

Article

Optimising Land Consolidation by Implementing UAV Technology

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Abstract: The increase in population and the growing demand for food that accompanies it drive the need to achieve sustainable agriculture. Technological progress and methodological novelties provide tools that may support the processes of improving the spatial structure of agricultural lands, as well as their management. One of the examples may be the application of photogrammetric and remote-sensing products to facilitate land consolidation. In the following paper, the systematised procedure of conduct is investigated to determine the moments at which these products could be adopted. In identifying the possibilities for implementing the abovementioned tools, we analyse the legal regulations governing the process and the literature on the subject, as well as some practical examples encountered in surveying practice. In addition, the usefulness of such geospatial products is tested on data gathered during an exemplary UAV flight. We then investigate the issues with implementing the abovementioned tools and assess their advantages and disadvantages in smart agriculture. The research proves that reliable elaboration of the consolidation project concept is critical for its correct realisation, while modern measurement methods providing efficient, up-to-date, factual data facilitate the procedures and support rational decision making. Moreover, they enable us to ensure the necessary accuracy of the data for the scope of the land use and avoid analysing a compilation of several cartographic materials concerning the surveyed object. In the present study, the RMSE_{xyz} mean square error at the control points for the orthomosaic, generated using the Matrice 210 RTK v2 professional flying platform, is 5.6 cm, while for the orthomosaic created from images from the amateur drone Mavic 2 Pro RMSE_{xyz}, it is 9.2 cm. The results obtained also indicate the usefulness of low-budget drones during the land consolidation process.

Keywords: consolidation; agricultural land use; UAV



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1. Introduction

According to the available climate scenarios, the demand for food will constantly grow on a global scale during the coming 3–4 decades due to our growing population and increases in the gross domestic product (GDP) of individual countries [1]. Atzberger (2013) emphasises that by mid-century, agriculture will have to strongly increase its production to provide food for the predicted nine billion inhabitants of Earth. Yet, in practice, a number of issues and factors negatively impacting the efficiency of agricultural production have been observed. To begin with, it is affected by the fragmentation of land and inadequate distribution of plots [2]. Moreover, changes in land use are also some of the factors causing a loss of biological diversity. According to the European Commission [3], changes in land cover, including growing urbanisation, caused an increase in expenditure over the past 15 years of more than EUR 25 trillion for the economy and agriculture as a result of soil degradation.

It is necessary to strive for the improvement of agricultural production efficiency and its maintenance conditions. Worldwide, new strategies for land protection to prevent

excessive exploitation and safeguarding of ecosystems have been observed, especially in the countries of the European Union [4], where tasks that support the growth of agriculture are fulfilled by the Common Agricultural Policy (CAP), co-financing production, as well as economic, social, and environmental processes [5]. Poland is one of the biggest beneficiaries of EU-supported projects oriented toward developing rural areas, where land consolidation works have a special position [6,7]. According to MRiRW [5], in 2018, the average area of agricultural land for a single farm equalled 11.3 ha, which places Poland among the EU states with the most fragmented farm structures. As is emphasised in the literature, among others in the study by Stańczuk-Gałwiaczek [8], a large percentage of rural areas in Poland require deep structural changes. The author indicates that such lands, situated particularly in southern and south-eastern Poland, are characterised by an excessive fragmentation (Figure 1) of land owned by individual farmers, a disadvantageous expanse of lands, and poor conditions for technical and institutional infrastructures (or a lack thereof). To reach the goal of sustainable and effective agriculture, it seems we must conduct studies targeted at improving the efficiency of agriculture and facilitating, for state authorities and farmers, decision making in the scope of production. The Food and Agriculture Organisation (FAO) [1] indicates that making prompt decisions and performing ongoing monitoring of crops are key to the improvement of agricultural statistics. As stressed by Feltynowski et al. (2020) and Shakhathreh et al. (2019) [9,10], the number of projects concerning the maintenance of sustainable development, including in rural areas, has increased. In the context of deepening urbanisation and protection of green areas, these have impacted health and quality of life. One of the main economic tools in Poland, supporting the European Agricultural Policy, is activities implemented in the scope of the rural development programme (RDP) [11,12]. The authors emphasise that the implementation of the RDP offers us a chance to improve the spatial structure of rural areas. The processes of modernisation and specialisation of farms are increasingly noticeable, particularly in areas with good production conditions, while the liquidation of unprofitable small farms is also becoming common [13]. Moreover, the sustainable development idea is reflected in legal acts and standards of different levels, and it also has practical implications at the local level, where development strategies are formed and implemented. Strategic documents are then the basis for implementing development plans that include, among others, agricultural engineering and approaches to overcoming land consolidation issues.

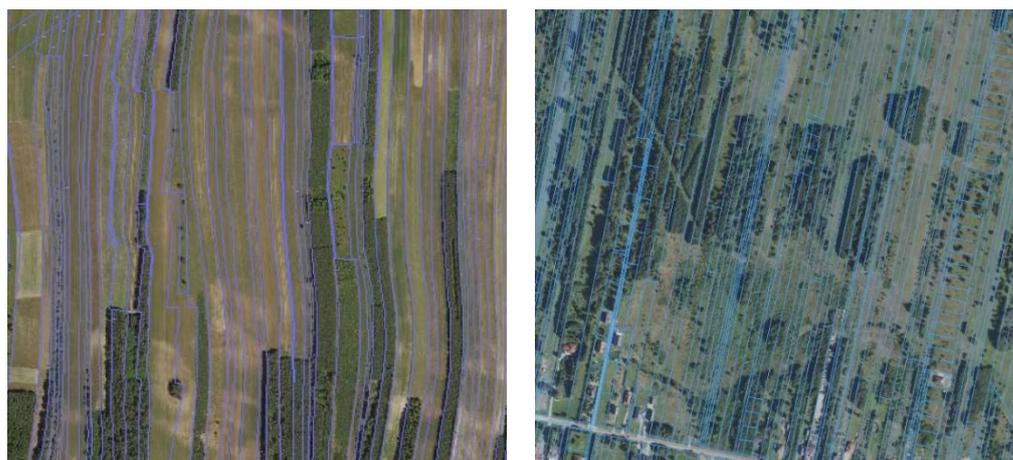


Figure 1. Examples of an area characterised by the excessive fragmentation of land owned by individual farmers (sources: www.jedrzejow.geoportal2.pl, www.geoportal.gov.pl; accessed on 18 April 2021).

Land consolidation constitutes a substantial tool in the scope of spatial management, with the potential to improve agricultural production efficiency by improving the spatial structure of agricultural lands on farms. Implementing land consolidation works in agri-

cultural areas improves the expanse of lands and corrects their structure, thus influencing the profitability of agricultural producers. This requires the regulation of the legal status of properties, the elimination of usufruct, and the development of cadastral documentation and its integration with the system of property registers. According to Vitikainen [14], it is also considered as a tool for cutting down agricultural production in a controlled manner and for increasing productivity by lowering the costs of production.

According to Sobolewska-Mikulska [15], several economic results may be listed, which may be achieved as a result of land consolidation:

- The reduced number of cadastral parcels, which results in the more rational expanse of lands with respect to settlements;
- The increased average size of a cadastral parcel;
- The reduced lengths of existing access roads to parcels, which results in lower costs and a shorter time of the transport and implementation of agricultural works;
- The increased profitability of the agricultural production per hectare;
- Accessibility of each cadastral parcel to a public road after land consolidation;
- A reduced number of irregular parcels;
- Elimination of unnecessary roads, delineation, and construction of a functional system of agricultural roads;
- Elimination of unnecessary balks and recultivation of those new fragments of parcels;
- Adaptation of new parcel borders to the system of agricultural roads, the system of water meliorations, as well as to the terrain relief;
- Arrangements of parcels planned as building sites in local spatial development plans, with the exclusion of infrastructural objectives.

