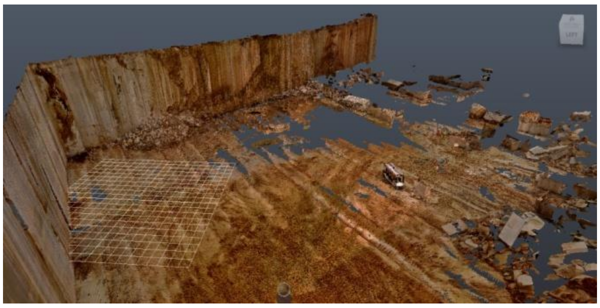

Figure 3.4.2 Obtained point cloud resulting from the connection of obtained individual scans – view from west

In the next stage, the ReCap Pro program was used to determine the volume of waste material presented in the study area. For this purpose, the "Distance" function, offered by the software, was used to measure the distance between individual scan points. The volume of waste material was determined based on the obtained point cloud. Figure 3.4.3 and Figure 3.4.4 illustrate how the rock dimensions were determined based on measuring the distance between points.

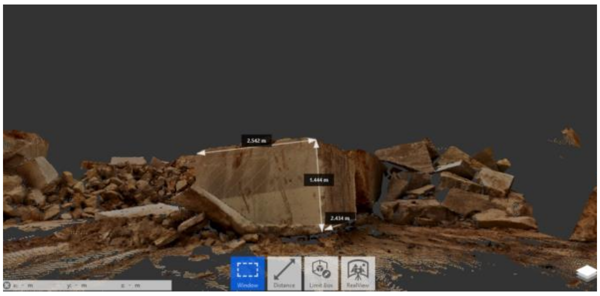

Figure 3.4.3 Measurements of limestone waste material using “Distance” function

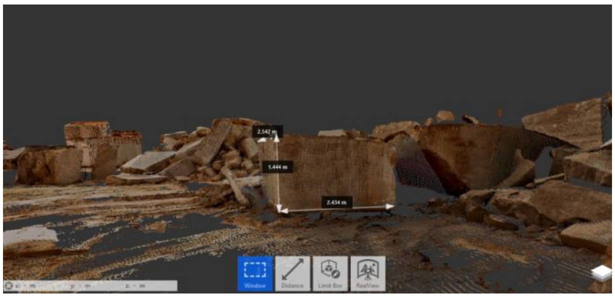

Figure 3.4.4 Measurements of limestone waste material using “Distance” function

The determination of rock dimensions was carried out for the entire study area, obtaining the data presented in Table 5.

Table 5 Volumes of the limestone waste material in the study area

waste material	dimension A [m]	dimension B [m]	dimension C [m]	volume V [m^3]
1	2.67	1.92	2.18	11.18
2	2.55	2.60	1.44	9.54
3	2.96	1.74	1.27	6.53
4	2.66	1.85	1.25	6.13
5	1.67	2.76	1.21	5.57
6	4.30	2.71	0.44	5.13
7	1.75	1.01	0.17	0.30
8	0.60	0.90	0.28	0.15
9	1.05	0.44	0.14	0.06
10	2.28	1.19	0.29	0.78
11	1.21	0.73	0.87	0.77
12	4.67	2.21	2.11	21.76
13	2.19	2.21	0.83	4.00
14	3.03	1.51	0.72	3.29
15	2.76	1.63	1.46	6.58
16	1.68	1.95	1.57	5.17
17	2.43	4.21	1.67	17.10
18	26.35	2.67	1.85	130.17
19	8.76	5.45	1.70	81.16
20	13.31	17.16	3.57	816.22
21	3.96	4.03	2.01	32.12
22	43.56	15.69	2.59	1770.67
23	27.97	2.88	1.28	102.79
24	27.97	2.50	0.88	61.35
25	14.78	3.35	2.49	122.98
26	18.88	5.10	2.70	259.47
27	11.68	6.30	1.78	131.20
28	19.04	10.04	1.10	210.45
29	18.77	2.63	0.64	31.38
30	1.44	0.89	0.26	0.33
31	12.37	5.22	3.09	199.81
			Σ_V	**4054.13**

Obtained data shows that the total volume of waste material located in the study area equals about 4054 m^3.

