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TLS POINT CLOUD AS A DATA SURCE FOR MULTI-LOD OF 3D MODELS

Przemysław Klapa

Summary

The development of science and technology had a strong impact on all branches of engineering, including geodesy and the possibility of acquiring and processing measurement data. The best example of this is the Terrestrial Laser Scanning, whih can perform measurements in the form of a multi-million-point cloud. The cloud, representing places and objects, becomes a spatial database. The current problem in engineering is no longer data acquisition and processing, but information excess and redundancy. The solution to this problem is optimisation, which is the process of reducing the amount of data. It should implement its assumptions in such a way as to remove or reduce unnecessary information without losing the information presented by an object. This issue is particularly important in the process of using point clouds in 3D modelling at various levels of detail. The appropriate levels of the LOD0–LOD4 model require a different type of data: on the one hand ensuring the obtainment of the appropriate accuracy class in the study, and on the other hand, the data source should not contain too detailed information that is unnecessary for the study, which makes the work harder and slows it down due to the need to operate on a huge amount of redundant information Therefore, the purpose of this paper is to determine the scope of work on the optimisation of the point cloud in order to adjust its number and quality to the needs of individual LODs. The results of the work allowed to determine the scope of data unification for the respective precision groups of 3D models generating.

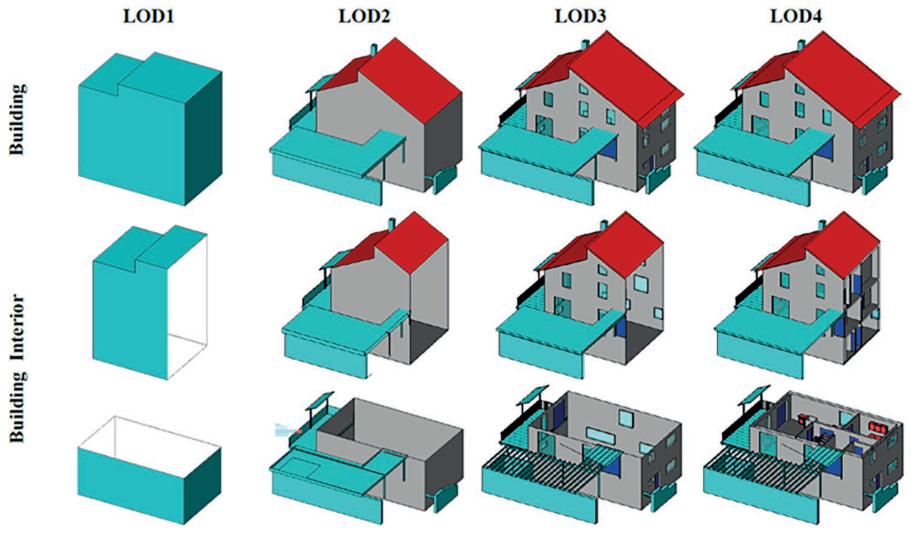
Keywords

data optimisation • point cloud • TLS • LOD • 3D modelling

1. Introduction

Terrestrial Laser Scanning (TLS) is a technological development of tacheometers commonly used in geodetic measurements, which measure distances using a rangefinder, and by registering the values of vertical and horizontal angles, they determine the direction of the measurement, and consequently determine the values of spatial coordinates of the target point. In this way, accurate measurement takes place in a short time, the result of which is a point cloud, which is a real reflection of the measured object [Bęcek et al. 2015]. Due to the recording of millions of points during data processing, difficulties arise in the quick and efficient processing of the generated information. Therefore, in order to facilitate and improve work efficiency, as well as to remove redundant information, the process of optimisation and unification of the point cloud is carried out, and the level and scope of its operation can be adjusted to the appropriate scope of the work performed. In relation to geospatial data, optimisation is the process of minimisation of the number of points recorded, which will ensure precise identification of objects, places and phenomena in the cloud. By eliminating redundant elements, we accelerate the process of finding and describing elements due to the removal of excess points that do not add new information to the dataset of a given geospatial database. The optimisation of the point cloud is based on the assessment of the largest distance between points – obtaining the appropriate resolution in order to recognise the required field details [Pesci et al. 2011].