The values of farms are also increased. Socially, these results are transferred to improvements of the quality of life, in its wide sense. As Zhang and Zhao [16] observed, land consolidation processes have a major impact on the relations of the owners of land covered by equipment (agricultural works). According to them, land consolidation should reduce possible disputes concerning land ownership as a result of the decrease in the number of mosaic plots. According to Noga et al. [17], in spite of the considerable amount of funds obtained for financing land consolidation, and particularly for post-consolidation management, it did not bring the intended effect, especially on the area with a very faulty plot patchwork. Due to its numerous drawbacks in the period of 1984–2016, the consolidated land area in Poland was only 677.474 ha [18]. The procedure is time consuming and laborious. Difficulties upon obtaining the output—materials presenting the factual status prior to consolidation and in allocation of reliable equivalents—are a disadvantage.

The tools that would facilitate the procedure of consolidation, in particular when it comes to the stage of obtaining data concerning the factual stage in soil and subsequently the ongoing land agricultural production, may be photogrammetric and remote sensing products.

Photogrammetric and remote sensing products also fit perfectly into other scopes of property management in rural areas as well as in the topic of agricultural production efficiency correctness, including, among others, smart agriculture. Agriculture, while striving for interoperability, combines the advantages of applying geographic information systems, methods of satellite navigation, and archiving as well as data management, using spatial database systems. The necessity to combine several systems into one is determined by the change in patterns and spatial relations on areas used for agricultural production, which are rapidly modified in the growing season [1]. Thanks to the potential of the GIS analytical capacity, the integration of many types of spatial data and searching for the parameters that will remove the negative impact on the environment and directly influence the plantations become advisable [4].

The technologies applied in smart agriculture may be divided into ground technologies such as automated irrigation systems and aerial such as unmanned aerial vehicles (UAV) or satellite multispectral imaging. What is more, the European Commission [3], while striving to achieve effective use of resources and a low-carbon economy, promotes the use of

remote-sensing data for the monitoring of plots of land in the context of direct payments to farmers. Remote sensing may in a significant manner contribute to ensuring the monitoring in short time intervals and obtain a precise image of the agricultural sectors on small and large scales of the region worldwide. Applying the remote sensing technology—satellite images or photographs with low bank photos, obtained by means of a UAV—enables facing the challenges related to optimising the agricultural structure management and abiotic and biotic stressors. In other words, remote sensing technologies assist in making more accurate—from the perspective of efficiency—decisions such as crop nurturing, proper irrigation, or reacting quickly to diseases in plants [1].

As specified, the solution to improving agrarian conditions and the efficiency of agricultural production is, first of all, the improvement of the land's spatial structure through the conduct of the land consolidation procedure, using modern measurement tools in the procedure and subsequently their implementation in the process of ongoing management and agricultural production. The goal of this publication is to identify the possibilities of implementing photogrammetric and remote sensing products in the land consolidation procedure in order to improve the land's efficiency. For this purpose, the following research was conducted:

1. An analysis of the legal regulations governing the procedure, the literature on the subject of consolidation, photogrammetric and remote sensing products, the advantages and disadvantages of the process and of the application of the abovementioned technologies, as well as the problems encountered that can be solved by means of modern geospatial tools.
2. Elaboration of the procedure of conduct upon improving the spatial structure by way of consolidation with a specification of the moments of implementing photogrammetric and remote sensing products.
3. Analysis of the usefulness of geospatial products gathered during an experimental UAV flight in collecting data for the needs of the land consolidation procedure and at the stage of current management and agricultural production.

2. Materials and Methods

2.1. Study Area

The analyses in question were carried out on examples originating from the area of the Świętokrzyskie voivodeship. As stressed by MRiRW [5], the quality of agricultural areas in Poland is lower than the average European Union quality and the adverse soil conditions—a large share of weak and acidified soils—decrease their agricultural usefulness. Furthermore, soils in Poland are characterised by their lower-than-average European Union soil productivity, which is a consequence of worse climate conditions. Data gathered by the GUS [19] indicate that agricultural areas occupy a total surface of 467,000 ha (64.7%). According to GUS [20], farms with a total area ranging between 5.00–9.99 ha prevail here.

Despite a decreased employment level in agriculture and the changing functional structure of rural areas, in Poland, the area of agricultural land still amounts to 14.7 million ha (as per the status in 2018; for comparison, in 1980 this number was 18.8 million ha; in 1995, 17.9 million ha; in 2005, 15.9 million ha; in 2010, 14.9 million ha). In 2017, Poland occupied the 61st place worldwide in terms of the area of agricultural land and the 5th place among the countries of the European Union [20].

The selected object of the study was areas/farms characterised by fairly high land fragmentation, with the occurrence of irregular-shaped and relatively narrow plots, requiring improvements in their spatial structure—situated in Belno (the Zagnańsk commune)—a village located in the northern part of the district of Kielce in the Świętokrzyskie Province (Figure 2). It is widely known that especially farms located in the southern and south-eastern parts of Poland require modification with regard to their size or to the shape of their area.

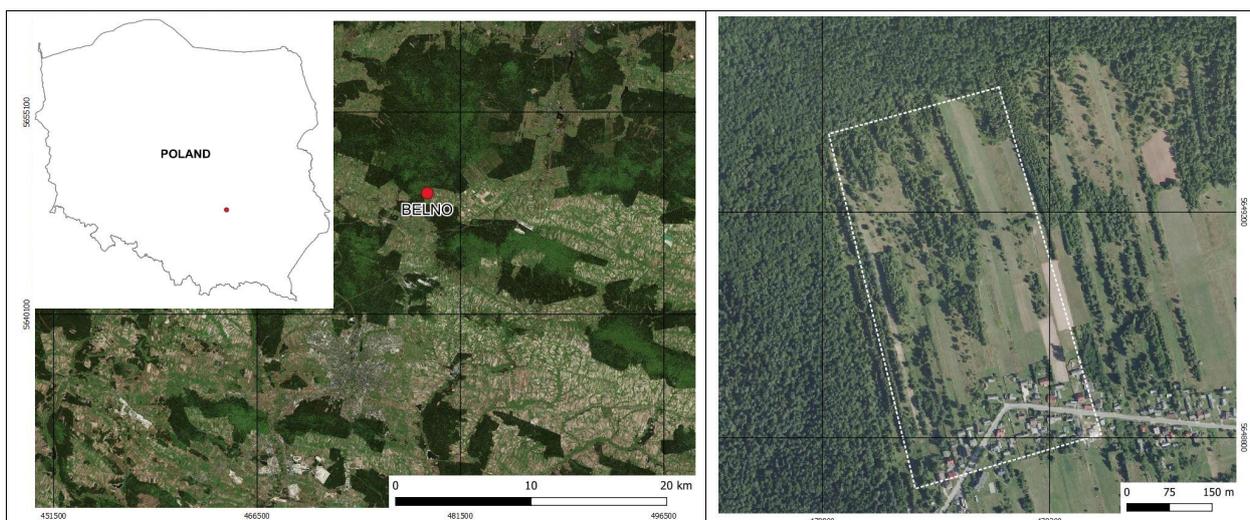


Figure 2. Location of the study area. UTM coordinates, zone 34N (WGS84) (source: own work on the basis of data from www.geoportal.gov.pl, accessed on 11 February 2022).