In the next stage, the point cloud was imported into AutoCAD software in order to determine the volume of limestone waste material necessary in the slope shaping process for given reclamation concepts, as well as to visualize the appearance of the excavation for individual reclamation proposals. Figure 3.4.5 – Figure 3.4.7 present the process of creating a visualization of the excavation slope.

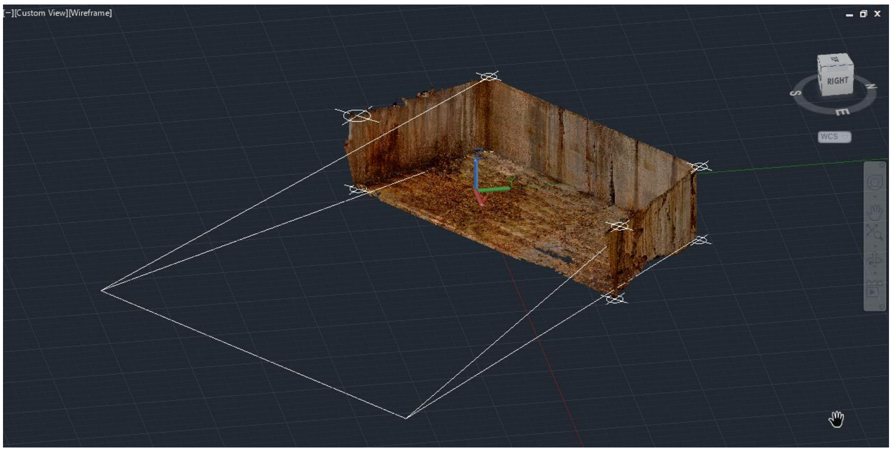

Figure 3.4.5 AutoCAD Point Cloud processing

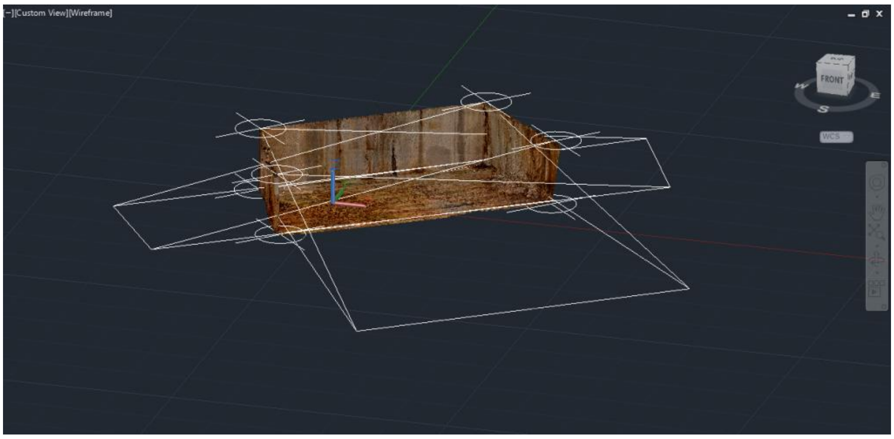

Figure 3.4.6 AutoCAD Point Cloud processing

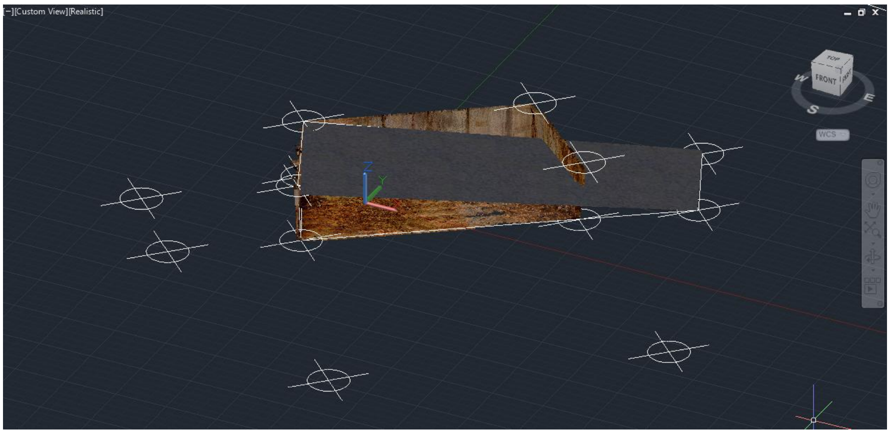

Figure 3.4.7 AutoCAD Point Cloud processing

3.5. Results

Below there are presented two suggestions for the reclamation of the research area, based on the scenarios mentioned in subchapter 2.3. The first of them assumes the creation of an alternative ecosystem (when compared to the original one), which is associated with the vegetation of the area. The second model aims to develop a new application for the research area.

Both proposals are based on land cover classification and analysis of hydrological conditions carried out in subchapter 3.1. The analysis shows that forests are the main terrain class in the research area. The most common tree species within the Filstone Natural mine are cork oak (Quercus suber L.) and eucalyptus (Eucalyptus L'Hér.). Tree species mostly used for planting in calcareous areas in Poland are, according to sub-chapter 3.1., black locust (Robinia pseudacacia) and birch (Betula verrucosa). The hydrogeological analysis contributed to the proposition of a water reclamation direction in the research area. It provided information that the mine area is located in the region of moderate and highly productive fractured aquifers.

The proposed concepts are also based on European law, cited in section 2.2., which presents the acceptable values of the slope angle for a specific reclamation direction. The angle of inclination of slopes of opencasts at the end of exploitation is usually large. Strong morphodynamic processes develop, including steep landslides and increased erosion, along steep slopes. According to the law, the permissible slope gradient for the forest direction is in the range of 28° to 35°.

Also, in the case of the water direction of reclamation, the most important element is the proper shaping of the slope inclination. The purpose of this treatment is to protect against erosion and slope slipping after filling the tank with water. In the case of reservoirs with a natural function, the slope should be formed in a ratio of 1:5 to 1:8.

Amongst the reclamation techniques presented in subsection 2.4., it was decided to use in both concepts the method of backfilling, in which the quarry void is filled with waste material, resulting from the excavation process, to give the desired slope.

Presented remediation solutions relate to the research area located in Portugal. However, a hypothetical proposal for land reclamation in Poland is also presented, based on the climate differences between both countries.

Proposal 1 - forest reclamation direction

The concept of forest reclamation involves shaping a slope with an acceptable inclination and then afforesting the post-mining area. Figures 3.5.1 to 3.5.3 show the visualization of the slope shaping process for the forest direction. Visualizations were made in AutoCAD software.