With regard to 3D modelling based on a point cloud, it is important to select an appropriate level of accuracy as well as qualitative and quantitative density of points in the cloud due to the need to obtain an appropriate level of accuracy of the model. The level of detail of the model depends on numerous factors, such as the source of data, selection of appropriate software, skills of the user (the person making the model), required accuracy of the model, and its purpose. Therefore, in order to standardise the quality of the 3D models made, the Open Geospatial Consortium team published the so-called OpenGIS Standard, which presents universal principles and guidelines for the development of the City Geography Markup Language (CityGML), which describe the principles of defining and presenting 5 Levels of Detail (LODs) of the models built. LODs, which are individual levels of detail, reflect the process of collecting data with different application requirements and facilitate efficient visualisation and data anal-



Source: OpenGIS [2012]

Fig. 1. Levels of Detail

ysis. In a dataset, the same object can be represented with different LODs depending on the needs and the required level of detail. The levels from LOD1 to LOD4 (Fig. 1) represent the same structure and form of data, presented differently in terms of quantity and quality of architectural details [OpenGIS 2008].

LOD0 is essentially a two-and-a-half-dimensional digital terrain model that can be textured with aerial photographs or maps. LOD1 is simple geometric bodies devoid of architectural details, reproducing buildings in a simplified form. They are characterised by a high level of generalisation and a minimised level of detail. At LOD2, diverse roof structures and thematically diverse surfaces appear. Models have clearly marked contours with holes, as well as basic structural elements. LOD3 are models enriched with simplified architectural details with structural details of walls, roofs, balconies, etc. High-resolution textures may appear, providing further information about the object. At LOD4, there are very detailed and accurately mapped architectural details. A model includes installation elements as well as furniture. A high detail is characterised by visible window and door joinery with handles and decorations.

This LOD is characterised by varying accuracy and a minimum dimension value so that the object is represented by an additional (separate) model. The accuracy requirements in the standards are informative, these values can be modified and adjusted accordingly due to the nature of the facility. At LOD1, the position accuracy is determined at a maximum level of 5 m, however, all objects with dimensions of at least 6 × 6 m should be taken into account. Positioning and height accuracy at LOD2 is 2 m or more and includes surfaces of at least 4 × 4 m. LOD3 and LOD4 are characterised by an accuracy of 0.5 m with a minimum range of 2 × 2 m. The positioning accuracy at LOD4 must therefore be at least 0.2 m. By using such combinations, you can prepare city model datasets in 3D studies. The section of the diagram (Table 1) presents the scopes and requirements for individual LODs.

Table 1. Diagram showing the Levels of Detail

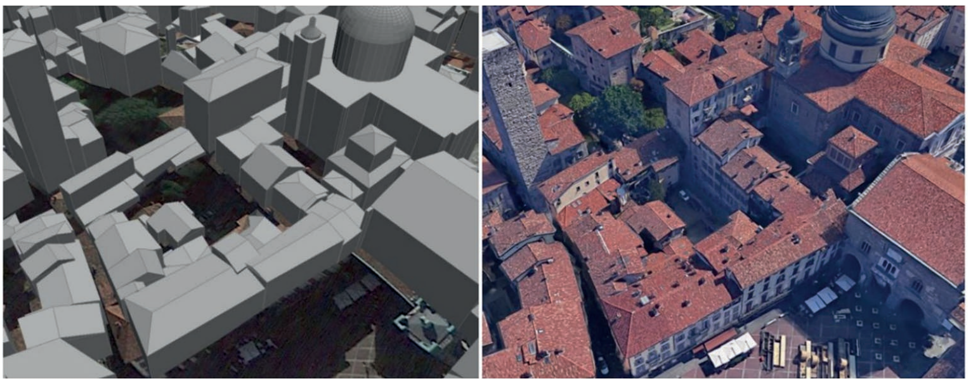
	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (outside), landmark	architectural models (interior)
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation (classification of land use)	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	-	-	-	representative exterior effects	real object form
Roof form/structure	no	flat	roof type and orientation	real object form	real object form
Roof overhanging parts	-	-	n.a.	n.a.	Yes
CityFurniture	-	important objects	prototypes	real object form	real object form
SolitaryVegetationObject	-	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	-	>50*50m	>5*5m	< LOD2	<LOD2
… to be continued for the other feature themes					

Source: OpenGIS [2008]

Categorisation makes datasets comparable with each other and provides a high standard of the studies performed [OpenGIS 2012]. Although OpenGIS standards apply to city modelling, they translate into modelling individual objects of buildings together with their equipment and components. The LOD remains the same, only the accuracy of modelling and the scope of creating a new 3D model may change, which depends on the requirements set by the contracting authority and the skills of the contractor.