Belno lies in the Świętokrzyskie Mountains, on the border with the Świętokrzyska Primeval Forest to the north. The district is situated in the middle of Little Poland Upland and is characterised by large differences in the height and morphology of the land. More than half of the Zagnańsk commune area, approximately 58.2%, is covered with forests (the European average is 32%). The terrain is varied, with high ground delevellings. The climate of the Świętokrzyskie Mountains differs significantly from the surrounding regions. The average annual temperature is 6–7 °C, whereas the average rainfall varies between 650 and 900 mm per year. For the purposes of analyses, the area within the boundaries with significant ground differences, steep slopes, and low soil valuation class was selected. In the analysed case, large areas situated north of the farms had not been cultivated for many years. The study area was greater than 0.25 km². The terrain is partly overgrown with trees such as birches and self-seeders. There are wetlands in some places. The width of the plots ranges from 5.5 to 22 m, their length reaches over 600 m, whereas the altitudes reach 18 m. Meanwhile, the area of the parcel ranges from 0.3500 ha to 1.3600 ha. The area has poor soils with very uncertain and low crop yields. As of 31 December 2020, there were 564 inhabitants in the village.

2.2. Methodology

From the perspective of the agricultural development, the positive aspects of the performed land consolidation works are clearly visible; they influence not only the effectiveness of farming but also the individual profitability of agricultural producers, as well as the effectiveness and conditions of work. Land consolidation is a multi-stage operation, and its correct conduct determines the availability of current and reliable register data, also including those concerning the factual state of the land—the state of the ownership of plots, their boundaries, contours, area, etc. In the first part of the research, the authors analysed the procedure of land consolidation as a tool for improving the spatial structure of lands. Nine key stages of proceeding were specified (Figure 3).

A difficulty often encountered amid the process of the consolidation of land and one pertaining to conditions ensuring the equivalence of the newly assigned plots of land is obtaining reliable data, compliant with the factual state on site, allowing one to reasonably prepare the field inspections and to fairly carry out the stage of land estimation. Ensuring the validity of input, cadastral data already at the stage of preparing the object before consolidation provides a guarantee of fulfilling the obligation in the scope of assigning a given participant to the land consolidation with an equal estimated value in exchange for the land possessed thus far. It is important to ensure that the reshaped property corresponds

to the former one as for the land use, quality, and other conditions. A reliable estimation of the value of land subjected to consolidation is undoubtedly a difficult and socially sensitive stage due to the fact that it concerns the personal rights and property of the participants. Hence, a detailed and thorough analysis of individual estimated contours on the consolidation area is purposeful. In practice, the consolidation project team undertakes actions of verification and subsequently achieves compliance of the registered state with the factual one. In the case of larger objects, and such were the subject of consolidation, it is extremely time consuming, and the burden of time pressure makes the contractor of works pursue more efficient solutions, which speaks in favour of the use of modern measurement and analytical methods.

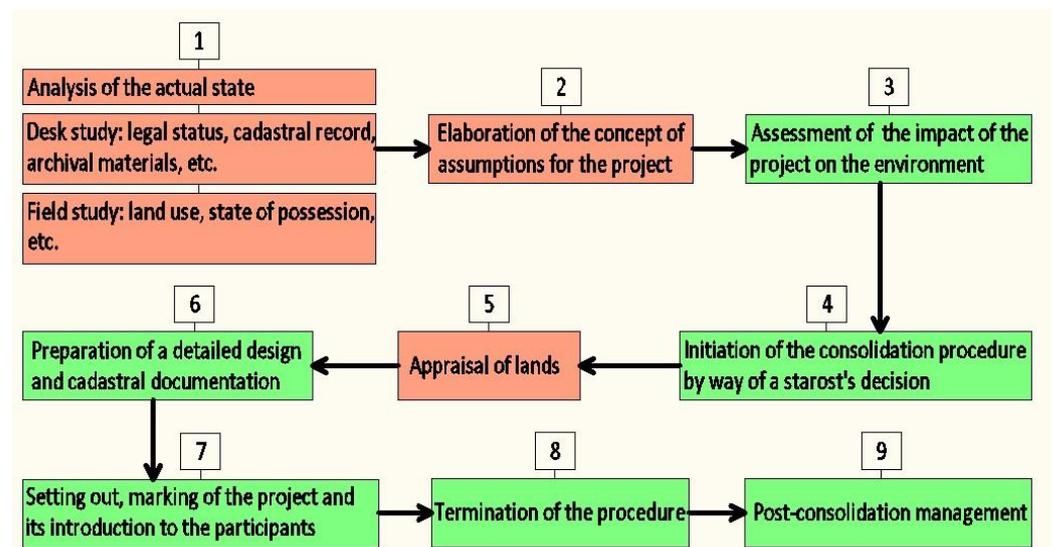


Figure 3. Stages of the procedure of actions upon conducting land consolidation.

For the needs of the next step of the research, the systematised procedure was investigated in order to indicate moments in which there was a possibility of facilitating the algorithm on the basis of photogrammetric and remote sensing methods. To identify the possibilities of implementing the above tools, an analysis of the legal regulations governing the process was carried out as well as the literature on the subject, and some practical examples encountered in the surveying practice were analysed. For certain selected stages, recommended sources of data for further analyses were selected (Figure 4).

Supporting the process of consolidation via modern photogrammetric and remote sensing technologies was very helpful in parts 1, 2, and 7 of the scheme (Figure 3). The choice of technology in the first part allowed for the conduct, in a relatively short period of time, of a multi-criteria and multi-faceted verification and data update, without which correct elaboration of the project of consolidation would not have been possible. These tools enable an illustrative presentation of the results and of alternative solutions in stages 2 and 7. The methodology of proceeding upon applying the above-stated tools was elaborated for the first stage of the procedure (part 1): analysis of the actual state of properties. That phase of the process consisted of, among others, preparation of the map of the field inspection for the purpose of analysis of the factual state on the ground—field studies. This action is needed due to the necessary conduct of input updates with respect to the object, including in particular data on land use, plantings, and forests, etc. The application of photogrammetric and remote sensing methods enables an effective and fast capture of data. In order to prevent potential complaints of project solutions, for instance, with respect to the hindered access to some parts of the property, the use of the numerical terrain model, aerial photographs, and low-altitude satellite images or radar images is also advisable upon carrying out studies and analyses of the factual state.

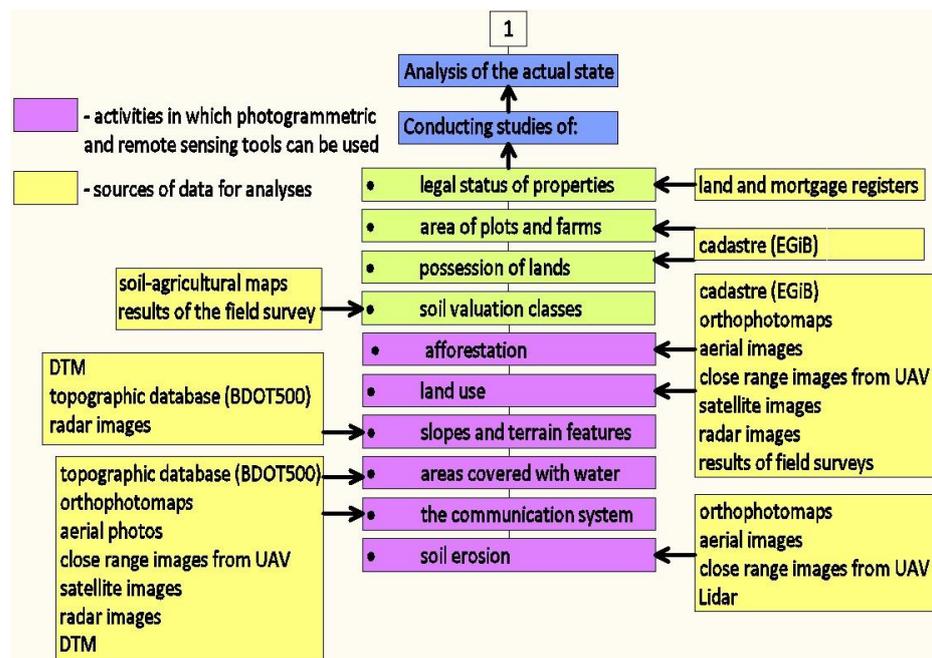


Figure 4. Methodology for the first part of the procedure—analysis of the actual state of properties.

