DETERMINING THE SPHERICITY OF SAND GRAINS BY AI COMPUTER VISION RESEARCH

Katarzyna Misiołek*,[1], Agnieszka Dąbska[1], Artur Mazurek[2]

*katarzyna.misiolek@pw.edu.pl
[1]Faculty of Building Services, Hydro and Environmental Engineering, Warsaw University of Technology, Nowowiejska 20 St. 00-653 Warsaw Poland
[2]Software Engineer

Abstract
The paper presents an approachable, free, open source and effective way of using AI models in geotechnics.

The research consisted of two stages. First, granulometric tests were performed according to EN ISO 14688–1: 2018. Second, sand grains were identified and measured in gathered microscopic images (from a light microscope and an SEM). Segmentation, which allows the identification of image pixels belonging to an object, is a well-known but problematic area of image processing, and the use of AI techniques is one of the possible approaches to dealing with the issues involved with segmentation. The estimation of grain sphericity is used as an example to present how geotechnics specialists can customize AI and other software for their benefit with only basic knowledge of the Python programming language.

Keywords
Sand, sphericity, AI, SAM

1 INTRODUCTION

Artificial Intelligence (AI)

Artificial Intelligence (AI) is becoming increasingly popular in every aspect of our lives. AI can be utilized in various applications and industries. It is commonly used in virtual assistants such as Siri (Apple), Google Assistant, Amazon Alexa, and Microsoft's Cortana, providing users with voice-activated actions and information. Search engines like Google use AI algorithms to deliver relevant information based on users' queries and behaviors. Social media platforms, such as Facebook, Instagram, and Twitter, employ AI to recommend suitable advertisements and for image recognition to enhance user experience. It is widely used in e-commerce for personalized product recommendations, chatbots for customer support and supply chain optimization in online retail. AI is also employed in healthcare to aid in medical imaging for diagnosis, drug discovery and personalized medicine. Artificial intelligence is also commonly applied in education for personalized learning (such as language learning), adaptive assessments and intelligent tutoring systems. With every passing day, AI technologies are becoming more sophisticated and more industries are finding ways to use artificial intelligence to improve efficiency.

Segment Anything Model (SAM)

The Segment Anything Model (SAM) is an open-source AI model from Meta (Facebook, Instagram) that can "cut out" any object in any image, needing only input point locations. SAM is a system with zero-shot generalization to unfamiliar objects and images without additional training [1]. Hence, it can be performed without additional training for unknown subjects, like recognizing sand grains in authors' microscopic pictures of soil structure. Finding an object in an image has been one of the leading research areas since the early days of image processing and computer vision [2]. The typical paradigm of using AI for such a task is to create a training dataset of multiple example images of objects. The next step is to annotate them, which means manually marking objects in the pictures using a tool like CVAT [3] and then using those to train an AI model, e.g. Tensorflow [4]. Such an AI model can then segment objects in images similar to those used in training. Moreover, it should be able to do it automatically. The issue with such an approach is that it requires the dataset, the time to annotate it, and the technical knowledge to conduct the training. A generalized segmentation model like SAM can help by annotating the training dataset for custom AI creation.

DOI 10.13164/juniorstav.2024.24138

The Segment Anything Model (SAM) was trained on the Segment Anything 1-Billion mask dataset (SA-1B), the largest ever segmentation dataset, allowing a broad range of applications and fostering further research into foundation models for computer science. The dataset is free for research purposes and a part of it can be explored online by anyone Fig. 1.

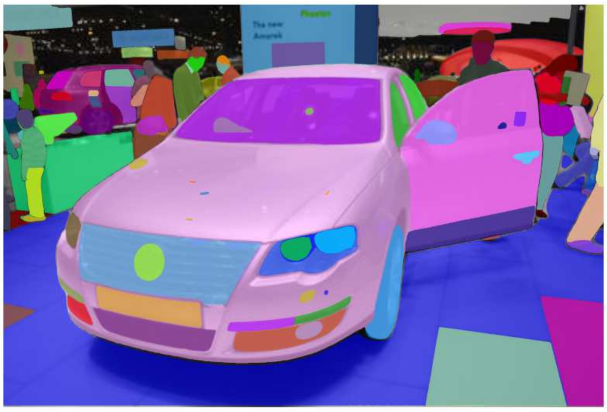

Fig. 1 Segmented image, a part of the SA-1B dataset [1].

