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The Surveying Inventory of Kraków-Częstochowa Upland's Rocks Illustrated with the Example of the Hercules' Club (Maczuga Herkulesa) in Pieskowa Skała**

1. Introduction

Acquisition of spatial data related to the surface relief of rocks by means of the laser scanning method may be motivated by various reasons. For example, differential research is being conducted on models built on the basis of a cloud of points measured during different surveying periods in order to detect falling rock fragments. The results of scanning surveys of coastal cliffs which, in comparison with other examples of rock surface, change their form relatively fast are favourable [2]. Also, the periodic monitoring of landslides and rockfalls is being performed in order to define the pace of cleft and the dynamics of rockfalls. On an industrial scale, the method of periodic survey by means of terrestrial laser scanning (TLS) is used in strip mines and stone pits. In such cases, it is used to calculate the volume of the mined rock mass by comparing point clouds or models in different surveying periods. Scanning can be used to study rocks of complicated shapes, hazardous stability, such as monadnocks, inselbergs and mushroom rocks. Interesting examples of such surveys are presented in [9] where scanning and modelling of the Echo Cliffs 'Precariously Balanced Rock' in California conducted by the United States Geological Survey Institute was described, as well as in [5], where the results of the Delicate Arch inventory were presented. There are also some specific rocks, scanning and modelling of which present cognitional characteristics in the field of anthropology and culture. For instance, prehistoric rock megaliths and petroglyphs (carved rock drawings) are subject to scanning. The analysis of the surface of a model, which was carried out on the basis of point clouds of high precision and resolution, facilitates reading petroglyphs that were not discovered with the naked eye, which is exemplified by the famous Stonehenge in Great Britain. Its scanning was conducted by two

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companies, namely Wessex Archeology and Archeoptics, and the scanning results are presented in [10]. Around the world attempts are being made to take inventories of monuments of an inanimate nature by means of TLS, including such monuments as rocks of various forms that are valuable elements of cultural landscape. Such studies correspond with the inventory of historic human works but they also cover the objects of natural genesis which are subject to human interest and often protected by law. For these reasons, the measurement of the Hercules' Club, one of the most important monuments of inanimate nature in Poland, was carried out by means of a laser scanner. The aim of the study was also to verify the usefulness of TLS in the inventory of such objects.

2. The Subject of the Study

150 million years ago in the area of southern Poland, rocks forming the Kraków-Częstochowa Upland, namely the Upper-Jurassic limestone rocks were formed as a result of sedimentation of organic remains. The light grey, or even white colour of the rocks is a distinctive mark of the forms lying in the Prądnik Valley. The limestone rocks, which can be found here are of two varieties: rocky and shoal. The rocky type is weather-resistant and more solid, it builds rock formations and the so-called monadnocks, appearing on the surface. The shape of the rocks resembles vertical columns, clubs, human silhouettes, gates [3]. The Hercules' Club (Fig. 1) lying in the 'Polish Switzerland', as the Prądnik Valley (about 20 km to the north-west of Krakow, in the Kraków-Częstochowa Upland, within the area of the smallest in Poland, Ojcowski National Park) was once called, can be defined as one of the most recognisable rocks.

Fig. 1. The Hercules' Club
(phot. Kamil Kmak, 2012)

The 30-metres-high monadnock built of solid limestone rocks was formed as a result of many years of destructive action of wind, sun, frost and surface waters. It stands on around 10-metre-hight rock bench called the Grand Piano (Fortepian). The monadnock is narrow at the bottom and slightly broadening upwards, resembling the shape of a prehistoric club, from which it gets its name.

3. The Technology of the Measurement

The three-dimensional description of natural-origin objects (such as caves, slopes) is a rich source of information describing the character of the surface of the objects and the changes in the surface occurring in the course of time [6]. It also facilitates the understanding of the dynamics and sources of the observed changes. Obtaining adequate data collections has recently become an easier and faster task in relation to the development of laser scanning technology [12], which enables the measurement of a large number (cloud) of points within a short space of time. The usage of this technology in order to control the natural environment is described in detail in [4].