Then, for the purpose of verification of the utility of the methodology for proper and efficient application of the abovementioned technologies, field inspection was carried out on the research area with an objective of verifying the validity of implementing photogrammetric and remote sensing products in the above-stated procedure and the quality of the obtained data. Attention was paid to the potential of UAV technology compared to the possibilities of traditional measurement methods, as well as to the derived products in the form of a digital terrain model (DTM). For the needs of the research, two photogrammetric flights were performed over a representative test site. The conducted research focused on the use of various UAV platforms—(a) the professional Matrice 210 RTK v2 platform dedicated to surveying purposes and (b) the Mavic 2 Pro vessel intended for people dealing with aerial photography—to generate cartometric products in the form of orthomosaic and numerical terrain models (DTM) and land cover (DSM). Before starting the field work, activities were planned to optimise the work and obtain the best results during the experiments. The values of longitudinal and transverse coverage of the photos obtained by both the unmanned aerial vehicles amounted to, respectively, 70%. The lenses used had different characteristics; therefore, in both cases, 2 cm/pix was assumed as the designed value of the terrain pixel, and to achieve this, the flights were made at different relative heights.

In order to minimise the impact of large terrain differences in the analysed area, the average terrain height was estimated before the flight and the starting point for conducted photogrammetric missions were selected at that height. Before the flights, the activity of the air zones above the testing site was checked, and the PANSAs services were informed about the conducted aviation activities, using a dedicated IT system in force in Poland. In the area covered by the measurement, 12 ground control points in the form of checkerboard discs and Maltese crosses were stabilised in order to improve the accuracy of the process of aerotriangulation of the photo blocks and to later determine the accuracy of the resulting products in the form of two orthomosaics and terrain models. Ground control points were surveyed using the GNSS RTK technique in 45 epochs, in two independent repetitions, in reference to the reference stations of the NETpro TPI network. During each of the photogrammetric flights, over 140 photos were obtained using both the Matrice 210 RTK v2 platforms and the Mavic 2 Pro ship. Their development was proceeded in the Agisoft Metashape software.

3. Results

3.1. Improving the Efficiency of the Process of Land Consolidation through the Introduction to the Procedure of Photogrammetric and Remote Sensing Products

In the process of improving the spatial structure by way of land consolidation, there are actions, including inspections of the actual state, elaboration of the concept, and appraisal of lands, that can be performed on the basis of the recommended geospatial tools. Remote sensing products are helpful during the initial, qualitative verification of changes in land areas, including planting and forest successions, land use, slopes and reliefs, the water relationship, communication network, and soil erosion (Figure 4, marked with violet). The possibility of improving the efficiency of the process of land consolidation through the introduction of photogrammetric and remote sensing products depends on their quality. As mentioned above, remote sensing data may be used in the initial assessment of changes of land cover; however, they may not be helpful in detail verification of the scope of each land use. Generally, the methodology of processing satellite images depends on the goal of the conducted tests and the type of image data (optic or radar). Three directions of carrying out tests with the use of multi-faceted images may be distinguished, that is, visual, qualitative, and quantitative. Visual analyses are the simplest and, at the same time, the most limited approach to carrying out field studies. They allow for the interpretation of the phenomena, covering with their reach larger and more general classes of terrain coverage. The interpretation is carried out on the basis of the analyses of RGB colour compositions or FCC false colour compositions, formed on the basis of spectral channels. The result of applying visual analyses is the scope of the occurring changes or a contour outline of the terrain coverage class. The quality approach to remote sensing is often related to the classification of the content of satellite images on the basis of the calculated signatures of the ordered classes. The classification of the area may also be conducted on the basis of the results of the carried out quantitative analyses and thresholding of the obtained values.

Meanwhile, photogrammetric tools allow for remote registration, making it possible to analyse even hard-to-reach areas and providing quick detection. High-resolution orthophoto maps allow one to precisely delineate the contours of land use, irrespective of the configuration of the terrain. A major advantage is the possibility of effective acquisition of data on land use for relatively large measurement areas, so that they are precious in the case of objects covered by the procedure of consolidation. They are particularly efficient upon interpreting the scope of land cover subjected to dynamic changes. Figure 5 shows the exemplary area for which analyses of archival orthophoto maps were performed to present differences in afforestation that took place over the years in comparison to the contours inscribed in cadastre. The cadastral data—the numerical contour of land uses within the parcel no. 889—differ from the actual state on the ground (R = arable land, Ls = forest, V, VI = valuation classes). The registration of such dynamically changing land cover as afforestation can easily be monitored with the photogrammetric tools, which gives it an advantage over the traditional methods of surveys.

For the purposes of the following paper, the usability of the UAV technology was verified on the basis of the analyses of the actual state on the ground. Two different flying platforms were used for the photogrammetric flights. Almost-vertical images were acquired with the Matrice 210 RTK v2 drone, together with a stream of RTK_RTCM23 corrections (TPI NETpro network) used to precisely determine the linear parameters of the external orientation of each image. The Mavic 2 Pro drone acquired 80° oblique images. The resulting orthomosaics with marked GCP points and check points from the photogrammetric flight of the Matrice 210 RTK v2 (Figure 6a) and Mavic 2 Pro (Figure 6b) are presented in Figure 6.



Figure 5. Orthophoto maps of the analysed area, prepared in 2005, 2010, and 2021, proving dynamic changes in land use, especially in afforestation (source: <https://www.geoportal.gov.pl/>; accessed on 29 January 2022).