Reducing the need for task-specific modeling expertise, computer training, and custom data annotation for image segmentation is at the core of the Segment Anything project. SAM has learned a general notion of what objects are, and it can generate masks for any object in any image or video. The Segment Anything project can even be used for objects and image types which have not been encountered by the AI during training. The SAM is general enough to cover a broad set of use cases and can be used out of the box for new image "domains" – whether underwater photos or cell microscopy — without requiring additional training [5]. SAM is already available in our cell phones for us to select any object we want Fig 2.

Hence, SAM can also be used as the go-to AI tool to segment sand grains from images without additional steps.

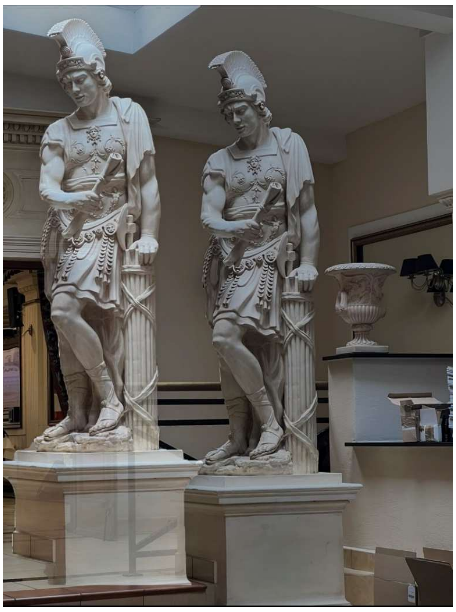

Fig. 2 Example of using the Segment Anything Model (SAM) on a mobile phone (own elaboration).

Sand grain characteristics

Grain size and shape characteristics significantly affect the engineering properties of a soil matrix. Terzaghi was one of the first engineers to investigate the influence of grain shape characteristics on soil properties by using flat-grained particles [6]. Numerous researchers have explored grain shape because of its importance for sand behavior in engineering processes [7]. Grain size and shape reflect material composition, grain formation, and release from the mineral matrix, as well as transportation and deposition environments [8]. Both mechanical and chemical processes influence the size and shape of the grain [9], [10].

There are three significant scales in grain/particle shape evaluation [11], [12], [13], [14]:

1. Sphericity *S* (cf. eccentricity or plainness) refers to the global form of the grain/particle and reflects the similarity between its length, height, and width.
2. Roundness *R* (cf. angularity) describes the scale of main surface features, which are typically one order of magnitude smaller than the grain/particle size Fig. 3.
3. Smoothness (cf. roughness) describes the grain/particle surface texture relative to its radius.

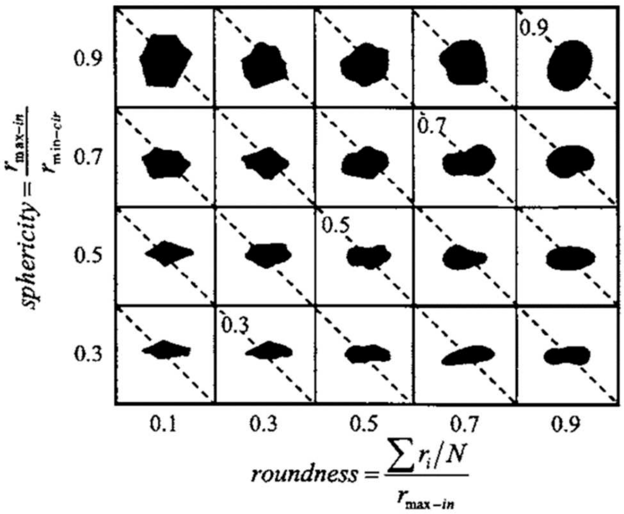

Fig. 3 Particle and grain shape determination according to Krumbein's chart – sphericity *S* and roundness *R* characteristics [13].

It has been noted that sphericity and roundness increase as a result of abrasion, but they do not increase proportionally. Furthermore, chipping a grain may increase its sphericity, but decrease its roundness [11]. Round grains can have nonspherical shapes (e.g., elliptical or disk grains) and equidimensional grains can be very angular (e.g., cube or hexahedron-shaped) [8].