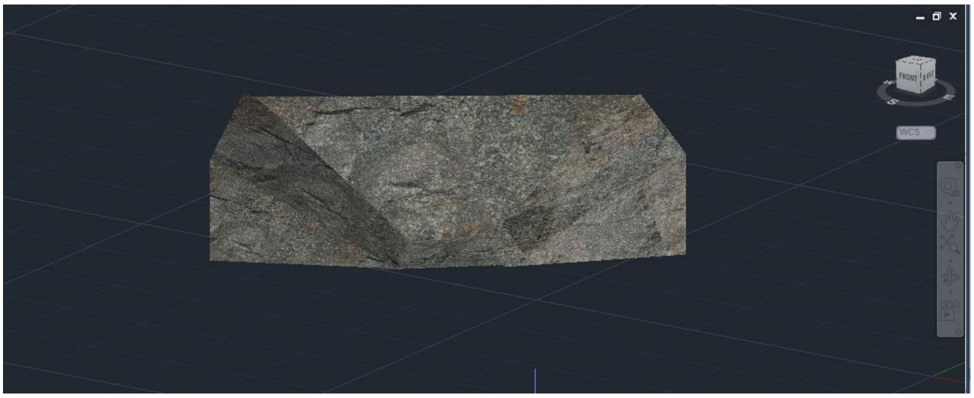

Figure 3.5.1 Visualization of a slope shape for forest reclamation direction

Figure 3.5.2 Visualization of a slope shape for forest reclamation direction

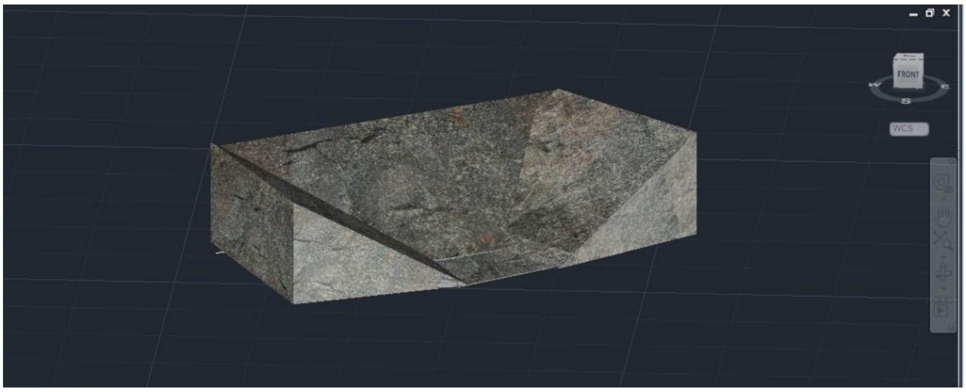

Figure 3.5.3 Visualization of a slope shape for forest reclamation direction

Table 6 presents the parameters of the forest reclamation direction, based on the information quoted in previous chapters. The table also contains information about the volume of waste material necessary to shape the slope.

Table 6 Parameters of the forest reclamation direction

	Portugal	Poland
Slope inclination	30°	
Selected tree species	Eucalypt (Eucalyptus L'Hér.)	Black locust (Robinia pseudacacia)
Calculated required volume of waste material	16980 m^3	

As Table 6 shows, the slope of 30° is given in a proposal for the reclamation in forest direction. Eucalypt trees are selected for planting, as this species is one of the most common species found in the research area. This ensures consistency with the ecosystem in this area. There is also presented a hypothetical proposal for the use of black locust trees for the reclamation of the same opencast mine in Poland. These differences result from the different climate conditions in both countries.

According to data in the table, the necessary volume of waste material to shape a 30° slope is 16980 m^3. Comparing this value with the volume of waste material in the study area, presented in subsection 3.4., it can be concluded that this volume is insufficient to shape the excavation in the forest direction. In this situation, it is necessary to use additional waste material from another part of the opencast mine.

Proposal 2 - water reclamation direction

The concept of a reclamation in a water direction concerns shaping a slope with an acceptable inclination and then creating a water reservoir in post-mining areas. Figures 3.5.4 to 3.5.6 show the visualization of the excavation after a reclamation process in the water direction.