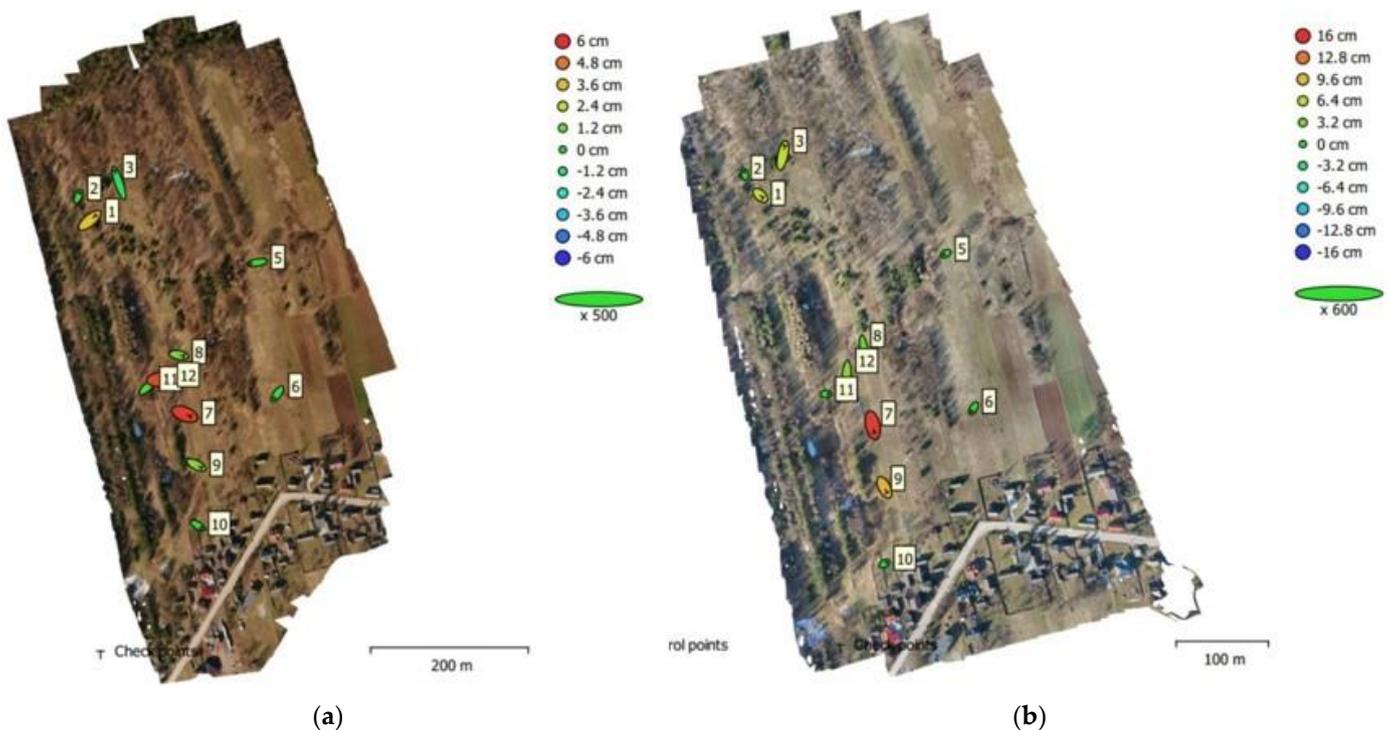


Figure 6. The result orthomosaics from the photogrammetric flights of (a) the Matrice 210 RTK v2 and (b) Mavic 2 Pro. The Z-coordinate error is based on the colour of the presented ellipses. The X- and Y-coordinate errors are based on the size of the ellipses.

In order to obtain reliable comparisons of the resulting products, the same GCP were selected for the aerotriangulation of the blocks of the photos for both photogrammetric flights. In the case of orthomosaic (a), a generalised $RMSE_{XYZ}$ for GCP of 2.7 cm was

obtained. For the second, orthomosaic (b), the $RMSE_{XYZ}$ error for the GCP was smaller and amounted to 0.9 cm. The accuracy analysis carried out at the checkpoints showed that the $RMSE_{XY}$ mean square error for orthomosaic (a) was 4.2 cm, and for orthomosaic (b), at the same photo points, it was 3.3 cm. Both results were considered as very satisfactory for further experimental work in the XY plane. For the $RMSE_Z$, greater errors were obtained at the control points, amounting to 3.7 cm (a) and 8.6 cm (b), respectively. Taking into account the spatially diversified area of the test site (height differences up to 70 m) and the problems with the even distribution of ground control points (densely bushy areas, tall trees determining significant radial shifts in the photos, no field details that could be used as a natural network in the analysed area), the obtained results were considered sufficient for further work.

The conducted experiments confirmed the further usefulness of the UAV technology in updating the actual state of possession. Below (Figure 7), a fragment of the orthophoto map showing the state of possession on the land, including fences (a–c), defining the scope of the built-up agricultural land (Br), is presented. In the illustrations, the fences were additionally marked with the obligatory symbolism. On the other hand, on the fragments of the orthophoto map indicated in Figure 7d–f, informal access roads can be seen. Information on their route may be useful when designing roads.

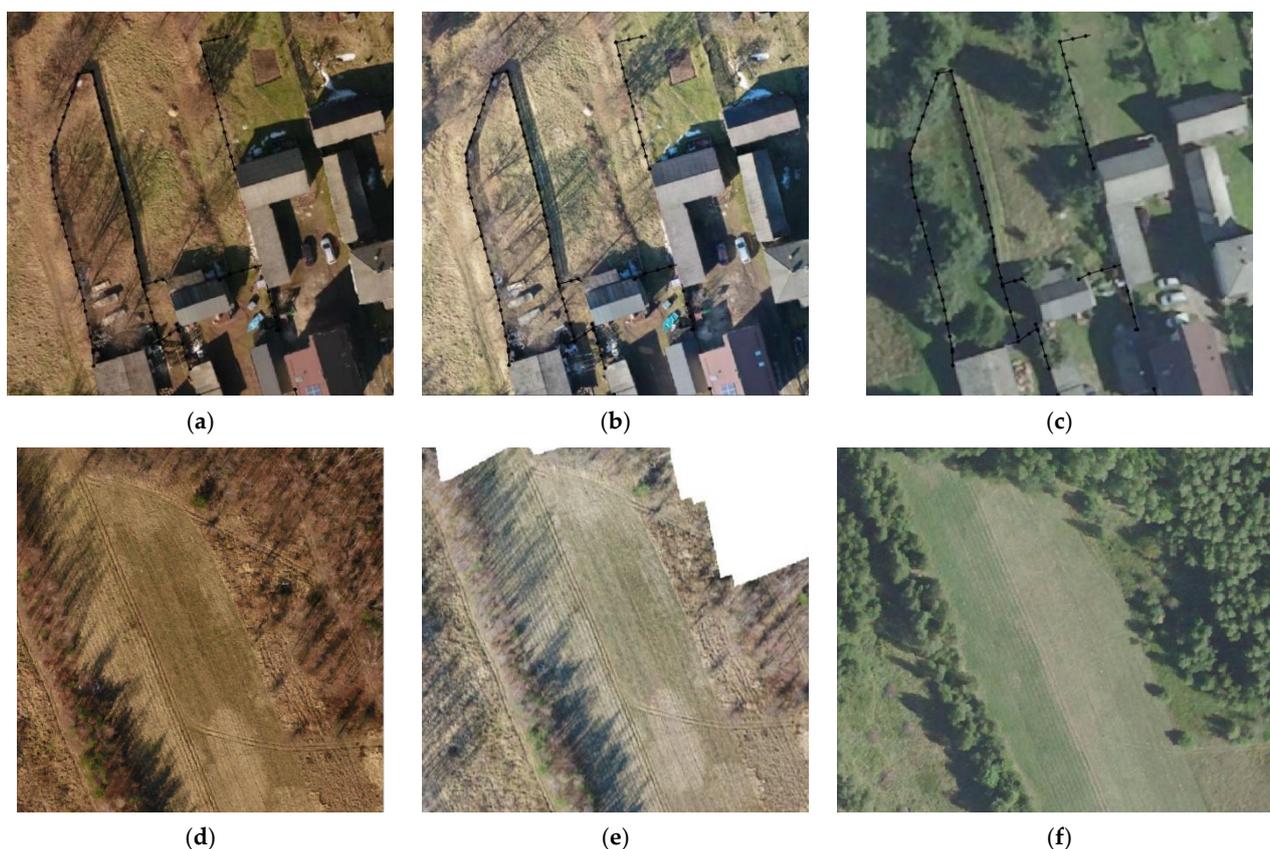


Figure 7. Fragment of an orthophoto map showing the state of possession on the land, including fences (a–c), defining the scope of built-up agricultural land, as well as presenting informal access roads (d–f). The orthophoto maps were obtained from different flying platforms: (a,d)—Matrice; (b,e)—Mavic (source: own research); (c,f)—on the basis of aerial photographs (source: <https://www.geoportal.gov.pl/>, accessed on 2 March 2021).

A valuable help is also the possibility of obtaining digital terrain models (DTM) (Figure 8), which are one of the products derived from the dense point cloud generated in the process of processing photos obtained from UAVs. A DTM is a raster representation of the height of points near the ground and objects protruding above the ground. The

knowledge of the elevation may be useful at the stage of creating a land consolidation project, in particular at the stage of designing the access of new registration plots to a public road. The figure below shows two digital terrain models generated on the basis of the photogrammetric flights carried out for the purposes of the following publication and the DTM available for the analysed area on the government website www.geoportal.gov.pl, accessed on 11 February 2022, obtained on the basis of data from the aerial laser scanning (ALS) in 2014.

