Identification of reclamation methods

for a limestone quarry using terrestrial laser scanning

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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.

Keywords: reclamation, rehabilitation, post-mining areas, terrestrial laser-scanning

Introduction

The exploitation of mineral resources is an ancient practice that dates back to the Stone Age. Although 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 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 yearly moves a

1 trillion dollar into the 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.

Methodology

The process to study the capacity of laser scanning as a supporting tool in the determination of land reclamation directions for quarries in after-use scenarios was based on the methodology presented in Figure 1.

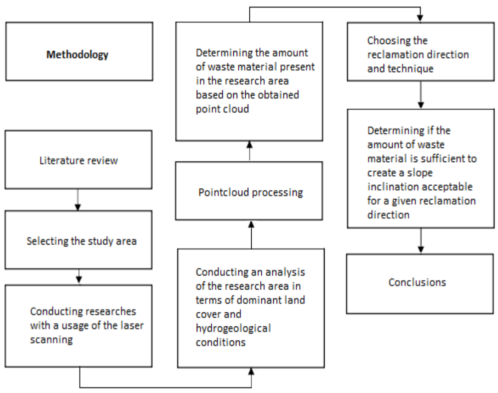

Figure 1 Thesis methodology

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 (Talento et al., 2020).

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).

Main reclamation directions and techniques

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).

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).

Proper choice of a reclamation technique is also a very important issue. Several recultivation techniques can be used to reduce the visual impact of quarries and provide biodiversity potential. These methods 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. 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: rollover slopes, backfilling, bench planting, restoration blasting, and natural succession. Each method is appropriate for different environmental, economic, and visual conditions.

Laser scanning as a measurement method

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).

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). Figure 2 shows the working principle of laser scanning measurements.

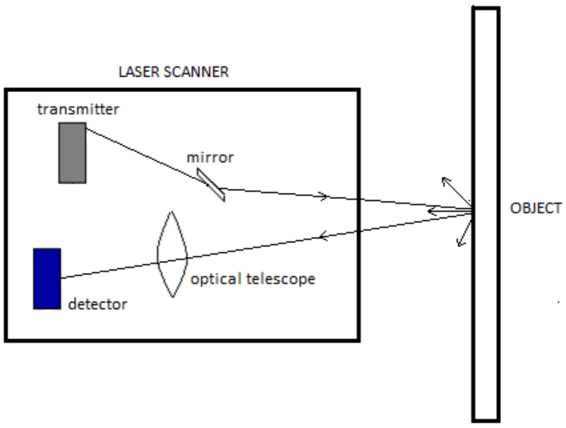

Figure 2 Laser scanning operation method

During the research, Faro Focus S70 was used as a measurement tool. 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. . 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. The device is presented in Figure 3.

Figure 3 FARO laser scanner in operation, author photo

Analysis of the study area

Measurements, using the FARO laser scanner, were carried out at the Filstone Natural limestone quarry in Casal Farto. The mine, located 6 km southeast from Fátima, annually extracts 30,000 m^3 of limestone with several beige to whitish hues and finishings. Figure 4 presents location of the quarry in Portugal.

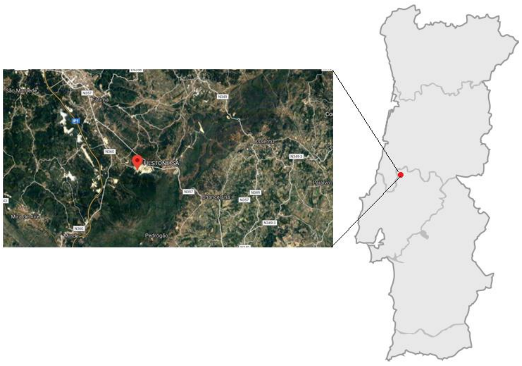

Figure 4 Location of the Filstone Natural quarry in Portugal. Image in detail extracted from Google Maps

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 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). A desktop geographical information system (GIS) software (QGIS) enabled to conclude that forest areas dominate the site surrounding area. Figure 5 shows forest areas around the mine in 2018. They are marked in yellow. It also allowed to establish that 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.).

