Article

Computer-aided calculation of the volume of soil masses using Civil 3D

Ramil Timirkhanov[1], Shyngys Zharassov[1,*], Nursultan Baltabekov[1], Aleksej Aniskin[2]

[1]Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan
[2]Department of Civil Engineering, University North, Varaždin, Croatia
*Correspondence: zhshzh95@gmail.com

Abstract. Accuracy and automation of processes in all areas of human activity play a significant role, so new technologies are increasingly replacing human labor. In all this variety of IT solutions, the logic is more and more rarely traced in the absence of calculation methodology with a combination of necessary tools. This article describes one way of calculating the volume of soil masses using Civil 3D software. As a result of comparison of traditional and automated methods of calculation of volume of earth masses, the essential difference both in total values, and in the time spent for calculations has been revealed. A parallel between surplus volumes and freight transport logistics was drawn. The described method of calculating the volume of soil masses makes it possible to visually estimate the work front, select a suitable method of excavation works, develop production organization, take into account the need for soil removal and filling, determine the cost and duration of excavation works.
Keywords: Civil 3D, Geodesy, Surveying, Automation, Topographic mapping

1. Introduction

The management of all construction processes is based on precision. It covers all phases of the construction process, from project initiation to full completion. The elements are generally considered to be the levels, planes and axes that are defined in the design in a given site. Any deviation from these parameters is fraught with serious consequences [1]. Often deviations appear due to the human factor. For this reason, every process requires automation in management. Automation is achieved through the continuous improvement and implementation of new technologies, especially IT [2]. Not all areas of human activity are being automated or digitized so quickly, but there is a trend, which can be observed in the construction industry. Touching the topic of calculation accuracy, which is an important factor for other industries as well, construction occupies a large part of it [3], since strategically important projects require an appropriate building or structure. The problem is reflected in the implementation of such projects. The increase in the cost of some work in the early stages of construction is very expensive and in this case, the use of new technologies can reduce costs and time during construction.

Based on the above, the early stage of design requires special accuracy, as at this stage all the necessary design documentation for the project is formed. The required accuracy is determined by means of given coordinates, which in turn require a number of competent engineers, tools, and methods for constructing horizontal and vertical planes, and calculating planned and actual volumes of soil masses. Competence in this area falls within the functional area of responsibility of the people performing the geodetic surveys, i.e., the geodetic engineer. A specialist in this field should be very versatile, as the determination of coordinates and heights of points of the earth's surface require both theoretical and practical skills of applying calculations and the use of modern technology. Therefore,

based on the importance of geodetic survey coverage, there exist a number of software solutions to automate and manage the functional area of responsibility of this engineer at the construction site [4].

A number of software products are available on the IT market that simplify and speed up the production processes during surveying (Table 1). The mathematical data processing and field measurements are fundamental to the software used in geodesy. Existing software can be divided into blocks used specifically for one task or complexes that consider calculations as a whole [1].

Table 1 – Types of geodetic surveying and their application

№	Types	Application
1	Topographic survey	Topographic plans and maps
2	Tachymetric survey	Determining the points location on a plane and elevation
3	Horizontal survey	Drawing a contour map of the earth's surface
4	Vertical survey (altitude)	Creation of cartographic maps showing the terrain relief

A simple example is using Excel spreadsheets. Despite the limited visual component, the range of applications of this tool is very large, such as the calculation of forward and reverse surveying, processing of theodolitic and leveling work, determination of areas and deviation from the project planes, as well as the determination of volumes and many other applied tasks [5]. This method is semi-automated and an incorrectly entered algorithm can lead to some errors. For this reason, there are specialized software to reduce the risks arising in the presence of the human factor. Among the domestic developments of the CIS countries, the line of products of the Belarusian company's Credo-Dialog with the Credo program complex of the same name is widely distinguished. The complex includes such modules as Credo-leveling, Credo-deformation calculation, Credo-topoplane and many other extensions [6]. Autodesk product lines such as AutoCAD, Civil 3D, and Map 3D are popular in Europe and overseas [7]. It is worth noting that the capabilities of this product line of Autodesk are quite wide as they combine all kinds of existing tools for geodetic activities, from linking with Excel spreadsheets to surface modeling and working with point clouds. In addition to software, it is possible to allocate design and geodetic platforms that are based on applications of Autodesk corporation. The purpose of project-geodesic platform is to adapt foreign developments to domestic technologies and standards. One of such modules is GeoniCS-surveyor, with the help of which processing of different types of measurements, designing, alignment and error detection, catalogs forming, calculations, data export and import can be performed. There are also highly specialized software programs that solve the problem much faster and more accurately than complex programs that require more in-depth knowledge and Agisoft PhotoScan is a proof of that. Being essentially an autonomous software product it can perform photogrammetric processing of digital images and create three-dimensional spatial data for use in GIS [8].