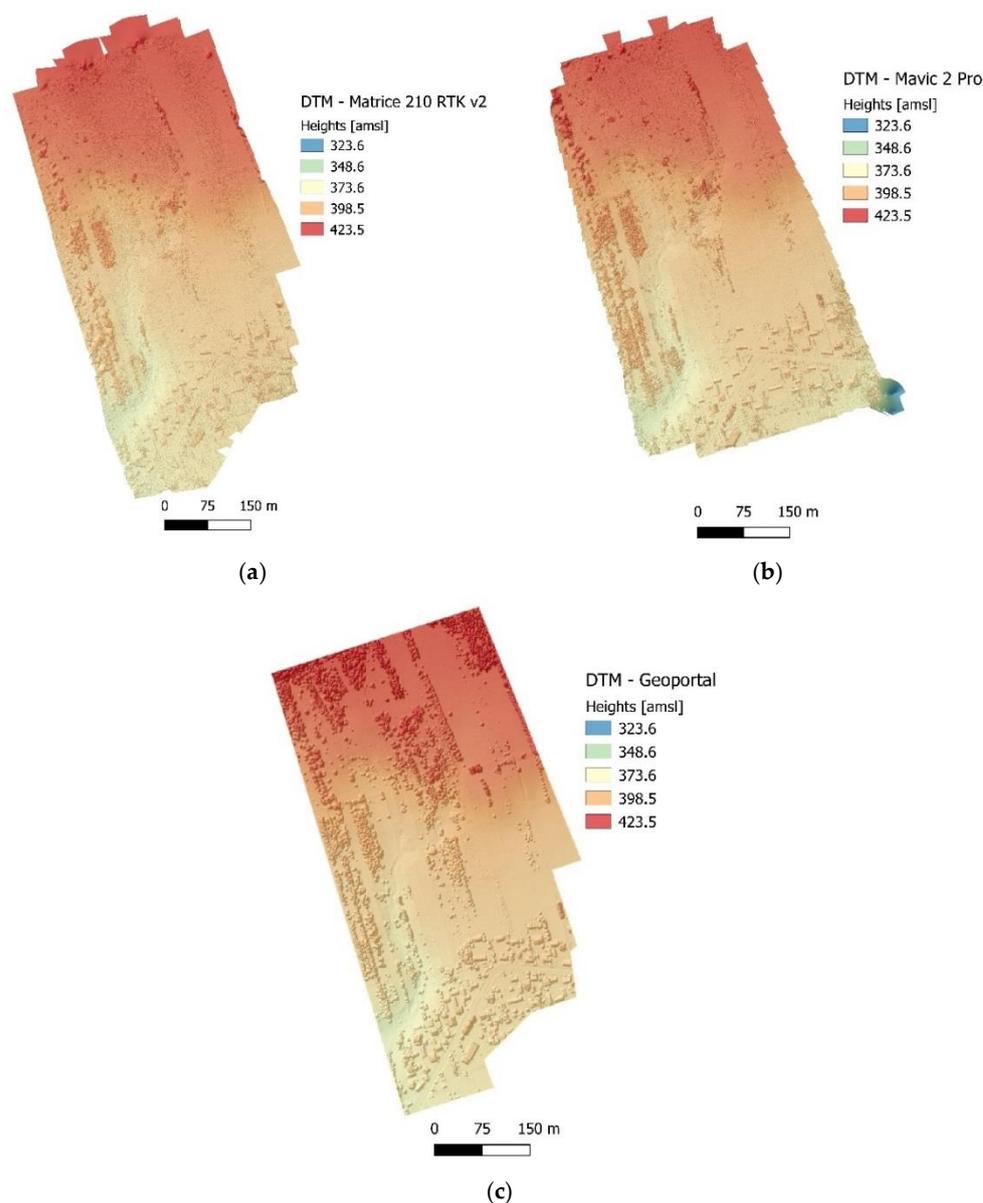


Figure 8. Digital terrain models (DTM) prepared from the photogrammetric flights of: (a) the Matrice 210 RTK v2, (b) Mavic 2 Pro, and (c) the DTM available on the government website www.geoportal.gov.pl, accessed on 11 February 2022.

The comparison of the abovementioned numerical terrain models was made on the basis of the control points measured in the field with the GNSS technology. The results of the analysis are presented in the diagram (Figure 9). The differences in height with relation to the reference measurement are within the tolerance limits.

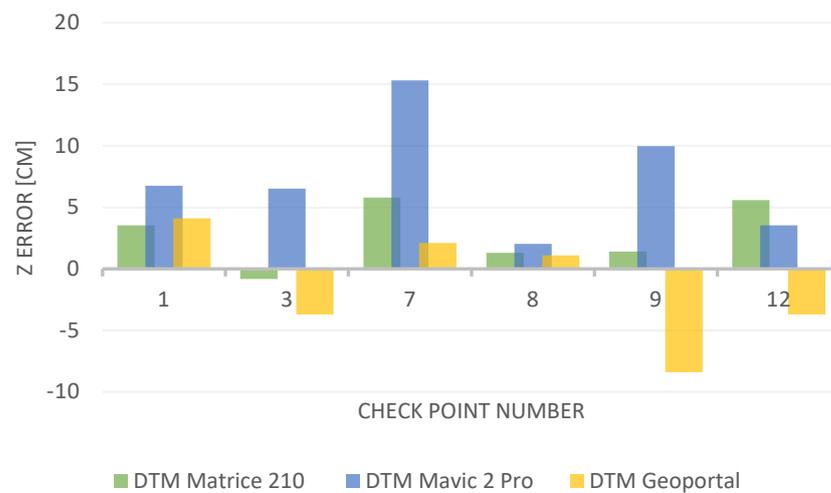


Figure 9. The differences in height of details measured with UAV technology with relation to the reference measurement.

Undoubtedly, the results of the situational measurement, with the use of a UAV, of the details such as buildings are not satisfactory enough. Below (Figure 10), a comparison of the results of measurements on the basis of the GNSS RTK method (green) and a photogrammetric forward section (red) against a background of an orthophoto map from the national geoportal (Figure 10a) and the current orthophoto map prepared on the basis of UAV images (Figure 10b) is presented. The visible differences show the unreliability of the data concerning the misconstrued course of the contours of buildings.



Figure 10. The results of measurements on the basis of the GNSS RTK method (green) and a photogrammetric forward section (red) against a background of an orthophoto map from the national geoportal (a) and prepared on the basis of UAV images (b).

3.2. The Scheme of Use of Photogrammetric and Remote Sensing Products for the Purposes of Improving Agricultural Production and Their Use in Smart Farming

As specified, the next step in the improvement of the efficiency of agricultural production with modern measurement tools is their implementation in the process of ongoing management and agricultural production. Combining the previously specified technologies with agricultural practices allows for the development of smart (precise) farming and increases the competitiveness of agricultural farms worldwide [21]. Applying many technologies or striving to integrate many solutions that require crop management, improving their efficiency and limiting the negative impact of some environmental factors, is of importance when it comes to precise farming [22]. The figure below (Figure 11) presents the scheme of applications of photogrammetry and remote sensing in individual aspects of agricultural production.