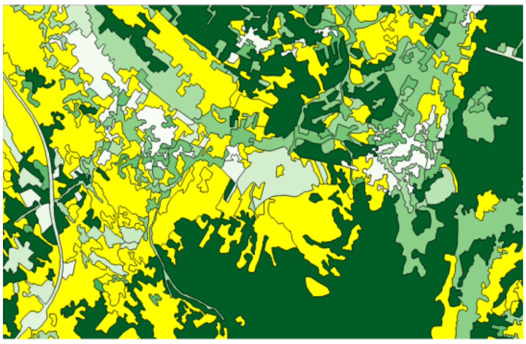

Figure 5 Forest areas nearby quarry in 2018

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 6 illustrates the hydrogeological conditions near the town of Casal Farto, which is marked in yellow.

Figure 6 Hydrological conditions nearby quarry area, adapted from Hydrogeological Map of Europe

Collecting data and processing

Measurements consisted of obtaining scans of the selected study area using the FARO laser scanner. 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. Table 1 presents the parameters of obtained scans.

In the next phase the Autodesk ReCap Pro software was used in order to open obtained scans and, as a result of their connection, create the global point cloud, presented in Figure 7. The same program was also used to determine the volume of waste material presented in the study area. Obtained data indicated the presence of waste material in a quantity about 4054 m^3.

Figure 7 Obtained Point Cloud resulting from the connection of obtained individual scans – front view

The last stage of collecting data was to import the point cloud into CAD software (AutoCAD) 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.

Table 1 Scans' parameters

First scan	
Selected Profile	Outdoor >20m
Resolution	1/4
Quality	4x
Point Distance	6,1 mm/10 m
Scan Range	360°
Scan Duration	779 s
Second scan	
Selected Profile	Outdoor >20m
Resolution	1/4
Quality	4x
Point Distance	6,9mm/10m
Scan Range	360°
Scan Duration	668 s
Third scan	
Selected Profile	Outdoor >20m
Resolution	1/5
Quality	3x
Point Distance	7,7mm/10m
Scan Range	360°
Scan Duration	422 s

Results

Two suggestions for the reclamation of the research area are presented. 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. Reclamation concepts are also based on European law, which presents the acceptable values of the slope angle for a specific reclamation direction.

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. The slope of 30° is given in that proposal. 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 presented in the Table 2, the necessary volume of waste material to shape a 30° slope is 16980 m^3. Comparing this value with the volume of waste material present in the study area, 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.

Figure 8 presents the visualization of the slope shaping process for the forest direction.

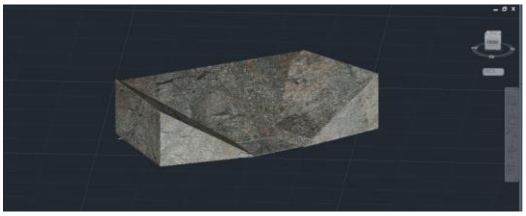

Figure 8 Visualization of a slope shape for forest reclamation direction

Proposal 2 - water reclamation direction

The concept of reclamation in a water direction concerns shaping a slope with an acceptable angle and then creating a water reservoir with, in case of that proposal, recreational functions. The water reclamation concept assumes the formation of a slope with inclination about 71°.

As it results from the data contained in Table 2, 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.

Figure 9 shows the visualization of the slope shaping process for the water direction.

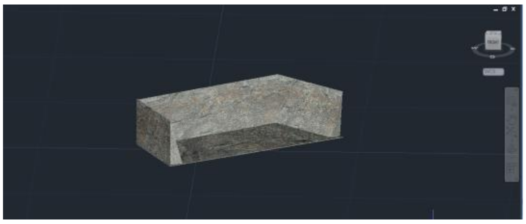

Figure 9 Visualization of a slope shape for water reclamation direction

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.

Table 2 Parameters of reclamation proposals

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

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 to create the slope with inclination acceptable for a specific reclamation proposal.

Based on the reclamation techniques, 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 considered. 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.

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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