Thus, apart from accuracy, which is a mandatory requirement, the use of some or other software in geodesy depends on the technical assignment, the level of competence of specialists and the timing of the planned tasks. In general, the above-mentioned software is only a tool in the hands of an experienced specialist, where the main factor remains only the speed and accuracy of achieving results [9]. Consequently, a judiciously chosen combination of tools involves achieving them quickly than the established traditional methods [7-10]. The only traditional method of counting is known, but for each geometric figure, i.e., constructive, it is different. Under the constructive, there are excavations, trenches and embankments. Constructivities are found in aggregate for this reason the figures are broken down into several simpler and more regular geometric bodies, and then their volume is summed up [11]. If we go deeper into the general systematic execution of the traditional method, we can highlight the following:

- Availability of a geodetic substrate with a vertical layout of the building site at a certain scale;

- Drawing a grid of squares where black (real), red (assumed) and working marks, which mean the difference between the existing and project data, are located in the corners;

- Determining the marks on the tops of the squares according to embankment and excavation, plus or minus, respectively;

- Tracing the uniform change in height, followed by connecting the obtained points to each other;

- Marking the lines of zero works, defining the area between the excavation and embankment.

In this regard, the authors formulated the purpose of this article, to present a version of the execution of the topographical survey on the example of calculating the earth mass of the site for the construction of a multi-storey residential complex within the city, where instead of the traditional method a fully automated method with minimal labor and time is applied.

2. Methods

The methodology proposed by the authors for calculating the volume of earth masses is applicable in the case of engineering network design, excavation development, landscaping, vertical planning of a land plot. In all this, the scope of application of the methodology is not limited to carrying out construction works and can be extended to such works as monitoring of mining operations and any other types of excavation works [12].

The volume of soil masses is taken as the difference between two surfaces on the basis of the topographic survey with the use of tools determining the initial coordinates of points relative to the level of the Baltic Sea [13].

The method of calculation begins with an AutoCAD file with the extension .dxf, obtained after the Tachymeter survey, where all the data is distributed by layers. Based on these data the earth masses cartogram with the relief image in the form of horizontals with a grid of squares is built. The grid of squares contains black and red working marks with intersecting lines of zero works. The resulting topographic survey was imported from the LEICA TS03 R500 Total Station into standard AutoCAD (Figure 1). This residential complex called "Besterek - 3" is located on the left bank of Nur-Sultan on Fariza Ongarsynova Street and has been successfully commissioned.
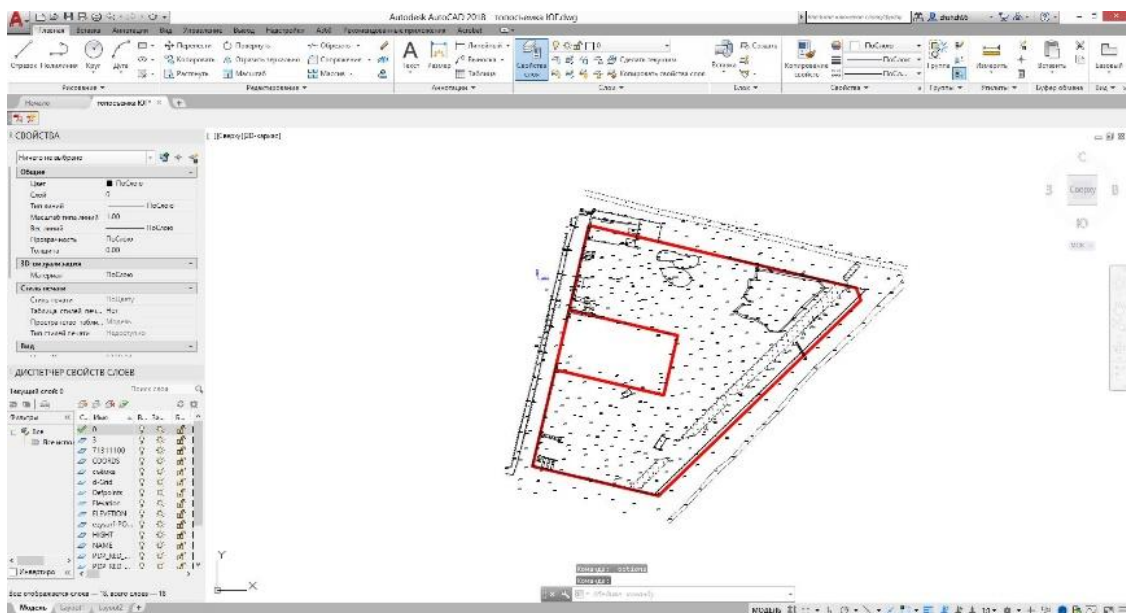

