Mobile Crowdsourcing in 3D Cadastral Surveys: Exploring the Public's Reaction and Data Quality

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Key words: 3D Cadastre, LADM, Crowdsourcing, Quality Control, 3D Spatial Data, Data Capture

SUMMARY

During the past decades we have witnessed an ongoing urbanization, leading to the emergence of several complex constructions and multi-dimensional property rights. The establishment of a modern land administration system (LAS) able to manage various types of rights in a uniform, standardized and reliable way, throughout three-dimensional (3D) space, is imperative. As traditional cadastral surveys often lead to delays, gradually increasing the cost of the cadastral procedure, a solution is sought in modern methods and technological achievements. Utilizing the latest technology, Information and Communication Technology (ICT) tools, low-cost equipment, crowdsourcing techniques, mobile services (m-services), web services, open-source software (OSS) and the international standard of Land Administration Domain Model (LADM ISO 19152), the development of a reliable, qualitative and affordable solution for the implementation of 3D cadastre, is feasible. Despite the progress achieved to date, regarding the development of innovative modern solutions for 3D cadastres, there are several challenges and questions that have to be answered. Is the quality of crowdsourced data sufficient for the implementation of 3D cadastral surveys? How will citizens be recruited in the cadastral process and what will be the motives to enhance their participation? The answer to these questions is of utmost importance in order to provide an effective, qualitative and reliable outcome, regarding 3D cadastre.

In this paper an evaluation of a LADM-based technical solution for the initial acquisition, registration and representation of 3D crowdsourced cadastral data, presented in our previous work, is conducted. A practical experiment for testing the examined technical solution was conducted for a multi-storey building in an congested area of Athens, Greece. A group of volunteers was organized, trained and reviewed, respecting the crowdsourced 3D cadastral survey. The main scope of this study was focused on investigating the usability, quality, reliability and potentials of the examined technical system. The main conclusions referred to the potential of this current crowdsourced solution for the initial implementation of a fit-for-purpose 3D cadastre, are presented.

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1. INTRODUCTION

The advent of new technologies and the internet revolution strongly influence all spheres of life, providing new potential opportunities for continuous improvement in business and government. These massive changes have affected the way that National Mapping Agencies (NMAs) work, paving the way for the development of modern Land Administration Systems (LAS). During the past decades, many countries attempted to develop geospatial data infrastructures, including geographic data and metadata as well as international standards, as the Land Administration Domain Model (LADM) (LADM ISO 19152, 2012) to support and upgrade the current LAS. Thus, over time, the so-called map-centric geospatial infrastructure describing the managment of the geospatial data have obtained a service-centric framework allowing the creation and update of the cadastral data in real time (Celt et al., 2019).
New technologies together with crowdsourcing techniques may accelarate the development of reliable and affortable tools and services, supporting all 17 Sustainable Development Goals (SDGs) and the 169 targets of Agenda 2030 (Celt et al., 2019). The widespread web has enchanced public interest in using technology for many purposes, enabling user's engagement and the use of crowdsourcing methodologies to acquire data (Web 2.0) (Goodchild 2007a,b). Innovative developments, such as smartphones, are equipped with imbedded GNSS receivers and other physical sensors, allowing the collection of spatially oriented data, and thus have become a promising cadastral data-capturing tool. With the emergence of Web 3.0 the capabilities of cadastral systems are expanding as 3D design may be used extensively in websites and services. Modern cadastral systems may provide secure tenure and property rights, even in 3-dimensional (3D) space, leading to economic growth by eliminating the economic gap between the 2.5 billion people who can register property rights and the other 5 billion people who cannot (Celt et al., 2019). The subdivision of 3D space through several uses and overlapping property rights in both the developed and the developing world, requires the establisment of a modern 3D LAS, able to manage various types of rights in a uniform, standardized and reliable way, both above and below the land surface.
During the past years, 3D cadastre has been attracting researchers throughout the world, bringing in line very interesting approaches for the development of 3D cadastres. Quite a number of countries have developed really interesting procedures for the establishment and registration of rights of 3D property units, in their cadastres (Gkeli et al., 2019a). Notable examples of these efforts are the 3D cadastre approach of Queensland, Australia (Stoter and Oosterom, 2005; Karki, 2013), Shenzhen, China (Guo et al., 2014), Israel (Benhamu, 2006; Benhamu and Doytsher, 2003; Benhamu and Doytsher, 2001), Taiwan (Chiang, 2012), Russian Federation (Vandysheva et al., 2011a; Vandysheva et al., 2011b), Netherlands (Stoter et al., 2012; Stoter et al., 2016), Spain (García et al., 2011), Bahrain (Ammar and Neeraj, 2013) and New Zealand (Gulliver, 2015). However, the introduction of crowdsourcing in 3D cadastres consists a relatively new field. Several researchers have investigated the potential use of