The size of sand grains is defined in the EN ISO 14688 – 1: 2018 Standard [15]. This classification is presented in Tab. 1.

Tab. 1 Fractions, classification by PN-EN ISO 14688 – 1: 2018 [15].

Symbol	Fractions (soil type)	Particle size (mm)
Sa	Sand	>0.063 ÷ 2.0
CSa	Coarse sand	>0.63 ÷ 2.0
MSa	Medium sand	>0.2 ÷ 0.63
FSa	Fine sand	>0.063 ÷ 0.2

The paper aims to present one of the multiple possibilities of using artificial intelligence in branches of engineering such as geotechnics. A key aspect of the research is showing the wide range of AI tool applications in geotechnical research for evaluating different sand grain sizes and shapes.

2 MATERIALS AND METHODS

The research consisted of two stages. Firstly, granulometric tests were performed and soil types were assessed according to PN-EN ISO 14688 – 1: 2018 [15]. Two types of sand were examined: fine and medium. The fine sand was obtained from a small village south of Warsaw, Starogród. The origin of the fine sand is post-glacial, resulting in the particles exhibiting sharp edges. The second sand was obtained from Chałupy, a Baltic seaside town. Hence, it should be of medium size with an oval shape. Sieve analyses were performed to define the soil types properly Fig 4. The sieve analyses confirmed the types of sand.

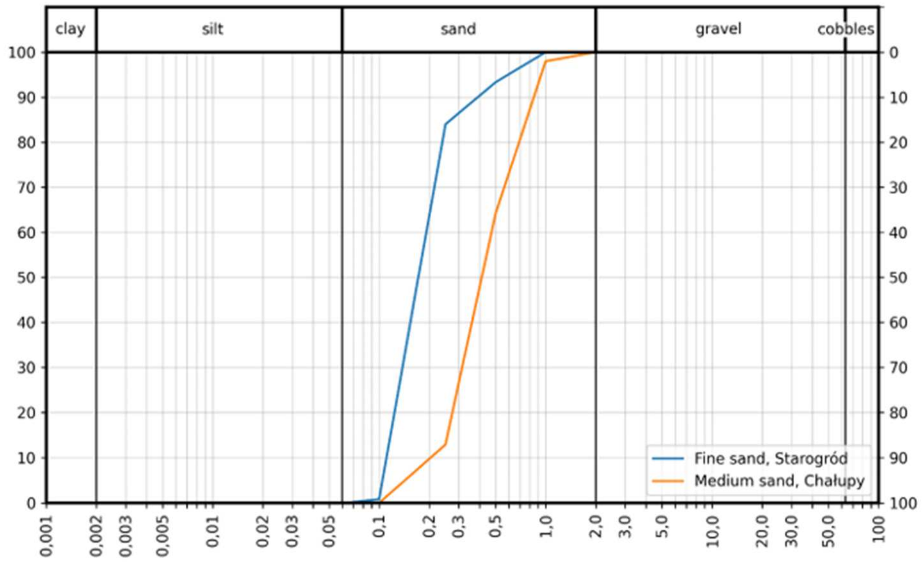

Fig. 4 Sand grain-size distribution curves (own elaboration).

Secondly, the tested grains of sand were examined by a light microscope as well as a scanning electron microscope (SEM). Sagittarius Analyth Mono, Bino and Trino light microscopes Fig 5 and 6 and the SU – 8000 scanning electron microscope (Hitachi High-Tech, Japan) (Fig 7 and 8) were used to generate the pictures of grains. The pictures were used for grain sphericity estimation according to Krumbein's chart and the Segment Anything Model (SAM).

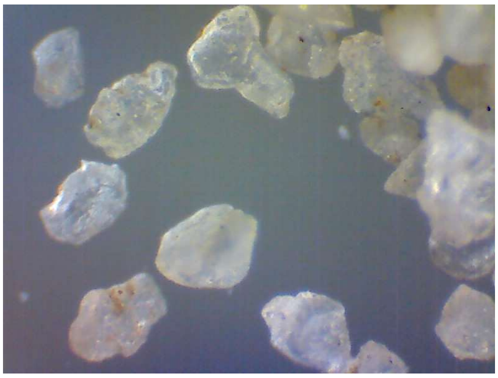

Fig. 5 Fine sand (Starogród) – photograph by LM microscope (own elaboration).