Figure 1 – Construction site tachymetric survey in AutoCAD

Then, all the data in the original coordinates were transferred to the Civil 3D environment, where the corresponding modules for the automated calculation were used. The automated calculation consists of data analysis modules using drawing area tools, which include points, point groups and surfaces (Figure 2).
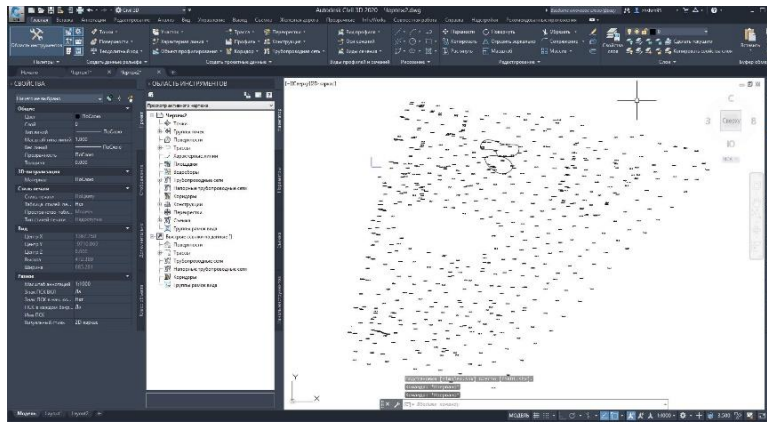
Figure 2 – Construction site tachymetric survey in Civil 3D

To process initial data into Civil 3D point format it is necessary to remove unidentified objects for further calculation. Unidentified object is any text except for point values and complex primitives that consist of one or more interconnected rectilinear and arc segments representing a single object, such as polylines and excavation boundaries. However, there are also calculations based on polylines, but in this case the calculation using specific points is applied [14]. In the case of Civil 3D, the polyline is only needed to build surface boundaries (Figure 3).
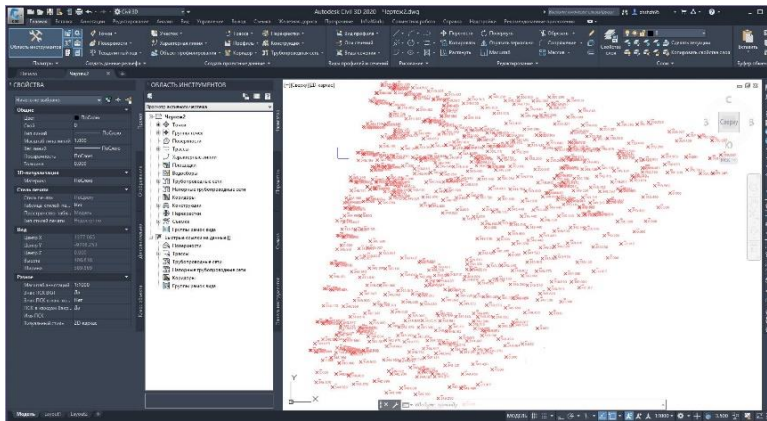

Figure 3 – Tachymetric survey of a construction site for processing in Civil 3D without primitives with the necessary data

After determining the desired points with the initial coordinate data, 2 surface boundaries are drawn for their subsequent comparison. The defined boundaries are drawn with a polyline and the points that are on the boundary of the design elevation transition, defining the construction area, take the following form, shown in Figure 4. The designation may be different depending on the user's settings.
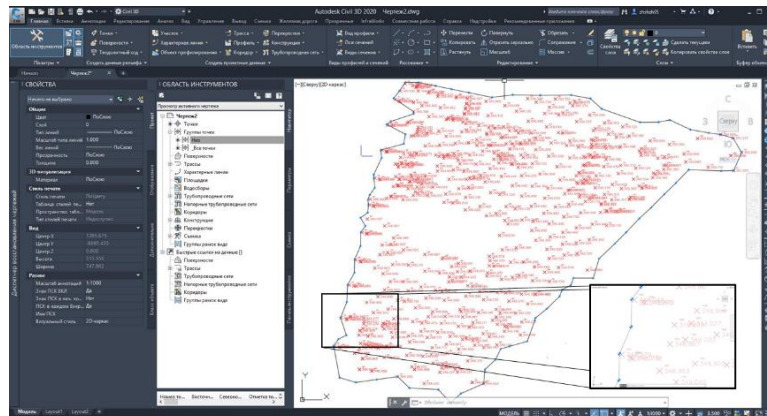