crowdsourcing in 3D cadastral surveys (Vučiće et al., 2015; Ellul et al., 2016; Gkeli et al., 2017a,b,c,d; Gkeli et al., 2018; Gkeli et al., 2019a,b), concluding that 3D crowdsourcing has notable potential for the initial implementation of 3D cadastres.

There is no doubt that new technological achievements in cooperation with crowdsourcing techniques have huge potential in 2D and 3D cadastral data sets acquitision and design, but there is always a concern. Due to the fact that data is collected by amauters/public, there are concerns regarding their reliability and credibility. The majority of NMAs doubt whether crowdsourced data can be integrated with authoritative data, as this integration may lead to quality and consistency reduction of the national datasets (McLaren, 2012). A quality assessment of crowdsourced data is of great importance, especially in terms of accuracy, completeness, reliability and usibility. During the past few years, there have been several investigations trying to highlight the public's perception about crowdsourcing data in land administration procedures. Keenja et al. (2012), explored the different views of Netherlands Kadaster staff members about crowdsourcing, utilizing a Q-methodology approach. It turned out that the perceived views were strongly influenced by the cadastral experience or profession of the participants. Crowdsourcing is viewed as a threat by public cadastral organizations. Similarly, Clouston (2015) investigated the potential integration of crowdsourcing data in thev New Zelands cadastre. A majority of participants were concerned for the reliability and trustworthiness of the cadastre if crowdsourcing data was added. There was a high level of concern about allowing crowdsourcing to influence the New Zelands cadastre especilly from cadastral professional participants (Clouston, 2015). However, despite the current concerns, the concept was generally supported, placing the crowdsourcing concept in the overarching set of future goals of their organisations (Keenja et al., 2012).

Therefore, it is paramount that the practitioners/citizens understand the motivation behind crowdsourcing and set their goals accordingly. Professional surveyors should offer their expertise in order to develop modern solutions able to manage crowdsourced data ensuring economic growth and poverty reduction as well as equal rights in access to land. With the appropriate incentives public engagement may be enchanced, strengthening the willingness of citizens' participation in social processes with a positive impact on its successful outcome (Apostolopoulos et al., 2018). A fit-for-purpose solution may promote the development of functional land administration systems for both the developed and the developing world, relatively quickly and with affordable cost to meet the 2030 UN Agenda SDGs (Enemark et al., 2014).

This paper presents a part of an on-going research project, intended to provide a practical technical tool for the acquisition and management of 3D property rights. Our main objective is to investigate the performance of such a technical tool, exploring the publics' reaction, and the quality of the result. Section 2, presents a literature review describing some key issues of our research. In Section 2.1 several approaches concerning implementation of crowdsourced 2D/3D cadastral systems, are presented. In Section 2.2 an investigation regarding the main parameters affecting the participation of citizens in a crowdsourcing project, is presented. Section 2.3 presents an exploration of the main elements that affect the quality of the geospatial data. Section 2.4 introduces a survey regarding the most important parameters in designing applications, affecting their usability. Section 3 presents an implementation of the examined crowdsourced technical solution in a multi-story building in the congested area of Athens, Greece, as well as the results of the overall procedure. Section 4 presents an assessment of the examined procedure, the achieved results and volunteers' feedback in terms of the usability, quality, reliability and potentials. Finally, in Section 5 the main conclusions regarding the potential of the examined crowdsourced solution for the initial implementation of a fit-for-purpose 3D cadastre, are presented.