The Leica ScanStation C10 pulse scanner was used for the inventory of the Hercules' Club. Its basic parameters are as follows: the speed of survey up to 50,000 points per second, the accuracy of a single measurement of point position – ±6 mm for 50 m distance, range 300 m (with 90% albedo) [8].

The scanning measurement, results of which were used to create a 3D model of the Hercules' Club, was designed with the assumption to obtain the most accurate location of the point cloud, so that in the case of another scanning of the rock, there would be the opportunity to compare the results of two surveying series. In order to achieve that, it was also necessary to georeference the collected scanning data.

Therefore, the field works began with the creation of a surveying control network consisting of 7 points surrounding the object (Fig. 2).

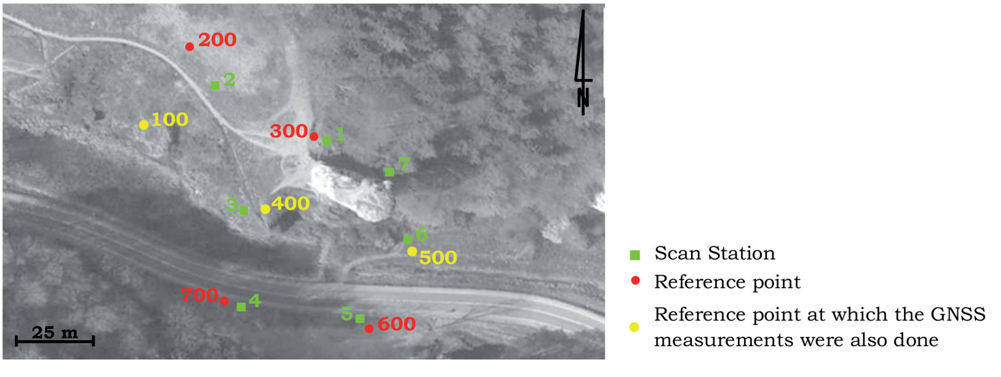

Fig. 2. The sketch of the location of the surveying control network points and of the scanner stations against the background of an aerial photo

Source: independent study on the basis of geoportal.gov.pl

The mutual localisation of the points was defined by the tacheometric method by means of the Leica TCA2003 instrument. Additionally, 6 points were marked at the foot of the monadnock, which will serve as orientation points in the next surveying periods in the future. In order to connect the undertaken surveys to the National Spatial Reference System, static GNSS surveys were conducted. The 4-hour static GNSS sessions were carried out on three points of the control network (Fig. 2) which were situated in places characterised by the least horizon coverage. The following devices were used in the survey: two Leica GPS1200+ receivers equipped with the ATX1230 GG type antenna and one Leica GPS500 receiver with the Choke-Ring AT503 type antenna.

The scanning of the Hercules' Club was conducted from 7 scanner stations marked with green colour in Figure 2. They were chosen on the basis of the visibility of both the observed object and maximum number of points of the control network. The maximum distance between scanner stations and the Hercules' Club was 60 m. The scanner stations were connected with the established control network by the resection method conducted by means of special HDS (High-Definition Surveying) targets, which were set on the points of the network. From each station at least three targets were scanned. The length of the sight line did not exceed 60 m. The scanning survey was conducted with the 7-mm resolution. Additionally, the C10 scanner took photographic documentation which was then used as a real hachure of the model. The study was carried out in December 2012. The measurement conditions were favorable (overcast, no rain, little wind).

4. The Integration of Surveying and Scanning Data and the Preliminary Analysis of the Results

The surveying control network set up in order to conduct the research was two-functional, therefore it was necessary to define the coordinates of the points in the National Geodetic Coordinate System PL-2000, as well as their elevations in the Kronsztadt normal height coordinate system (PL-Kron86-NH).