Figure 4 – Delineation of surface plotting boundaries in Civil 3D

During data preparation for analysis, there may be system errors that may occur during data transfer. One of such moments is frequent error of definition of a point outside the initial coordinates, which is tied to zero in the working environment of 3D model. The error is solved by excluding the detected points by a given condition of marks exceeding the mark zero in the working environment (Figure 5).
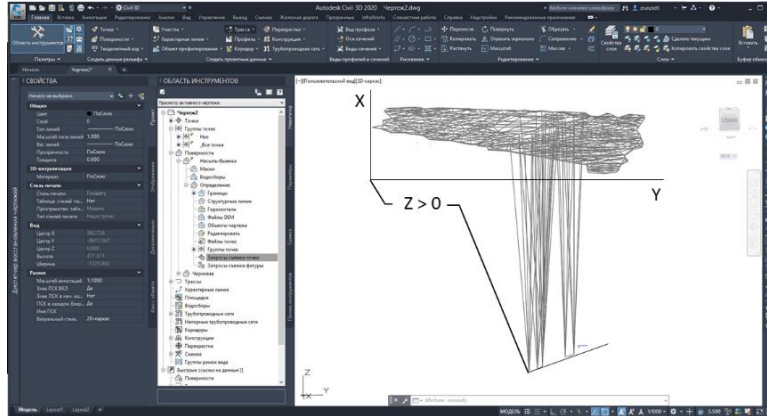

Figure 5 – Error in determining points outside the initial coordinates in the Civil 3D environment

The finite element grid built from the processed data provides an opportunity for evaluating the vertical layout if the existing topography of the construction site does not meet the requirements (Figure 6).
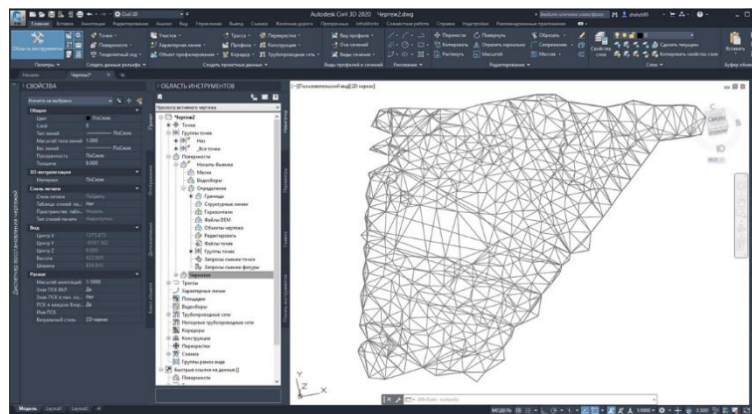

Figure 6 – Finite element grid in the Civil 3D environment

Further visualization of the grid clearly shows where soil cutting or replenishment is required (Figure 7).
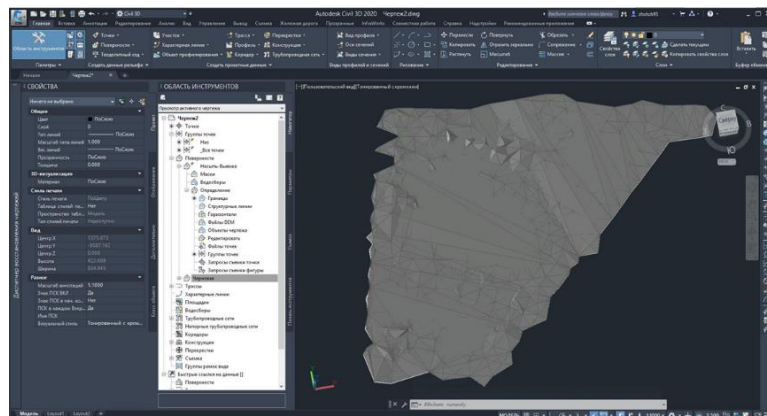

Figure 7 – Visualization of vertical planning in the Civil 3D environment

On the basis of the resulting 3D model, you can perform a calculation where given surfaces by comparing the excess volumes in one degree or another form the black and red working marks on the map of earth masses.