2. LITERATURE REVIEW

2.1 Crowdsourcing in Cadastral Surveys

During recent decades we have witnessed an overwhelming technological revolution intensively affecting the way that geospatial data are acquired, maintained, analyzed, visualized, used and disseminated. Information and Communication Technology (ICT), low-cost equipment, crowdsourcing techniques, mobile services (m-services), web services and open-source software (OSS) introduce a new era for cadastral surveys, minimizing the financial costs as well as the time required to perform field surveys. To date there have been many studies exploring the use of crowdsourcing and VGI (Volunteer Geographic Information) in the context of cadastral systems (Basiouka and Potsiou, 2012a,b; Mourafetis et al., 2015; Jones et al., 2017a,b; Apostolopoulos et al., 2018; Molendijk et al., 2018; Gkeli et al., 2016; Rahmatizadeh et al., 2016). As it has turned out, VGI and crowdsourcing techniques in cooporation with location based application may lead to positive results.
However, the introduction of crowdsourcing into 3D cadastral surveys is more complicated, posing challenges concerning the 3D modeling of the real world as well as the managment and visualization of 3D cadastral data. As the complexity of a building's structure is only known to the occupants, crowdsourcing seems to be the best choice for a cost-effective and fast implementation of an effective, efficient and reliable 3D cadastral system, with incrementally upgraded accuracy. Recent research has proved that low-cost sensors, often available in smartphones, enable 3D geospatial data acquisition and visualization by non-professional citizens. Until now, there are very few studies exploring the potential use of crowdsourcing in 3D cadastral surveys (De Almeida et al., 2016; Ellul et al., 2016; Gkeli et al., 2017a,b,c,d; Gkeli et al., 2019). As a result, through proper methodological steps and the development of 3D-assisted mobile (Ellul et al., 2016; Gkeli et al., 2017a,b,c,d; Gkeli et al., 2019) or web application (De Almeida et al., 2016) it has been shown that crowdsourcing may be integrated in 3D cadastral surveys leading to very promising results, providing the basis for the implementation of a fit-for-purpose 3D cadastre.
This effort may be strengthened by adopting standardized modeling prototypes such as LADM, which enable communication between the involved parties within one country or between different countries, and facilitates the data exchange in heterogeneous and distributed land administration environments (Lemmen et al., 2015).Thus, the transparency in land administration procedures may be ensured. In Jones et al. (2017a), a low cost LADM-based approach for the implementation of a post conflict fit-for-purpose 2D cadastre in Colombia utilizing modern GIS technology, is presented. Gkeli et al. (2018) present an innovative LADM-based technical solution for the initial acquisition, registration and representation of 3D crowdsourced cadastral data. Even though the research in this domain is newly emerging, we can argue that a fit-for-purpose 3D crowdsourced cadastral surveying technical solution based

on LADM standard might be of significant value in order to speed up the necessary processes for establishing 3D cadastres, especially in densely populated and informally developed areas.