Fig. 6 Medium sand (Chałupy) – photograph by LM microscope (own elaboration).

DOI 10.13164/juniorstav.2024.24138

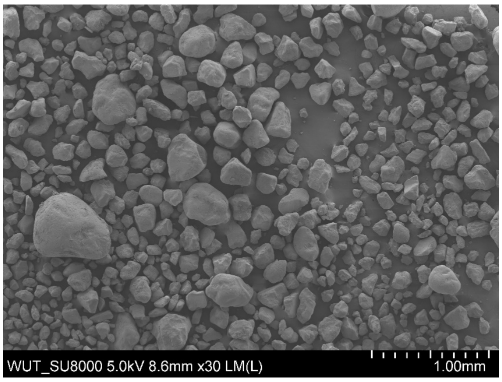

Fig. 7 Fine sand (Starogród) – photograph by SEM microscope (own elaboration).

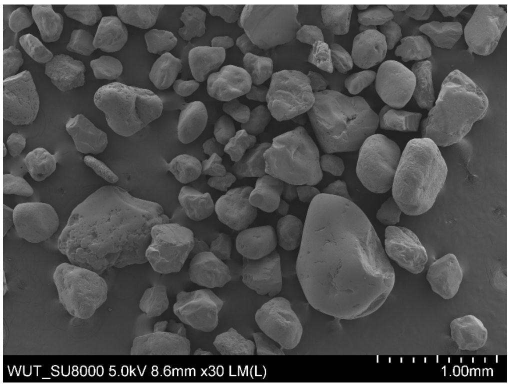

Fig. 8 Medium sand (Chałupy) – photograph by SEM microscope (own elaboration).

The first method, i.e., the grain sphericity assessment according to Krumbein's chart, involves the visual determination of grain sphericity and the comparison of the shapes of the tested grains to the standard shapes defined in Krumbein's chart. Hence, the assessment of grain shape is a subjective assessment by the person performing it.

The second method leads to a parameterized, objective assessment of grain shape. It is based on segmentation (SAM), which allows the identification of image pixels belonging to an object. Moreover, it is a well-known problem in image processing and Meta have recently released their AI segmentation project for public use. A program was written in Python to analyze the shape of sand grains. Its source code and usage instructions can be found on the Authors' Github [16]. At a high-level overview – when run, it displays any microscopic picture of sand given to it via the command line and allows the user to select grains that interest them by clicking on them. It marks the selected grain and draws a circle fitted to it along with a statement of the estimated sphericity of the selection.

The rendering of the image, masks and annotations is performed using Matplotlib, an open-source library for visualizations in Python that can also be used to build interactive elements or can be embedded in other toolkits [17]. The actual segmentation using given prompts is performed using the Segment Anything Model project's default model and SAM predictor parameters. The result of a single prediction is a table expressing whether or not a pixel is considered to belong to the object under the location prompt. Finally, the determination of a good covering circle is conducted using another open-source project [18]. This actually helps solve another well-known and challenging problem in computer science – the determination of a covering disc. Given a list of positions, the result of such fitting is the location and radius of the disc. All of the used open-source code is released under permissive licenses.

The authors wrote custom code to achieve the needed functionality of glues mentioned in open-source projects using less than 200 lines of commented Python code. It implements the interactions with the graph. It translates the table of pixel belongings into a list of their (x,y) coordinates and feeds that list into the circle-fitting library. As the last step, the sphericity is easily calculated by dividing the number of masked pixels by the surface area of the received covering circle.

DOI 10.13164/juniorstav.2024.24138

3 RESULTS

The results for the evaluation of sand grain sphericity via two methods can be found in Tab. 2.

Tab. 2 The sphericity of fine and medium sand grains.