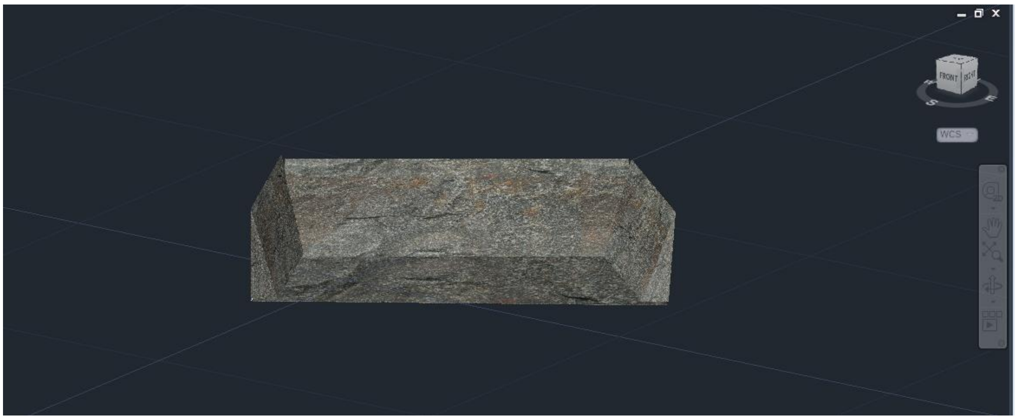

Figure 3.5.4 Visualization of a slope shape for water reclamation direction

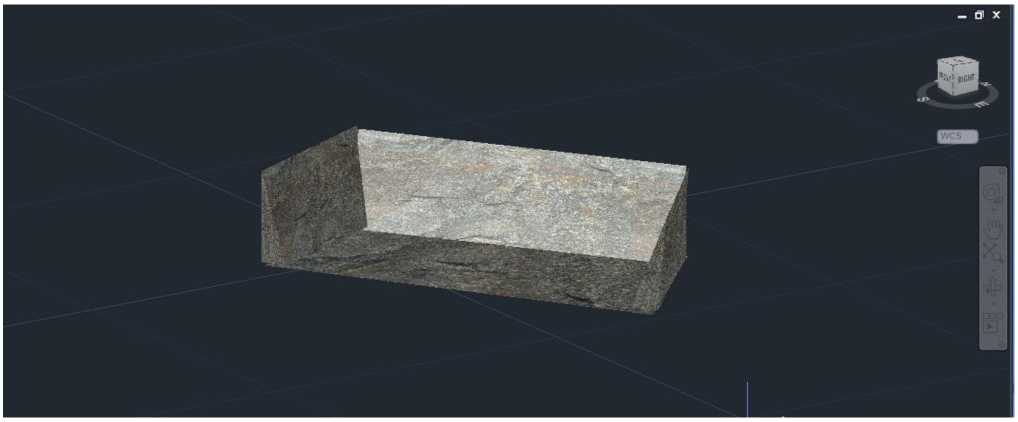

Figure 3.5.5 Visualization of a slope shape for water reclamation direction

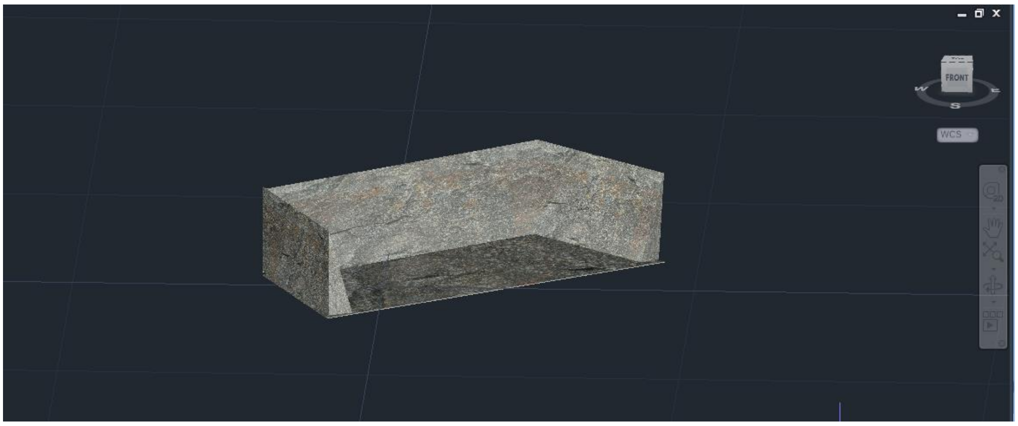

Figure 3.5.6 Visualization of a slope shape for water reclamation direction

In the following, Table 7 shows the parameters that were given for water reclamation. The table also contains information about the volume of waste material necessary to shape the slope in the water direction.

Table 7 Parameters of the water reclamation direction

Parameter	Value
Ratio of the slope sections to adjacent areas	1:8 (≈71°)
Calculated required volume of waste material	3724 m^3

This proposal assumes the formation of a slope with inclination about 71°. This way of forming the slope would occur both in Portugal and in Poland, which results from the regulation of European law.

As it results from the data contained in the table, the necessary volume of waste material to shape the slope in a ratio 1:8 is 3714 m^3. Based on the comparison of the obtained value with the calculated volume of waste material present in the research area, it can be concluded that this amount is sufficient to shape the slope in the required angle.