2.2 Motivation for Participation and Public Willingness

One of the most important parameters affecting the success of any crowdsourcing application is the productivity of the participants. During recent decades, there have been several investigations attempting to highlight the main motives of the participants, and attempting to engage them and maintain their willingness to stay active through the overall process (Nov, 2007; Coleman et al., 2009; Coleman et al., 2010; Basiouka and Potsiou, 2014). Coleman et al. (2009) divided participants into five categories based on their knowledge, capabilities and background, ranging from neophytes through to expert authorities. In a later research, Coleman et al. (2010) posed a list of the potential motives that might attract contributors, including altruism, professional interest, intellectual stimulation, protection or enhancement of a personal investment, social reward, personal reputation, self-expression opportunity and civic pride.
The engagement and recruitment of the participants in a crowdsourced project is another issue addressed in the current literature. Several approaches have been proposed towards public recruitment, including the method of gamification (Apostolopoulos et al., 2018), incentivizing participants with various monetary or other rewards (Brown and Kytta, 2014) or even with advertising through flyers and social channels such as Facebook (Sirbu et al., 2015). As reported in Gkeli et al. (2019), following gamification strategies, a reward for the rights holders' participation in the cadastral procedure, such as a discount on taxes or registration fees for the most active, may strengthen the motives of citizens and ensure the smooth, robust and efficient implementation of the crowdsourced process.
Through proper briefing of the public about the benefits of a crowdsourcing project, awareness may be raised, encouraging citizens to join the project. However, the effectivness of a crowdsourcing framework depends heavily on "finding the balance in which for the non-professional participants the operation of collecting and contributing data is not too complex in a way that might impair the quality of the data; but on the other hand, making sure that the contributor is motivated – intellectually and practically – will benefit the processes." (Celt et al., 2019).

2.3 Quality Control

Data quality is an often debatable topic in the research community that still remains a valid concern (Goodchild, 2008b). In ISO 8402 (1994), quality is defined as "the totality of characteristics of an entity that bear upon its ability to satisfy stated and implied needs". Data quality is often referred as data fitness when describing geospatial data, arguing that the product's quality depends directly on the intended application. In this sense, data quality or data fitness may be considered acceptable if data are fit-for-purpose. Although data quality has several different aspects, it may be considered as a value with two broad perspectives - the internal and the external (Celt et al., 2019). The internal perspective is based on the *a priori* requirments as presented by the producers and providers, while the external perspective is referred to the necessary requirments for reusing the data. Thus, data quality or fitness-for-purpose may be described and evaluated by examining some quality criteria that determine whether or not the produced data is compatible with the data product specification. Occasionally, various standards have been proposed, in an attempt to define the most appropriate quality descriptors for the evaluation of data quality. The ISO 19157 (2013) standard (Figure 1), describes spatial data quality through 21 quality elements which belong to 6 different categories: completeness, logical consistency, thematic accuracy, temporal quality, positional accuracy, and usability.

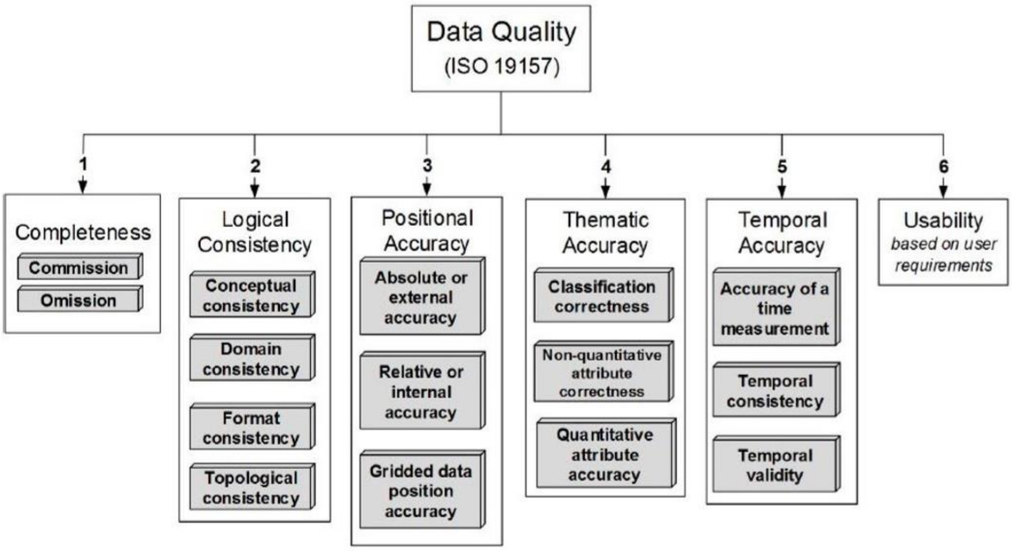

Figure 1: Data quality descriptors basen on INSPIRE technical guidelines - ISO 19157 (Celt et al., 2019).