Type of sand	Type of photograph	Number of grains	Sphericity according to Krumbein's chart	Sphericity determined by AI
Fine sand	LM	1	0.9	0.75
		2	0.9	0.74
	SEM	1	0.6	0.65
		2	0.9	0.74
		3	0.5	0.55
		4	0.7	0.64
		5	0.7	0.63
		6	0.8	0.76
Medium sand	LM	1	0.9	0.75
		2	0.8	0.76
	SEM	1	0.7	0.68
		2	0.9	0.82
		3	0.8	0.67
		4	0.3	0.32
		5	0.8	0.73

An example output of the program used by the AI can be seen in the figures below Fig. 9-12. Sand grains taken from the Starogród and Chałupy locations are presented in the following images taken by a light microscope, in Fig. 9 and 10, respectively. The authors' Python program adds annotations with circles and sphericity estimates. The same was performed for images sourced from the SEM microscope for Starogród sand Fig. 11 and Chałupy sand Fig. 12. The blue overlay visible in each figure is a feature of the application. It draws the segmentation mask on the last selected sand grain for more responsive user interactions.

It should be noticed that in Fig. 10, the bottom-right sand grain, while correctly segmented, appears only partially in the picture. Therefore, the sphericity estimation is incorrect, and hence it was not included in the analysis. Segmentation does not indicate if an object is fully visible, so the calculations usually proceed. This can be easily ignored by a person using this tool.

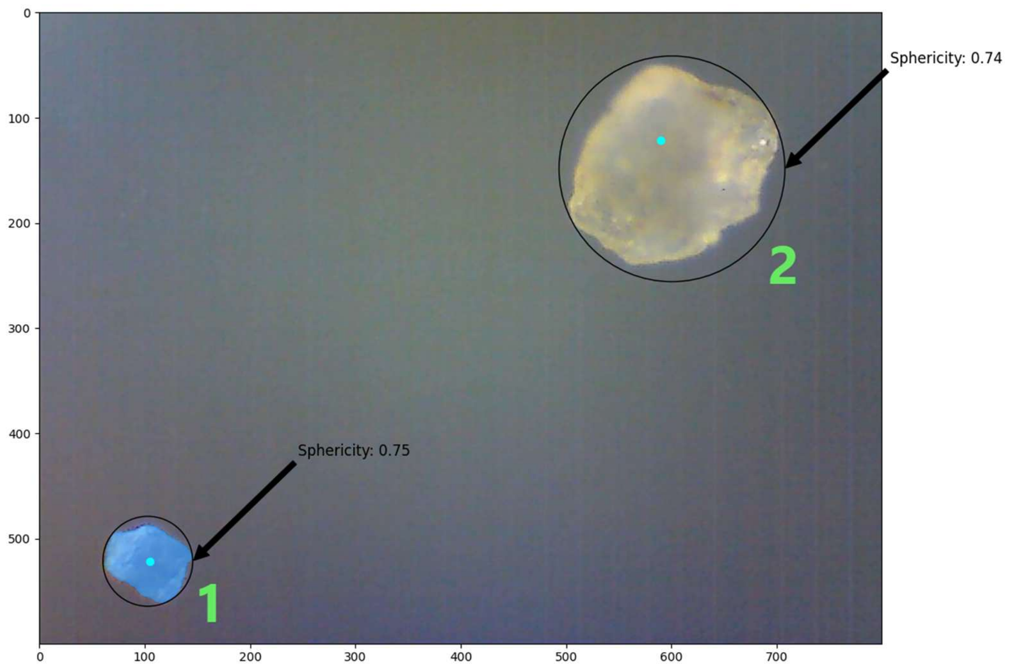

Fig. 9 Fine sand (Starogród) – photograph by LM microscope (own elaboration).