With the development of the Internet and the popularity of city modelling, more and more 3D studies are available on web platforms and mobile applications. Numerical models of terrain and buildings are usually made on the basis of point clouds from aerial scanning (LiDAR) or on the basis of aerial photographs. Building modelling is done automatically, and only geometric checks and corrections are performed manually by the person supervising the entire process. The level of detail of objects is selected depending on the needs of their presentation, although most often it is at LOD1 and LOD2, due to the accuracy of geospatial data and the completeness of the obtained point cloud from LiDAR [Yi-Chen and Chao-Hun 2016]. Automatic reconstruction of building models, depending on the degree of generalisation and visualisation needs at different LODs, is important for the correct operation of various applications and computer programmes. In most solutions, rough models using simplification and aggregation parameters are used on small-scale 3D building models or on 2D projections [Yang et al. 2017].

Until a few years ago, basic information was provided mainly by LiDAR data. The development of image-based measurement techniques encourages the increasing use of aerial photographs and those acquired using UAV platforms. High spatial resolution optical images allow for extraction of 3D points with high geometric resolution, accuracy and reliability. Rapidly developing automatic methods using skewed images in modelling and texturing of image show high potential for detailed reconstruction of building façades. When automating reconstruction processes of very accurate building models, manual correction and correctness control of the completed studies are still



Source: Toschi et al. [2017]

Fig. 2. 3D cartographic reconstruction of an urban environment, image on the left: LOD1 model, image on the right: LOD3 model supplemented with oblique photos

required. The use of, e.g., parameterised types of roof shapes facilitates the efficient generation of correct building models consistent with the assumptions of LOD2. By complementing cartographic studies with oblique images and dense point clouds from air platforms, we get the opportunity to create a full reconstruction of a 3D image of a complex urban environment at LOD3 (Fig. 2) [Toschi et al. 2017].

The purpose of this paper is to determine the scope of work on the optimisation of the point cloud in order to adjust its number and quality to the needs of individual LODs. Optimisation is designed to avoid data redundancy, as well as adjusting the level of cloud unification to maintain the appropriate accuracy level with high performance work on the point cloud. The aim of the study is to select unification parameters (optimisation) to maintain the golden mean between accuracy, number of points in the cloud, level of unification and the appropriate 3D model LoD.