The study of the data collected by satellite surveys was conducted on the basis of coordinates of the ASG-EUPOS network's stations (LELO, KRA1 and KATO), which were used as reference points. As a result of the rigorous adjustment of tacheometric observations and GNSS vectors, adjusted coordinates of all of the points were defined. The mean errors of situational position did not exceed ±3 mm, whereas the elevation errors were not beyond ±5 mm.

The integration of the point clouds from the particular scanner stations was conducted by means of Leica Cyclone dedicated software. In order to obtain a point cloud visualising the whole object mutual orientation of the scans was conducted. As it has been already mentioned, the scanning surveys were connected to the coordinate system PL-2000 and normal height system PL-Kro86-NH in order to secure the repeatability of the geometry measurements of the object in the future. For this reason, spatial coordinates of reference points (common points, connecting scans from different stations, here: points in the control network) were determined by means of surveying methods. The mean error of fitting the point clouds, including the coordinates of reference points in the adjustment, was ±4.2 mm. Finally, combined clouds, composed of 80 million points, were obtained.

The collected spatial data included many redundant pieces of information about the objects surrounding the Hercules' Club, such as trees, rocks as well as the area and infrastructure around the monadnock. The redundant elements were removed from point clouds. The surface of the clouds was also cut to the foot of the Hercules' Club in the place where it touches the ground.

Then the point clouds, transformed into a uniform system of coordinates, were unified, that is, submitted to the final and irreversible combination of the scans into one cloud. During this process, the redundancy, resulting from multiple coverage of one fragment of the object with points measured from various scanner stations, was removed by imposing a permanent distance between neighbouring points of the cloud, which was set as 7 mm. The cloud created as a result included around 61 million points. It was then submitted to initial analyses, among others things, several sections of the object on assigned levels were performed. One of the CloudWorx software versions (Leica CloudWorx for MicroStation) was used to this purpose [7].

The point cloud representing the Hercules' Club was divided into sections, one every 0.5 m along each of the axes. The horizontal sections of the monadnock were made from the height of 430.5 m to 459.0 m. Next, the 1-cm thick "slices" of the cloud of points were vectorised (in internal outline). In non-scanned places where shuttering occurred, especially in the area of the cave at around 440.0–445.0 m level and near the peak at 458.0 m, the vectorisation of the full outline was impossible. The prospect of all of the overlapped 3D sections in the isometric projection was presented in Figure 3a.

The largest horizontal section among those obtained is situated on 447.5 m level and measures 72.97 m^2, whereas the smallest one, measuring 58.11 m^2 is located on 433.5 m level (Fig. 3b). For the cross sections of the object, the centres of the mass were drawn at the levels of every 1 m, starting from 431 m. This allowed for the creation of a chart showing the centres of mass on the consecutive levels of height in order to estimate the deflection of the manadnock, similarly to the cases, in which charts presenting the deflection of high objects are prepared. The centre of the mass of the section on the 431 m level at the foot of the rock was regarded as the starting point of the system of deflections. The sections at 441–444 m levels were omitted due to the lack of full vectorisation of the outline, therefore the inability to define their centres of mass. It was ascertained that the centre of mass is strongly shifting to the south-east direction with the increase of height. The deflection of mass centres at the levels located in the area of the peak is over 2 m in the eastern direction (Fig. 4). The obtained result may be a contributory factor to conduct a further analysis in order to assess the stability of the monadnock due to the effect of eccentric forces acting on the object.