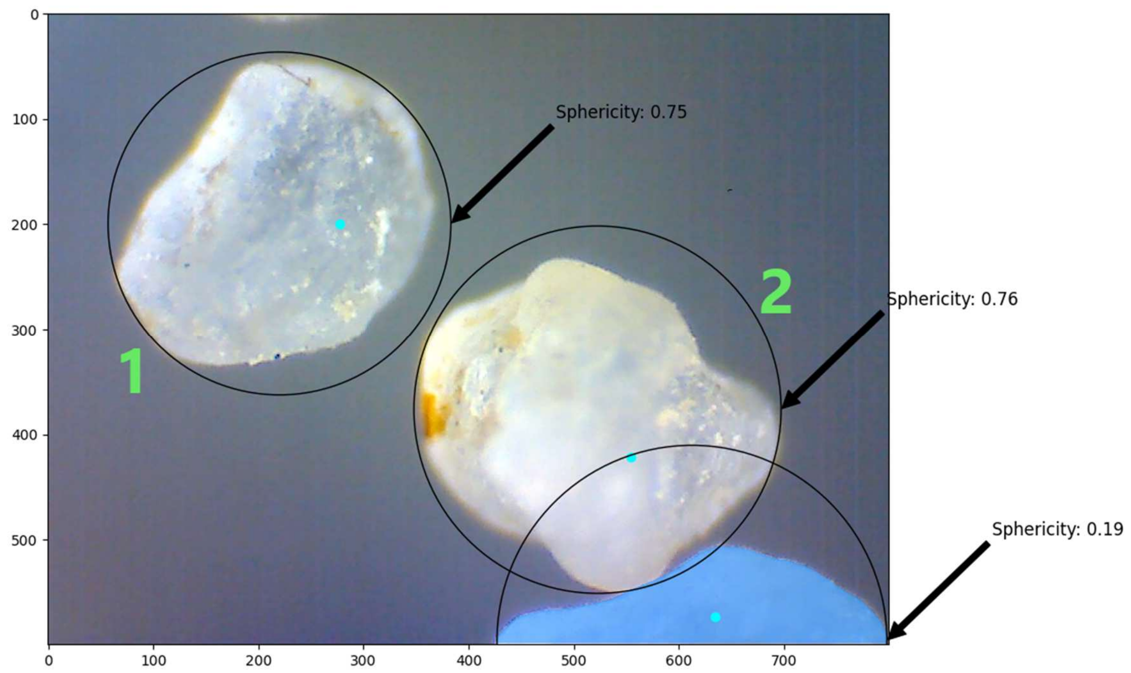

Fig. 10 Medium sand (Chałupy) – photograph by LM microscope (own elaboration).