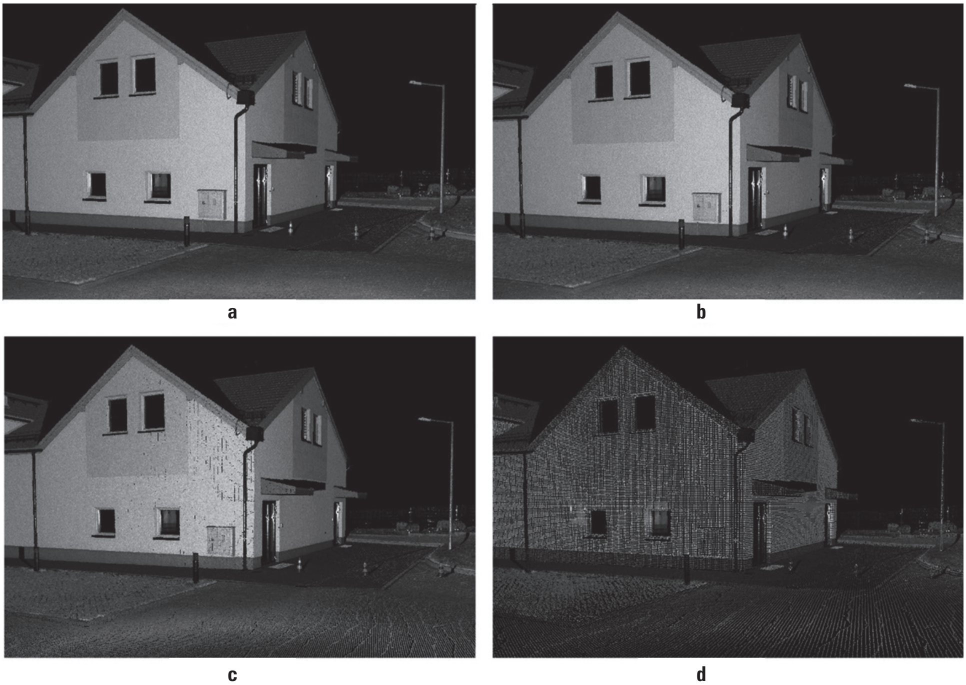
2. Research subject and methodology

The research was carried out on the building complex of the University Centre of Veterinary Medicine UJ–UR: Centre for Experimental and Innovative Medicine of the University of Agriculture in Krakow. The measurement was made using the Leica P40 ScanStation terrestrial laser scanner. For point clouds orientation, individual scans merging and georeference assignment, clearly identifiable terrain points and target plates deployed on the facility were used.

As part of the work on the processing of measurement data from TLS performed from numerous stations, the process of assembling individual clouds into one object was carried out. The database generated in this way was transformed using GCP into a global coordinate system.

The accumulation of a huge amount of information at high intensity of redundant points that do not belong to the scope of the studied area, as well as measurement noise, significantly limits the possibility of using such a database to perform surveying and cartographic works. A similar situation occurs in the case of integration of measurement data from different sources, where the measurement for certain places was performed repeatedly with different measurement tools. In such cases, it is important to carry out the database unification process. Unification in its basic meaning is bringing all objects into one form with unification and merging of different elements. For point clouds, it includes standardising the form of recording, merging individual point clouds into one object, and saving a common base in one space. Unification of the record also results in a better allocation of computer memory resources, which significantly improves the work quality and time.

The first and basic optimisation works included the removal of sections of point clouds not belonging to the studied area. For all cases, points beyond the boundaries of the studied area were removed, which allowed for a reduction of geospatial bases by 30%. The next stage was to merge point clouds into one object. For this purpose, Leica Cyclone software was used, in which it is possible to combine point clouds and save them as a single object. There are two processes available, i.e., cloud integration and unification. While merging consists in combining points from different bases into a common cloud, unification allows not only to combine elements, but also to reduce the number of points. Unification of a point cloud by automatic reduction can take place at the assumed intensity of reduction (low, medium, high, highest) or by the user-defined parameter of the distance between the cloud points. If the clearance parameter is too high and a high level of point reduction is applied, this approach may lead to excessive generalisation of the stored information and deletion of the relevant information. Therefore, it is important to rationally use this tool by selecting the appropriate parameters, depending on the further purpose of the cloud. Properly planned and performed unification significantly reduces the number of points in the cloud, and thus improves work efficiency [Cyclone – User Manual 2017]. Point cloud densities were unified depending on the LOD using optimisation and unification tools to appropriate cloud density levels of 0.001 m, 0.01 m, 0.1 m (Fig. 3).



Source: Author's own study

Fig. 3. Comparison of clouds for: a) original cloud from measurement,unification to the level of: b) 0.001 m; c) 0.01 m; d) 0.1 m

3. Results

LOD1 was made on the basis of an optimised point cloud unified to the level of 0.1 m, which ensured a reliable outline of buildings and large spatial objects, as well as their height and location in the adopted global coordinate system. Figure 4 shows the area elements for LOD1. This study modelled only the range of occurrence of objects in the form of simple three-dimensional solids.