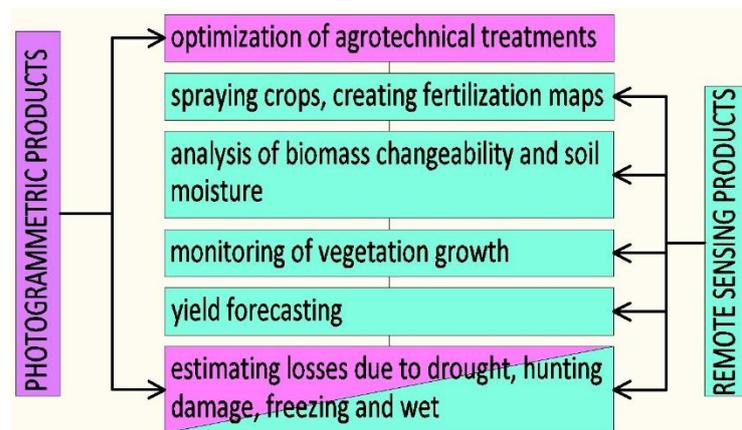


Figure 11. The scheme of use of photogrammetric and remote sensing products for the purposes of improving agricultural production and their use in smart farming.

4. Discussion

To begin with, the issue of improving the efficiency of agricultural production through carrying out land consolidation is an internationally universal one. As Wójcik-Leń and Leń et al. [11] indicate, in general, the procedure of consolidation works for EU countries is similar. However, the authors emphasise that as each rural area is unique, the adjustment of solutions to environmental and landscape conditions individually for each area is particularly important. At present, they are performed according to the provisions of the rural areas development programme [23] and have been used as one of the instruments for its implementation (for the period 2014–2020, still continued). In the period 2004–2006, land consolidation works were performed for 10,079 hectares and in the period 2009–2015 for 15,345 hectares, mainly in central and eastern voivodships. However, it may be observed that their scope and intensity of works are too low, compared to existing demands. At present, the greatest “patchwork of field” exists in southern Poland, where high demands for such works occur [24]. From an economic point of view, land fragmentation is the main weakness of Polish agriculture that has adverse economic and social consequences; it reduces farm incomes and prevents the accumulation of capital for investments that could improve the efficiency of farming practices [25]. Therefore, measures to empower and facilitate the procedure are justified.

Land consolidation also enjoys a long tradition throughout Europe. For more than 100 years, land consolidation was addressed to improve agricultural production and to safeguard the food supply of the population. During the 1970s, this sector-oriented approach changed to a broader approach to spatial development [26]. The earliest land consolidation attempts in the world were made in Scandinavia, in particular in Finland, Sweden, and Denmark, where major land consolidation projects were already implemented in the 18th and 19th centuries. In turn, according to Branković and Parezanović et al. [27], during the transition period in the 1990s, Central and Eastern European countries implemented the land consolidation process as a part of a strategy to depart from planned agricultural production, specific for socialistic societies, towards the privatisation and market-oriented economy aimed at increasing agricultural revenues. Nowadays, in Eastern Europe, the objectives of land consolidation are developing from those of agricultural production to the creation of environmental and infrastructural facilities [28]. In Poland, as discussed in the professional literature [15,29], land consolidation is applied for:

- Conventional works, aiming at the creation of better farming conditions, in particular through the elimination of the so-called “Patchwork of fields” and improvements in the shapes of fields and the technical infrastructure of rural areas;
- Infrastructural works, aiming at the minimisation of the results of the disintegrating impacts of investments on farms and disturbances resulting from line investments;

- Infrastructural works performed due to the implementation of flood protection operations, where land consolidation is one of the methods of land acquisition for the needs of such protection;
- Secondary works, being an answer to the scattering and fragmentation of agricultural properties in already consolidated areas. Other purposes of secondary land consolidation works also exist, such as protection against erosion, the possibility to terminate land communities, and consolidation of forests or forested lands;
- Ecological works, which are directed towards transformations of lands in order to allow for the rational development of the agricultural space while protecting and planning the elements of the landscape and ecology.

In Germany, in order to meet the concrete development needs and objectives in a determined developing area, and to avoid overburdening or even the lack of administrative means, the German Land Consolidation Act contains five different “tailor-made” land consolidation tools; for the East German part, its specific (post-socialistic needs) three additional tools are established through the law on adjustment of agriculture [26]. As emphasised by Hendricks and Lisek [30], the standard land consolidation procedure is the most comprehensive solution and usually includes the construction of rural roads, management of water resources, village renewal, soil protection, nature conservation, etc. Meanwhile, the simplified land consolidation procedure constitutes fast readjustments of property, excluding the road and water resources plan. The aim of the procedure is to improve production and working conditions in agriculture and forestry by the exchange of plots on the basis of mutual agreements. In turn, the voluntary land exchange refines the structure of agricultural land by way of the optional exchange of parcels between landowners. Last but not least, land consolidation for large-scale projects constitutes an expropriation proceeded only if ordered by law. According to Hendricks and Lisek [30], such a procedure is implemented in order to distribute the loss of land amongst landowners and to limit the damages effected by land dissection.

Interestingly, according to Pawlikowska, Popek, Bieda, Moteva, and Stoeva [31], in Bulgaria, the structure of agricultural land is more fragmented than in Poland. As emphasised by Davidova and Buckwell et al. [32] and Moteva and Mondeshka et al. [33], this is caused by the lack of an effective state policy during the agrarian reform, which should strengthen the process of land consolidation, a legal mechanism that could prevent the further process of real estate subdivision through inheritance and sales, as well as proper management of land and water resources.

The improvement of the consolidation procedure with the application of photogrammetric and remote sensing tools would be valuable on a larger scale. As stressed by Vitikainen [14], the land consolidation procedure includes similar main stages in all countries. The author claims that, similar to in Poland, the surveys are based on checking and possible updating of the data either in the cadastre or on the cadastre map and in the land register (e.g., in Germany and The Netherlands). Basista and Balawejder [18], emphasise that it is necessary to pay attention to the preparation and selection of data for the analysis. Only plausible input data determine assigning the equivalent of the relative value. Nevertheless, subject literature authors have questioned on several occasions the quality and reliability of cadastral data. For instance, within the experiment carried out by Noga, Balawejder, and Matkowska [34], verification of the field data with the data from the Land and Buildings register (EGIB) showed significant disproportions and inconsistencies. Kocur-Bera [35] indicates that spatial data pertaining to the same fragment of land (in the aspect of geometry or description attributes) do not always adequately reflect the reality. The research performed by Cienciala, Sobolewska, and Sobura [36] also proved that the data on land use disclosed in cadastres are, in many cases, unreliable and outdated; meanwhile, the modern photogrammetric tools may allow for their regular verification, providing the basis for their update. What is more, participants of consolidation may establish principles other than those specified in the rules [23], in which the reliability of the data on the current state may play an important role.

Input materials for elaborating the comparative estimation of land in such cases may involve some additional information that constitutes the content of orthophoto maps, not just the information that is presented on cadastral and topographical maps. While elaborating the comparative estimation of lands covered by consolidation, one must also consider evaluation of the land, agricultural usefulness of soils, and principles of estimation specified in the resolution adopted by the consolidation participants. Defining the estimated contours of land covered by consolidation ought to lead to a situation whereby the border of the estimated contour runs along the borders of situational details or soil–agricultural complex borders.