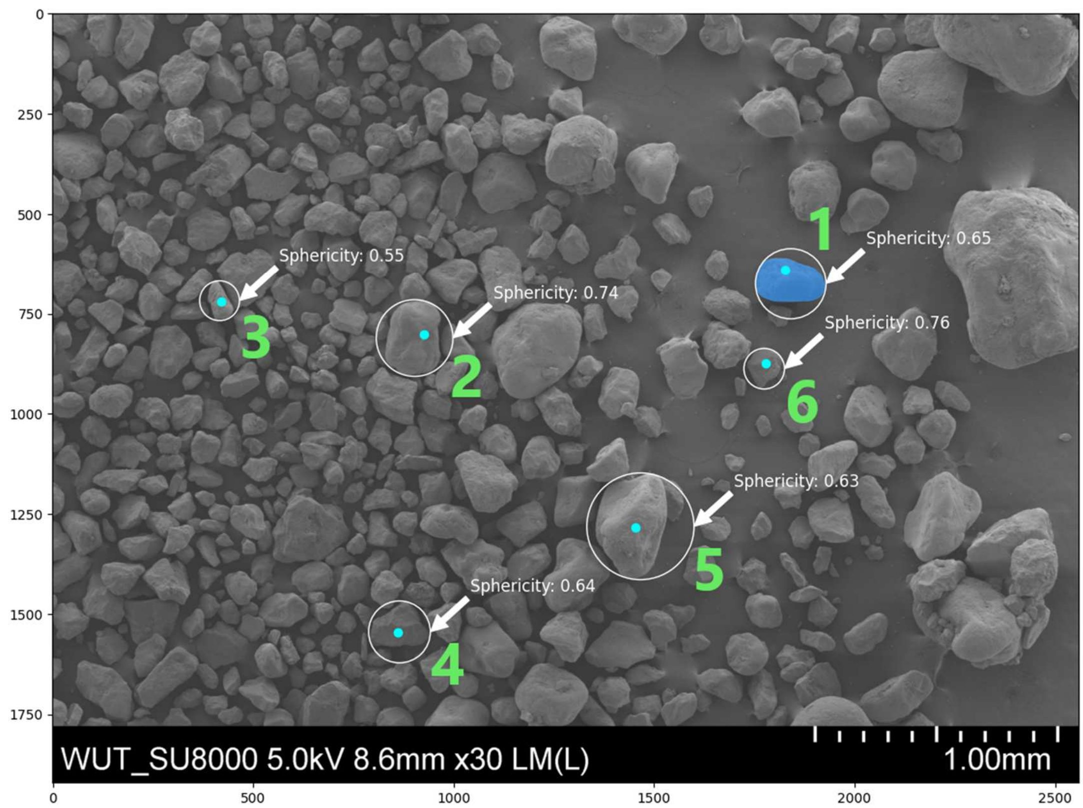

Fig. 11 Fine sand (Starogród) – photograph by SEM microscope (own elaboration).

DOI 10.13164/juniorstav.2024.24138

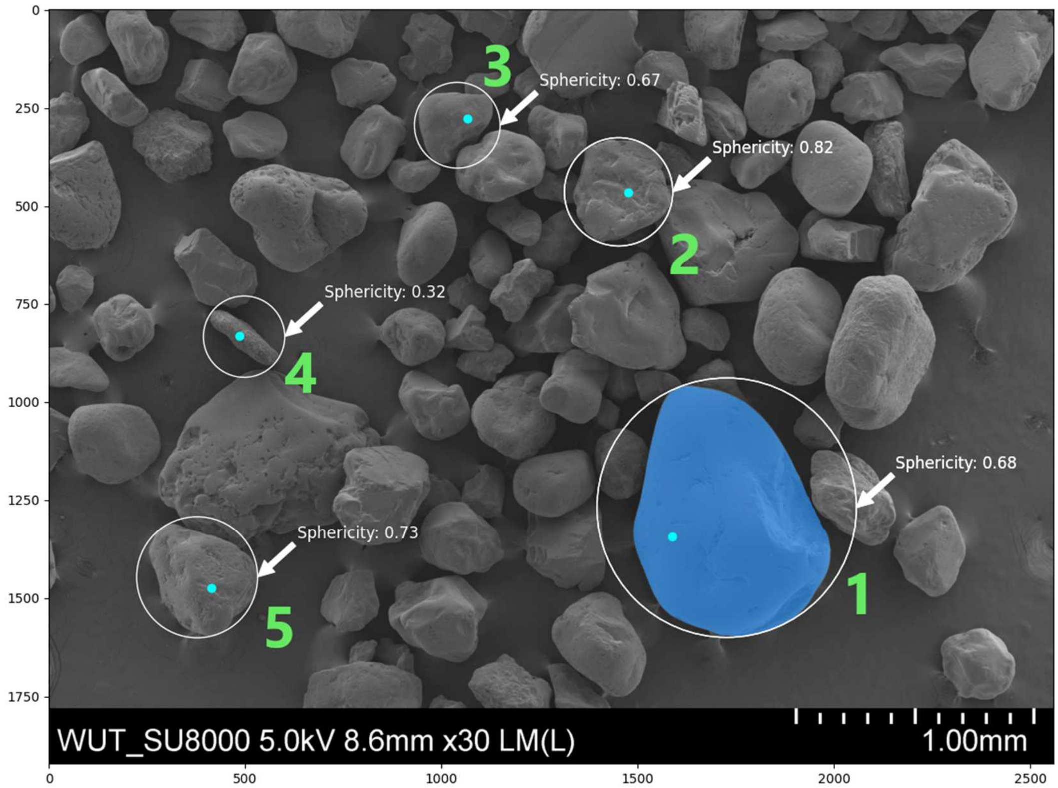

Fig. 12 Medium sand (Chałupy) – photograph by SEM microscope (own elaboration).

4 DISCUSSION

The sphericity of 15 grains of 2 types of sand was assessed according to Krumbein's chart and by AI Tab. 2. Comparing the results of the sphericity assessment based on Krumbein's chart versus the program output, it can be seen that the sphericity results obtained from Krumbein's chart are higher than those from the AI in most cases. 12 of the 15 AI measurements are smaller than those based on Krumbein's chart, but the difference does not exceed 0.16. In three cases, the assessment results according to the AI are lower than those from Krumbein's chart, with a maximum difference of 0.05. It must be noted that the assessment by Krumbein’s chart is entirely subjective, while the program output is more precise and objective.