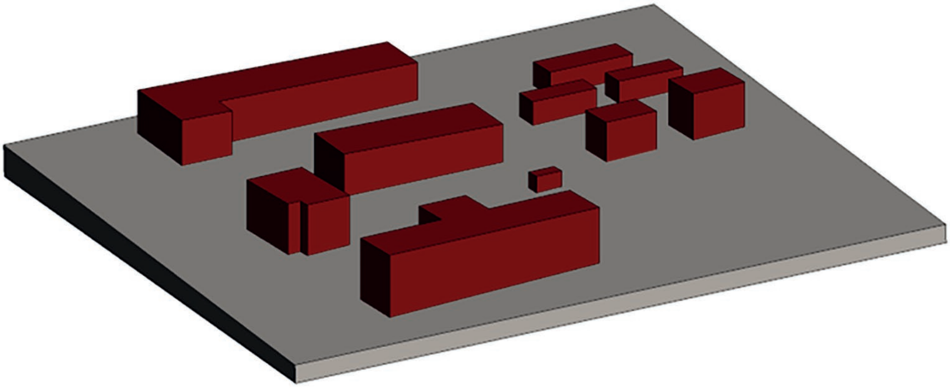


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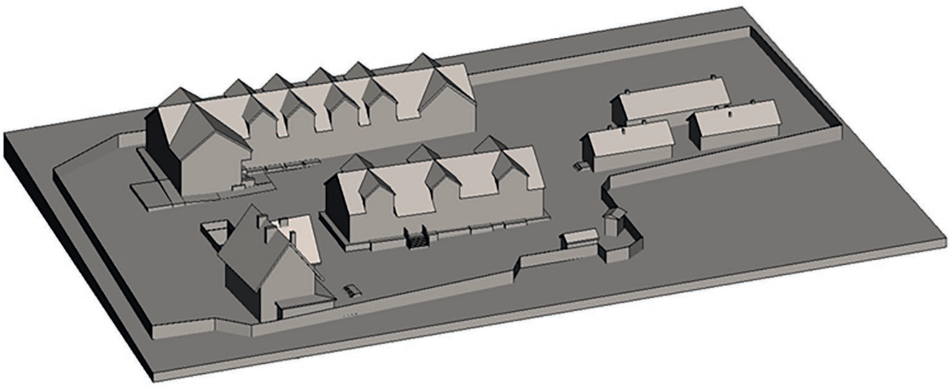
Fig. 4. Object model for LOD1

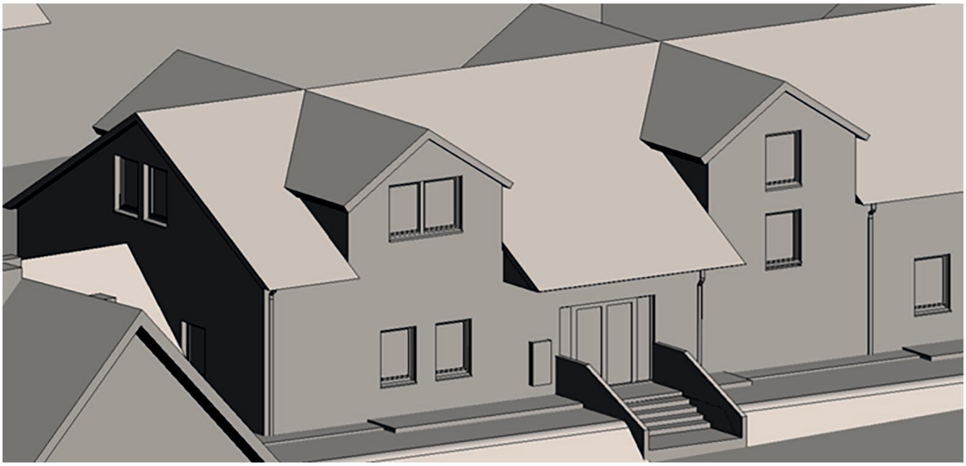
The implementation of 3D models for LOD2 was carried out on the basis of an optimised point cloud up to a resolution of 0.01 m and the use of automatic plane detection and spatial object detection, as well as solid modelling in MicroStation V8i software. Maintaining the level of detail and taking into account the elements and detail required for this level, 3D models of places and buildings were made (Fig. 5).



Source: Author's own study

Fig. 5. Object model for LOD2

Optimised and unified point clouds at the 0.01 and 0.001 levels were used to model the objects for the purposes of maintaining LOD3. Models were made for the high architectural detail required at this level of detail (Fig. 6).