3. Results and Discussion

The comparison of traditional and automated methods of calculating the volume of earth masses revealed a significant difference, both in the final values and in the time spent on the calculations.

The difference found when comparing the two versions of the calculations, gives a clear picture of the losses at the construction site, because if the total difference in the soil to translate the number of special equipment for its transportation, it comes out 17 trucks of 80 tons each. For small projects this may not be significant, but for large-scale projects the losses are very large (Figure 8, Table 2).
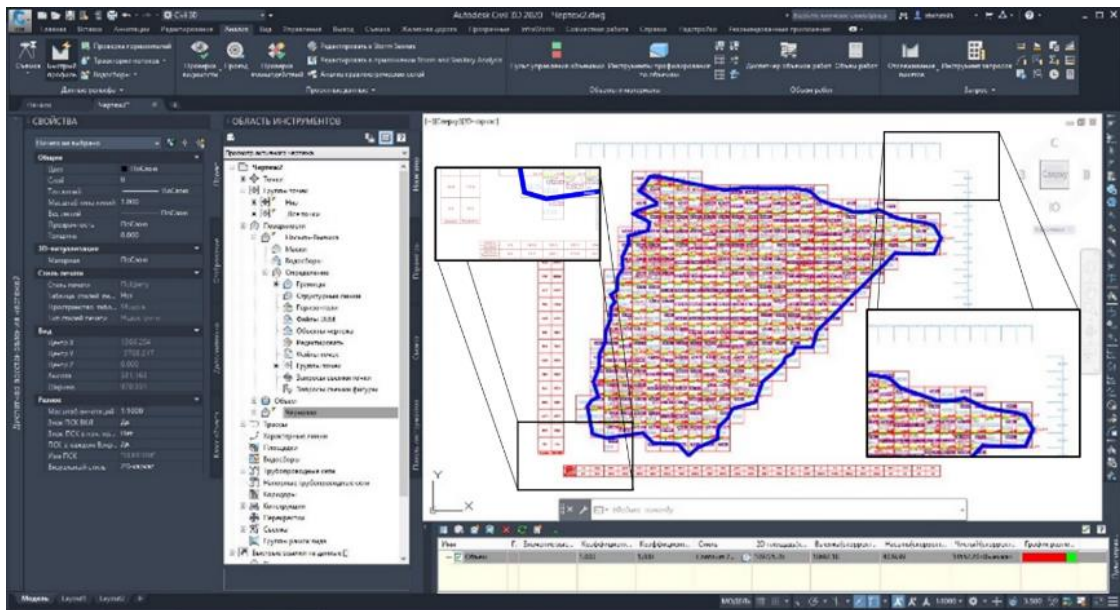

Figure 8 – Calculation by grid method of vertical leveling in the Civil 3D environment

Table 2 – Comparison of traditional and automated calculation of the volume of soil masses of the vertical leveling of the construction site in the Civil 3D environment

№	Indicator	Traditional calculation		Automated calculation		Deviation	
		Filling	Removing	Filling	Removing	Filling	Removing
1	Volume, m3	7873	301	6594.85	396.79	1278.15	-96.79
2	Time spent, hours	1.5		0.5		1.0	
					Total, m^3	1374.94	

It is possible to continue the method of calculating the volume of earth masses using autonomous software, for example Agisoft PhotoScan [15]. The positive side of the use of such software is the independence and adaptation to different systems. In this case, the main tool is an unmanned aerial vehicle (UAV) to obtain high-quality images for further photogrammetry.

4. Conclusions

The authors of the article present a technique for automating the calculation of the volume of earth masses using Civil 3D software, which allows:

1. Visually assess the work front.

2. Select a suitable method of excavation works;
3. To work out the organization of production;
4. Take into account the need for removal of soil and formation of embankments;
5. Determine the cost and duration of earthworks.