Goodchild and Li (2012), distinguished three different approaches in order to assure geospatial data quality, as follows:

- The crowdsourcing approach argue that data may be more accurate if a large group of people agree on it. Information based on a single individual's observation does not have the same impact.
- The social approach, based on the fact that trusted users or administrators, may check the inserted new data in order to minimize errors.
- The geographic approach, based on the principle that geographic data may be checked against some rules, even automatically.

Navratil and Frank (2013), examined how these three approaches may be adopted in land administration to assure that crowdsourced geospatial data may provide a reliable source. As crowdsourced and VGI data are user-generated, they are strongly affected by contributors' personal knowledge, interests and willigness. In case of land administration, where for example property boundaries are of main interest, VGI data may be a reliable source only if boundaries are obvious by direct observation. However, the majority of such cadastral information is only known by a few of people, mainly owners, or by professional surveyors after the necessary measurements. Thus, based on this fact, crowdsourced cadastral data may be reliable if the contributors are mainly owners or trained citizens in cooporation with owners (Gkeli et al., 2018; Gkeli et al., 2019).

2.4 Application Usability Inspection

Usability provides one of the most important parameters in designing products, as it affects the users' reaction concerning the product. In ISO 9241-11 (1998) a definition about usability is presented, as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". As specified in ISO/IEC 25010 (2011), the quality of a product may be defined by 8 parameters "functional suitability, reliability, performance efficiency, usability, security, compatibility, maintainability and portability". With regard to usability, the necessary characteristics that may represent a usable application interface are the recognisability, learnability, operability, user error protection, user interface aesthetics and accessibility (ISO/IEC 25010, 2011).
Usability presents a qualitative way to assess how easy the user may interact with applications interface. Nielsen (2012), defines usability as a combination of five quality components, as follows:

- Learnability: how easy it is for users to complete some basic tasks during their first interaction with the applications' interface.
- Efficiency: the necessary time for users to accomplish a task once they have learned how the system works.
- Memorability: how easily can users re-interact with the systems' interface after a period of not using it.
- Errors: the amount of errors that the users make when performing tasks and how easily they can recover from them.
- Satisfaction: how pleasant it was for the user to use the system.

Usability evaluation is important in order to improve applications interfaces, aiming to produce more qualitative products and therefore qualitative data useful for several applications.

3. BACKGROUND INFORMATION ON THE LADM-BASED TECHNICAL SOLUTION

The examined technical solution presents an alternative approach for the initial acquisition, registration and representation of 3D cadastral data (Gkeli et al., 2018). The proposed framework combines crowdsourcing techniques, Information and Communication Technology (ICT) tools, low-cost equipment, mobile services (m-services), web services, open-source software (OSS) and the international standard of Land Administration Domain Model (LADM ISO 19152, 2012). This effort aims to develop a standardized technical framework and a methodology able to serve the needs of the countries with limited financial resources, and provide a fast solution and a practical tool able to safeguard and manage 3D property rights, exploiting the available cartographic infrastructure of each country. It is noted that the examined framework focuses on the physical aspect of 3D spatial units, that is their geometry and representation. The investigation of the legal aspect, is not included in the objectives of this research.
The architecture of the proposed technical framework is simple, consisting an end-to-end system (Figure 2). On the first end, the web server of ArcGIS Online (ESRI, 2019) and a LADM-based Database Management System (DBMS) (Gkeli et al., 2018), are obtained. The LADM-based DBMSs' conceptual schema is enriched with new classes able to support the geometry of the 3D spatial units, describing the 3D land parcel and the 3D building unit / property (Gkeli et al., 2018). On the second end, the data capturing tool, which in this case is