Source: Author's own study

Fig. 6. Section of an object model for LOD3

LOD4 includes a model with a high level of architectural details. Apart from the main body of the building with all structural elements, at this level, detail is important, which is defined as a detailed and faithful reflection of all components. LOD4 is a model with an outline and presentation of even a few centimetre objects, e.g., door handles, small decorations, frames with all recesses and other, even the smallest changes to objects. For such purposes, the original (very dense) or unified to the level of 0.001 m cloud of points from the Terrestrial Laser Scanning is perfect, although also

Source: Author's own study

Fig. 7. Textured section of an area model for LOD4

the so-called edge effect which rounds the edges of objects reflected in a point cloud should be considered. These errors can reach a value of just a few millimetres [Klapa and Mitka 2017]. For the purposes of LOD4 model implementation, neither the ALS point cloud nor the cloud generated on the basis of aerial or UAV images are suitable. Additionally, terrestrial digital photos taken in high resolution, which visually show the smallest construction details accurately and precisely, may be helpful.

Figure 7 shows a section of the model made for LOD4, with all the elements and components, presented in the form of additional texturing of the model using digital photos.

4. Summary and discussion

Each LOD has a different required accuracy, and typically a 3D model is made by integrating multiple spatial data sources. LiDAR data is mainly used for LOD0, LOD1, LOD2 models. On the other hand, for the purposes of generating LOD3 and LOD4, more precise geospatial data sources are required, e.g., photogrammetric terrestrial studies or TLS. Data derived from TLS can be used to generate any LOD due to the high level of accuracy of the generated measurement data (Fig. 2). The problem is the redundancy of information (points) for generating lower LODs, therefore it is recommended to optimise and unify the number of cloud points in order to facilitate and accelerate 3D modelling processes. Regardless of the software and modelling techniques used, 3D cartographic studies made on the basis of the TLS cloud are characterised by very high accuracy, precision and detail of information [Akmalia et al. 2014].

In most cases of geospatial data analysis, the set should firstly be subjected to a specific methodology for processing the cloud itself. It usually consists of the following elements: obtaining data from laser scanning, pre-processing (including filtration and elimination of measurement noise) and principal processing. The problems concern mainly the time needed to process a huge number of observations stored in the cloud [Błaszczak-Bąk et al. 2011]. Although the technical, performance and graphic elements of computers improve constantly, the number and size of the generated point clouds are growing rapidly [Remondino and El-Hakim 2006)]. The solution to these problems may be the use of tools for optimising the stages of acquiring and processing geospatial data, as well as techniques for automating their processing and the subsequent generation of ready-made studies.

5. Conclusions

In the case of TLS point clouds, information redundancy, as well as uneven distribution of measurement points in the studied area are a frequent phenomenon. The scanning resolution is a linear parameter which increases with the decrease of distance between a target point from a scanner. The unification of points allows to minimise this problem, but it is not a solution due to the uneven distribution of points in the cloud.

Optimisation allows the removal of excess information and minimise the size of databases, thus improving the efficiency and effectiveness of work with high-quality results.

At the design level, optimisation of data recording and the scope of the work carried out through the appropriate selection of techniques and measurement methods, as well as the number of measurement stations, can significantly improve the quality of the obtained data while limiting redundant information. Thanks to the optimisation of these processes, a database in the form of a point cloud is obtained, containing the minimum possible number of excess points and measurement noise. The unification of point clouds by combining individual clouds from individual stations or measurement methods may prove helpful in this process. During this process, point cloud thinning algorithms that operate in a random or object-oriented way by parameterising the removal of points with a specific density, resolution or removing outliers can be used. A cloud generated in this way allows for faster and more efficient processing.

Data derived from TLS is a reliable, accurate and precise source of data for 3D models made for LODs 0–4. Data from TLS is ideally suited for traditional 3D models as well as for studies made in BIM technology (assuming that when generating BIM models, information that will enrich the model with data on architectural, structural and construction aspects are available).

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Dr inż. Przemysław Klapa
University of Agriculture in Krakow
Department of Land Surveying
ul. Balicka 253a, 30-198 Kraków
e-mail: przemyslaw.klapa@urk.edu.pl
ORCID: 0000-0003-1964-7667