References

1. Planning and Implementation of Construction Investments - The Basic Stage of Works / K. Noga // Civil and Environmental Engineering Reports. — 2021. — Vol. 31, No. 4. — P. 184–195. https://doi.org/10.2478/ceer-2021-0056
2. Efficiency optimization and quality control of engineering geodesy processes in civil engineering / V. Berkhahn, F. Berner, H. Kutterer, V. Schwieger, J. Hirschner, I. Rehr, N. Rinke, J. Schweitzer // BAUINGENIEUR. — 2010. — Vol. 85. — P. 491–501.
3. UAS Point Cloud Accuracy Assessment Using Structure from Motion–Based Photogrammetry and PPK Georeferencing Technique for Building Surveying Applications / J.G. Martinez, G. Albeaino, M. Gheisari, W. Volkmann, L.F. Alarcón // Journal of Computing in Civil Engineering. — 2021. — Vol. 35, No. 1. — P. 05020004. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000936
4. Geodäsie im Investitionsbauprozess auf den Bahngebieten in Polen / A. Kampczyk // Bautechnik. — 2014. — Vol. 91, No. 6. — P. 409–413. https://doi.org/10.1002/bate.201300105
5. Web-Based Architecture for Automating Quantity Surveying Construction Cost Calculation / J.H. Yousif, S.N. Abdul Majeed, F.J.I. Al Azzawi // Infrastructures. — 2020. — Vol. 5, No. 6. — P. 45. https://doi.org/10.3390/infrastructures5060045
6. CREDOS: A Conservation Reserve Evaluation and Design Optimisation System / N.D. Crossman, L.M. Perry, B.A. Bryan, B. Ostendorf // Environmental Modelling & Software. — 2007. — Vol. 22, No. 4. — P. 449–463. https://doi.org/10.1016/j.envsoft.2005.12.006
7. Peculiarity of Software selection for training of landscape design / V.F. Shpagin // Information Technologies and Learning Tools. — 2018. — Vol. 68, No. 6. — P. 181–192. https://doi.org/10.33407/itlt.v68i6.2152
8. Assessing the performance of commercial Agisoft PhotoScan software to deliver reliable data for accurate3D modelling / A. Jebur, F. Abed, M. Mohammed // MATEC Web of Conferences. — 2018. — Vol. 162. — P. 03022. https://doi.org/10.1051/matecconf/201816203022
9. UAV and the comparison of image processing software / D. Kaimaris, P. Patias, M. Sifnaiou // International Journal of Intelligent Unmanned Systems. — 2017. — Vol. 5, No. 1. — P. 18–27. https://doi.org/10.1108/IJIUS-12-2016-0009
10. Performance comparison analysis of 3D reconstruction modeling software in construction site visualization and mapping / A. Keyvanfar, A. Shafaghat, M.S. Rosley // International Journal of Architectural Computing. — 2022. — Vol. 20, No. 2. — P. 453–475. https://doi.org/10.1177/14780771211066876
11. Interstate standard GOST 21.508-93. System of building design documents. Rules of fulfilment of working documentation of general layouts of enterprises, buildings and civil housing objects.
12. The Accuracy of Low-Altitude Photogrammetry of Drones / N. Guo, Y. Li // International Journal of Pattern Recognition and Artificial Intelligence. — 2020. — Vol. 34, No. 08. — P. 2059029. https://doi.org/10.1142/S0218001420590296
13. Ob utverzhdenii Pravil organizacii zastrojki i prohozhdeniya razreshitelnyh procedur v sfere stroitelstva [Electronic resource] / adilet.zan.kz. — [2015]. — Mode of access: https://adilet.zan.kz/rus/docs/V1500012684 (accessed date: 19.08.2022).
14. An Algorithm of Offsetting Complex Region Based on AutoCAD / F. Gao // 2008 International Symposium on Computer Science and Computational Technology. — Shanghai, China: IEEE, 2008. — P. 648–651. https://doi.org/10.1109/ISCSCT.2008.348
15. Assessing the Accuracy of High Resolution Digital Surface Models Computed by PhotoScan® and MicMac® in Sub-Optimal Survey Conditions / M. Jaud, S. Passot, R. Le Bivic, C. Delacourt, P. Grandjean, N. Le Dantec // Remote Sensing. — 2016. — Vol. 8, No. 6. — P. 465. https://doi.org/10.3390/rs8060465

Information about authors:
Timirkhanov Ramil – MSc Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan, romaversache@mail.ru
Shyngys Zharassov – PhD Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan, zhshzh95@gmail.com
Nursultan Baltabekov – MSc Student, Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan, bna0575@gmail.com

Aleksej Aniskin – Candidate of Technical Sciences, Assistant Professor, Department of Civil Engineering, University North, Varaždin, Croatia, aaniskin@unin.hr

Author Contributions:
Timirkhanov Ramil – concept, resources, drafting, testing.
Shyngys Zharassov – methodology, modeling, analysis, funding acquisition.
Nursultan Baltabekov – data collection, visualization.
Aleksej Aniskin – interpretation, editing.