The abovementioned research by Cienciąła, Sobolewska, and Sobura [36], concerning the utility of aerial photographs as an evidence material on land use, showed that unmanned aerial vehicles (UAVs) may enable the acquisition of a high-resolution orthophoto map (in the analysed case with a GSD of 3 cm), ensuring the accuracy of the data on the scope of land use higher than demanded (in Poland ≤ 0.5 m). Karabin, Bakuła, and Łuczyński [37] also emphasised that measuring land use outlines with photogrammetric technology was highly justified, especially when working on extensive agricultural areas. Puniach and Bieda et al. [38] also confirmed that data collected on the basis of UAV flights may be sufficiently accurate to be used in surveying and legal procedures connected with the update of the cadastral database. The accuracy of photogrammetric measurements can be additionally increased by calibrating the UAV sensor [39]. In recent years a substantial increase in commercial applications of the UAV technology may be observed. According to Krupowicz and Czarnecka et al. [40], an orthophoto and OpenStreetMap are even considered to be the most user-friendly background data that help orientate less experienced users on the map. As stressed by Tsouros and Bibi et al. [41], it was initially used for military purposes as a result of the technological progress and miniaturisation of UAV devices in the 1990s, and it found its broader application also in the economy, including farming. Currently, unmanned aerial vehicles are used, among others, in the following solutions:

- Elaborating plans for nitrogen fertilisation and the conduct of aerial spraying of pesticides [42,43];
- Defining the plantation area for payments of agricultural insurance compensations as a result of seed damages after winter or caused by hunting damages [44];
- Elaborating plans of the irrigation of crops and soils [42,45];
- Detecting weeds and plantation diseases [1];
- Monitoring qualitative indicators for soils and plants during periods of droughts [45].

As inferred from the literature studies [41–44] and empirical experiences of the authors, a significant factor that determines the use of a UAV for the collection of remote sensing data in smart farming is its low dependence on weather conditions in the form of cloudiness or slight rainfall. In the case of using satellite, multi-spectrum images in the area of Poland, one should consider the fact of the frequent occurrence of clouds in the growing season of plants (April–June), which significantly hinders the use of optic images for further analyses [41,42]. The technology based on obtaining images with the assistance of a UAV is more cost effective in the case of larger areas of agricultural activity conduct, whilst a fast reaction time is necessary in order to ensure the correct growth of crops. Table 1 subjectively compares various measurement technologies supporting the undertaking of decisions in precise farming [10].

Table 1. Comparing technical aspects between the UAV technology, manned aircrafts, and satellite images for the needs of realising the works in smart farming (+ = low, ++ = medium, +++ = high).

Factor	UAV	Manned Aircraft	European Space Agency (ESA) Remote Sensing Imaging
Price	++	+++	+
Availability	+++	+	++
Dependency on weather conditions	+	+++	++
Area of elaboration from the obtained images	+	++	+++
Intensity of the work elaborated in the area for realisation of analyses	++	+++	+
Possibility of use in the case of smaller agricultural farms up to 10 ha	+++	++	+
Difficulty of data processing	+	+	+++

Source: own elaboration based on [10].

Moreover, modern geospatial tools may constitute a crucial support in improving plant-based production while minimising the costs incurred for fertilisers and pesticides. By means of new technologies in the field of remote sensing supplemented by the information obtained from various sensors located on different altitudes, the farmer may monitor the condition of plants and implement the right actions when potential damages occur [46]. The use of satellite observations for the identification and monitoring of land areas on agricultural lands is also of significance for administrative entities, which enforce complex applications for surcharges. Creating maps on the basis of satellite imaging in the process of supervised classification allows one to establish the irregularities between the submitted application and the result of the plot classification and to explain the potential irregularities by way of on-site inspection [47]. Below (Table 2) are the advantages and disadvantages of the application of UAV technology.

Table 2. Advantages and disadvantages of the UAV technology.

Advantages	Disadvantages
Possibility of eliminating ground inspections and time-consuming and costly field measurements	High cost of thermal cameras in comparison to optic and multispectral ones
Possibility of detecting dynamic changes in the factual state of land, i.e., manner of land use, tree successions, etc., including in hardly accessible locations	Difficulty in processing multispectral and thermal data
Material useful at the stage of elaborating field studies, designing and presenting the results	The value of spectral indexes or specifying humidity/temperature on the basis of thermograms is on several occasions interrupted by the impact of the atmosphere and the phenomenon of mixed pixels related to the radiation of the soil surface
UAV high-resolution imaging as a fast and economic method for conducting monitoring of crop conditions	Decreasing the length of the conducted UAV flying time along with an increased message transmission optimisation mechanism (MTOM) parameter, which enforces obtaining various types of UAV applied for various goals, i.e., mapping or carrying out spraying
Possibility of performing fully autonomous and repeatable UAV missions in the future	The necessity to use complex algorithms for the conversion of DN value into the value of the reflection coefficient
Creating digital terrain and land cover models based on UAV images	The necessity to consider shades and exclusion of the land in order to obtain a plausible analysis [26]

A detailed analysis of digital images enables the provision of information, which may almost instantly impact the decisions made at an agricultural farm. Based on the information from geotagged short-range photographs (UAV, smartphones), shapes, altitudes, speed of growth, or the change of colour of plants may be obtained, allowing one to model the beneficial and unbeneficial processes related to the plantation [48]. The use of advanced classifiers of machine learning of the convolutional neural network (CNN) type on digital

images with tagged reference samples may serve the purpose of automated diagnosing of the state of cultivation and thus facilitate the projection of the occurrence of anomalies with a very high efficiency level, exceeding 95% [45,48].

Until recently, some of the limitations in applying remote sensing techniques in smart farming have been the small number of constellations available for civil use and exempt from fees, the relatively low resolution of multispectral images, and the long period of return visits, which translated into a difficulty in obtaining optimal space–time characteristics [49]. These limitations were overcome with the launching of the European constellation Sentinel-2 in 2015 with an MSI sensor equipped in an improved spatial and spectral resolution, and the satellite trajectory was selected in such a way so as to optimise the time of return visits to several days. The goal of the mission was to fulfil the needs of the agricultural society—both the farmers and scientists dealing with the subject matter of agriculture—considering the development of intercontinental farming [22]. Another step in satellite remote sensing was the formation of the so-called constellation of nanosatellites named Planet and thus a large number of compact sensors (between 150 and 200) weighing approx. 10 kg, ensuring better geometrical resolution (3–5 m/pixel) and time (possibility of obtaining daily photos) in comparison to the Sentinel-2 constellation [49]. In contrast, satellite multispectral images have been available for a long time, that is, from the moment of NASA launching the Landsat project in 1972; however, they continue to require implementation of the know-how resources for correct functioning and results interpretation. Accepting such a position allows one to save both time and money, which stems from the possibility of carrying out monitoring of the plant stress and the optimisation of irrigation and fertilisation with a direct translation to the size of crops [22]. The future of smart farming depends on technological progress, and UAVs equipped with additional sensors are yet another step on the path towards further progress in this field of science [21,50].

5. Conclusions

Reliable elaboration of the consolidation project concept is critical for its correct realisation, while modern measurement methods, providing up-to-date factual data in an efficient manner, enable facilitating the procedures and undertaking rational decisions. The idea concerning the application of photogrammetric tools at the stage of carrying out field studies is universal and may constitute a valuable course of action in other countries. The analysis of the existing state, especially in the scope of the state of land use, including afforestation and planting, water relations, etc., requires conducting analyses of current spatial data, as only they may ensure the possibility of elaborating the consolidation project concept in a comprehensive manner with the possibility of indicating alternative solutions. The functionality of technology enables the conduct of visualisations of the proposed project solutions in a multi-criteria and transparent manner, which is of particular importance from the point of view of the project promotion and social participation in the process of consolidation. Moreover, it ensures a much-needed higher accuracy of the data on the scope of land use and avoids analyses of the compilation of several cartographic materials concerning the surveyed object (cadastral maps, topographical maps, base maps, etc.).

What is more, modern measurement tools are gradually implemented in the process of management and agricultural production, causing their improvement. Remote sensing may ensure monitoring in short time intervals and gather a precise image of the agricultural sectors on small and large scales worldwide. However, applying remote sensing technology—satellite images or photographs with low bank photos, obtained by means of a UAV—enables facing the challenges related to optimising agricultural structure management and abiotic and biotic stressors. In other words, remote sensing technologies assist in making—from the perspective of efficiency—more accurate decisions on matters such as crop nurturing, proper irrigation, or reacting quickly to diseases in plants.

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