5 CONCLUSION

The prepared Python application shows that the estimation of sphericity using segmentation can be performed both on images from relatively low-cost light microscopes as well as from SEM microscopes. Thanks to the availability of free and open-source software, an application to conduct such estimations can be created with less effort than ever before. It shows that the method of estimation used by the program, which is to divide the mask pixel count by the area of the fitted circle, can be used successfully. The estimates provided by the program are even more precise than the quantities method based on Krumbein's chart. Hence, using the developed AI application for grain sphericity assessment allows us to avoid the sphericity overestimation that results from chart-based methods. However, it must be noted that specialists should verify all AI helpers.

References

[1] META, AI. Segment Anything. Meta. 2023 [accessed 2023-11-25]. Available at: https://segment-anything.com

[2] SICILIANO, Bruno, KHATIB, Oussama and GROEN, Frans. FastSLAM: A Scalable Method for the Simultaneous Localization and Mapping Problem in Robotics. *Springer Tracts in Advanced Robotics*.

2007. Vol. 271. ISBN 978-3-540-46399-3
[3] CVAT [online]. CVAT.ai Corporation. 2024 [accessed 2023-11-25]. Available at: https://www.cvat.ai
[4] Available at: https://www.tensorflow.org, [accessed 2023-11-25].
[5] KIRILLOV, Alexander et al. Segment Anything [online]. Cornell University. 5 Apr 2023 [accessed 2023-11-25]. https://doi.org/10.48550/arXiv.2304.02643
[6] TERZAGHI, Karl. *Erdbaumechanik: auf bodenphysikalischer Grundlage*. 1925. Leipzig ; Deuticke.
[7] CABALAR, Ali Firat and AKBULUT, Nurullah. Effects of the particle shape and size of sands on the hydraulic conductivity. *Acta Geotechnica Slovenica* [online]. 2016. Vol. 13, no. 2, pp. 83–93. ISSN 1854-0171
[8] CHO, Gye-Chun, DODDS, Jake and SANTAMARINA, J. Carlos, 2006. Particle Shape Effects on Packing Density, Stiffness, and Strength: Natural and Crushed Sands. *Journal of Geotechnical and Geoenvironmental Engineering* [online]. Vol. 132, no. 5, pp. 591–602. DOI 10.1061/(ASCE)1090-0241(2006)132:5(591)
[9] MARGOLIS, S.V. and KRINSLEY, D. H. Processes of formation and environmental occurrence of microfeatures on detrital quartz grains. *American Journal of Science* [online]. 1974. Vol. 274, no. 5, pp. 449–464. DOI 10.2475/AJS.274.5.449
[10] RAHAMAN, M.N., 1995. Ceramic processing and sintering. *Dekker, New York*. DOI 10.1201/9781315274126
[11] WADELL, Hakon. Volume, Shape, and Roundness of Rock Particles. *The Journal of Geology*. 1932. Vol. 40, no. 5, pp. 443–451
[12] KRUMBEIN, William Christian. Measurement and geological significance of shape and roundness of sedimentary particles. *Journal of Sedimentary Research*. 1941. Vol. 11, no. 2, pp. 64–72. ISSN 1938-3681
[13] KRUMBEIN, W. C. and SLOSS, L. L. Stratigraphy and Sedimentation. *San Francisco: Freeman*. 1951. Vol. 114, no. 2961, pp. 335–336. DOI 10.1126/science.114.2961.335. ISBN 0038-075X
[14] BARRETT, PJ. The shape of rock particles, a critical review. *Sedimentology*. 1980. Vol. 27, no. 3, pp. 291–303. ISSN 0037-0746
[15] DĄBSKA, Agnieszka. Podstawy geotechniki. Zadania według Eurokodu 7. 2020. 2nd ed. Oficyna Wydawnicza Politechniki Warszawskiej. ISBN 978-83-7814-028-3
[16] MAZUREK, A. Available at: https://github.com/arturmazurek/juniorstav, [accessed 2023-11-25].
[17] Available at: https://matplotlib.org, [accessed 2023-11-25].
[18] Available at: https://www.nayuki.io/page/smallest-enclosing-circle, [accessed 2023-11-25].