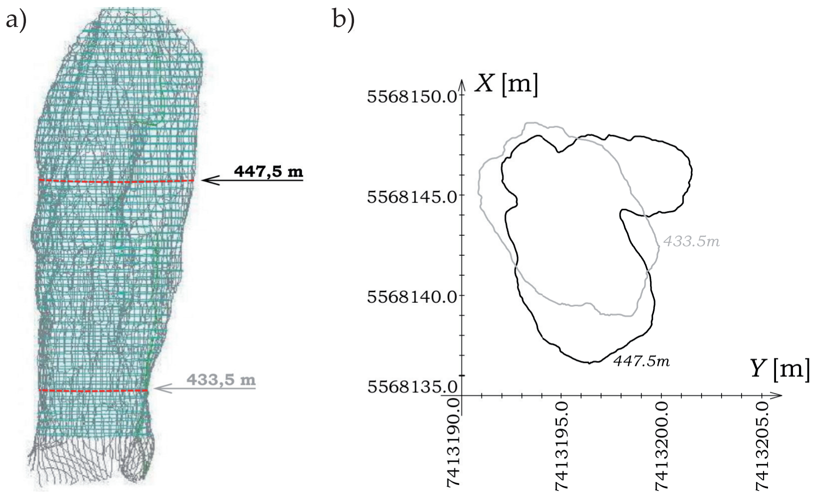

Fig. 3. The prospect of sectional curves of a 0.5 m network in isometric projection (a); the sections of the largest and the smallest plane (b)

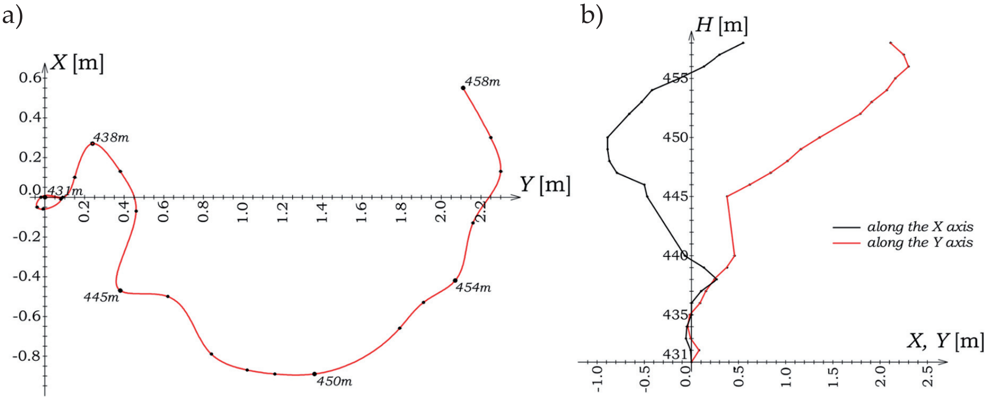

Fig. 4. The chart presenting the deflection of the Hercules' Club in relation to the 431 m level: a) in the XY plane; b) in the XH and YH plane

5. The 3D Model of the Rock

The purpose of this study and the final stage of the works was building a 3D model of the Hercules' Club on the basis of the point cloud. The chosen method was the triangle mesh. There are many different programmes, designed for building models of objects that use advanced algorithms, build a network by means of growing planes methods, as well as on the basis of the octree algorithm that divides the space into a hierarchical structure instead of referring to just one plane [1].

The CloudCompare programme was used in order to statistically filter the protruding points and therefore to cut out a substantial number of redundant cloud elements that represent the flora. The filtered data was imported to the VRMesh Studio programme which was created to edit the point clouds and to build models of triangular mesh. It uses advanced algorithms to filter clouds of points as well as to create and modify mesh models. In order to improve the work, the imported cloud was at first submitted to the screening algorithm using the average distance method, with the parameter of 1.5 cm. This allowed the reduction of the cloud of points by less than 5 million records and a significant advancement in rendering the prospect and conducting further analyses. Next, the noise reduction and smoothing filter was used. The Denoise Point Cloud command removed noises from point cloud with the preservation of important surface features like sharp edges and corners [13]. The point cloud prepared in such a way was submitted to the algorithm of building triangular mesh. The created model was built properly for those parts of the object, for which spatial data representing them was collected. In shuttered spots, invisible for the scanner, the mesh was not built, and the model is incomplete but geometrically accurate. For the surface scanned densely enough, the model correctly represents even such elements as bends, grooves, hollows and overhangs (Fig. 5b–d). The number of disturbances made by the flora is minimal, it was almost totally reduced by means of filtration, first in the CloudCompare programme and then in the VRMesh.