Summary

In this part of the work, proposals for the land reclamation stage of a section of a limestone quarry in an opencast mine were presented. Based on the *in situ* measurements carried out with the use of a laser scanner, particular scans were be obtained. Scan data processing software was used to connect received scans and, as a result of this operation, to obtain a global point cloud. In the next phase, the amount of limestone waste material, presented in the study area, was determined. Based on the analysis of the study area conditions carried out in a desktop GIS program and based on obtained data and climatic differences of both countries, possible to propose reclamation solutions were presented and discussed. Rehabilitation concepts were visualized with the support of CAD software.

4. Conclusions

The process of post-mining land reclamation is nowadays a very common discussion subject. The reasons for that are changes, both environmental and visual, caused by the mining industry, and thus - the need for regeneration of degraded areas.

Reclamation of post-mining areas is a stage of mining activity that compensates for adverse changes caused by this activity. Reclamation measures aim to give for degraded areas the utility or nature value, which is achieved by improving physical and chemical properties, regulating water relations, or restoring the soil. A very important element of land reclamation is also proper shaping of terrain and this rehabilitation aspect has received the most attention in this work.

Presented concepts of reclamation of the Filstone Natural mine are based on giving the proper slope of the excavation. The legal framework for mine reclamation in Poland and Portugal is presented, based on European law, which specifies the permissible values of the slope for a given reclamation direction.

Laser scanning was used as a tool in the process of determining the reclamation direction for the studied area. Measurements were carried out using a laser scanner, resulting in 3D scans. As a result of combining these scans in the processing program, a global point cloud was created presenting the excavation area. Using the program function, the amount of waste material, presented in the study area, was determined. In the next phase, the point cloud was imported into CAD software to visualize the slopes for a given reclamation concept and to determine if the amount of waste material is sufficient in order to create the slope with inclination acceptable for a specific reclamation proposal.

Based on the reclamation techniques described in the theoretical part, it was decided to use the backfilling method, which used the waste material to fill the quarry void to establish a desire landform. Economic factors influenced the choice of this method. The waste material used to shape the permissible slope comes from quarry exploitation, so this process is not burdened with additional import costs from an external source. In addition, after the reclamation carried out using this method, the vegetation can be established anywhere, and in the case of the proposed concepts of land reclamation, this is particularly important.

The two recultivation concepts were determined based on the classification of the dominant land cover and the hydrogeological conditions carried out in the GIS program. The existence of two possible scenarios for the implementation of post-mining land reclamation was also taken into account. The first concept is based on the terrain revegetation scenario, taking into consideration also the data obtained from the classification of the dominant surface coverage. This proposal assumes shaping a slope with 30° of angle and planting eucalypt trees in the research area. In case of a hypothetical concept of recultivating the same area in Polish conditions, Robinia pseudacacia trees would be used for planting. These differences are due to the climatic differences between the countries. The second proposal is based on the scenario of creating a new application for the studied area. The data obtained as a result of the hydrogeological analysis were taken into account and based on them, the water reclamation direction was developed. This proposal assumes the formation of a slope with the inclination of about 71°.

In the last phase, the CAD software enabled the determination of the necessary volume of limestone waste material to shape the slope for the concepts discussed above. The obtained data supported the conclusion about the insufficient amount of waste material for the forest reclamation direction and the sufficient volume of material in the case of water reclamation.

Obtaining the results presented above and proving the working thesis was possible after prior exploration of the state of knowledge related to the subject of the thesis. A very important issue was also to get known about the laser scanner operation method. Thanks to theoretical and practical knowledge of its operation, it was possible to make measurements that enabled further progress of the work. It was also necessary to get known about the operation of programs, such as ReCap Pro, QGIS, and AutoCAD, which enabled the processing of the obtained data and their analysis at the final stage of work.

The research was conducted using laser scanning as a measurement method. The obtained results allowed to state that laser scanning is a helpful tool in the process of determining the direction of land reclamation.

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