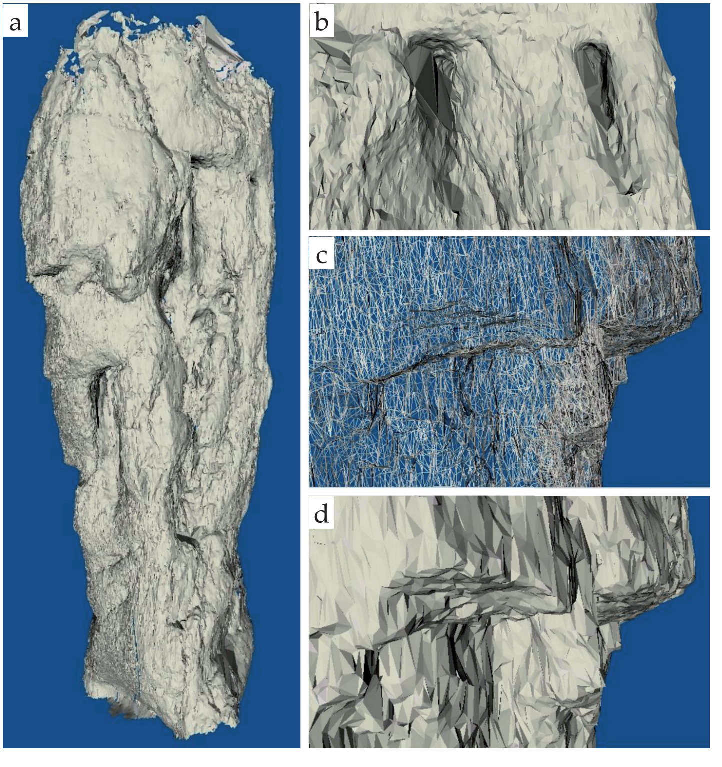

Fig. 5. The prospect of the final model of the Hercules' Club

In order to create a visually consistent model, the option, that facilitates filling the gaps in the model, was used. The gaps in the model resulting from insufficient data in the input data collection can be filled to a limited extent. It is possible to define the parameter describing the maximum size of the space, for which the filling will be generated. However, such a model will not accurately reflect the original object in those fragments. The final model of the Hercules' Club was presented in Figure 5. The whole surface of the rock was not presented in the model, especially the top area is missing (Fig. 5a). It is, however, the optimum transfer of the real object in terms limited by the capability of terrestrial laser scanning.

6. Discussion and Conclusions

The work presents the consecutive stages of creating a 3D model of the chosen object that is of the monadnock rock. The laser scanning was indicated as a way to transfer the object to a point cloud accurately and, indirectly, by using proper numeric algorithms, to a 3D model built of polygonal mesh. The conducted stages: survey, data analysis and modelling allowed for the estimation of the potential and the limits of the used methods. The undeniable advantages of this method are: high speed of data collection as well as completeness and accuracy of information about the geometry of the measured object. However, main limitation of TLS is a very expensive hardware and software. The result of the study – the metric point cloud having the georeference in the National Spatial Reference System and the triangular mesh model – can serve as the basis for further analysis of the object's behaviour in the future. The prepared geometric representation of the object can be treated as an initial survey in the first of many surveying periods. It is advised to take further periodic scanning surveys in order to conduct differential analyses that are made on other objects such as vertical walls, cliffs and rockfalls. According to the Nature Conservation Act [11], the Hercules' Club as a monument of inanimate nature is subject to protection and obligatory inventory of its state. It was proven that the chosen surveying methods are useful and efficient in conducting such an inventory which should be an indication and encouragement for the institutions responsible for environment protection to undertake identical activities concerning other monadnock rocks and nature monuments in the the same way as it is done in case of monuments that are human works.

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