the mobile device, and an open-sourced self-developed mobile application for Android devices, is obtained (Figure 3). Through the developed mobile application, the collection, management and storage of the necessary 3D crowdsourced information by non-professionals, as well as the registration of the cadastral data and their relationships within the LADM-based cadastral geodatabase, is allowed. The application provides a set of tools for the identification and digitization of the land parcel's and building unit's boundaries on the available basemap (2D architectural plans, orthophotos, aerial photos), as well as the insertion of all necessary proprietary information (descriptive and geometric), available documents (e.g., plans, deeds etc.) or even photos, for the declaration of the property rights. By inserting the necessary geometric information regarding the structure of each building unit / property (height, floor, digitized boundaries), an automated algorithm processes the declared geometric data, utilizing a Model-driven approach, and generates the 3D block models (LoD1) of the land parcel and the property unit, respectively. Subsequently, the 3D property models (land parcel and building unit) may be visualized on the mobile's phone screen, both above or below the ground, by selecting each one of the visualization tools (Gkeli et al., 2018).

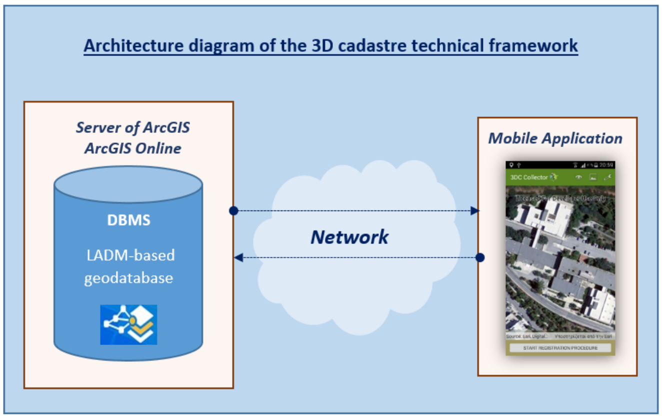

Figure 2: Architecture diagram of the 3D cadastre technical framework.

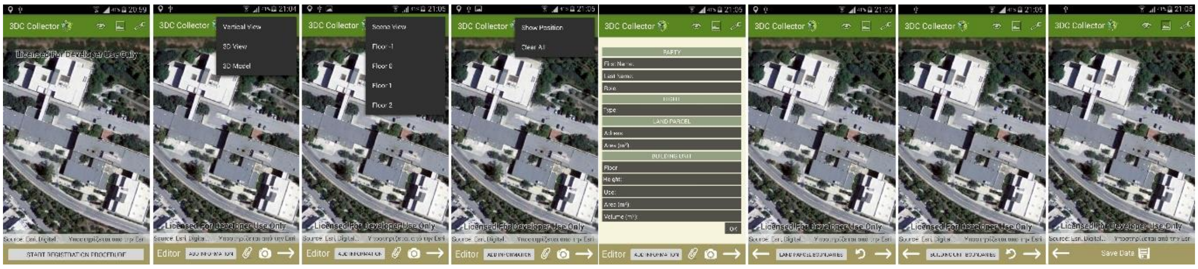

Figure 3: Users interface overview of the developed mobile application (Gkeli et al., 2018).

The proposed framework follows an innovative crowdsourced methodology for the compilation of cadastral surveys. The role of right holders is advanced, they do not just declare their rights but they undertake the responsibility for the initial collection of the cadastral data. The proposed crowdsourced methodology consists of five (5) main phases (Gkeli et al., 2018) (Figure 4). In the first phase, the declaration of the area subject to cadastral survey, is conducted by the government. Next, a draft cadastral basemap utilizing the current available geospatial infrastructure should be provided by the National Cadastre and Mapping Agency (NCMA). As the available geospatial infrastructure varies from country to country, various basemaps may be used, affecting the achieved geometric accuracy of the 3D recording. In order to achieve the better geometric accuracy, a recent orthophoto or a 2d cadastral map of the studied area, may be used; similarly existing architectural plans of the building units, may be used to improve the geometric accuracy for each level. In this case, the geometric accuracy meets the accuracy of the technical specifications (Mourafetis et al., 2015; Gkeli et al., 2018; Gkeli et al., 2019a,b). In absence of such accurate basemaps, an aerial photo or even an Open Street Map (OSM) basemap can be used where the land parcel boundaries and the building footprints will be digitized, thus reducing the geometric accuracy.

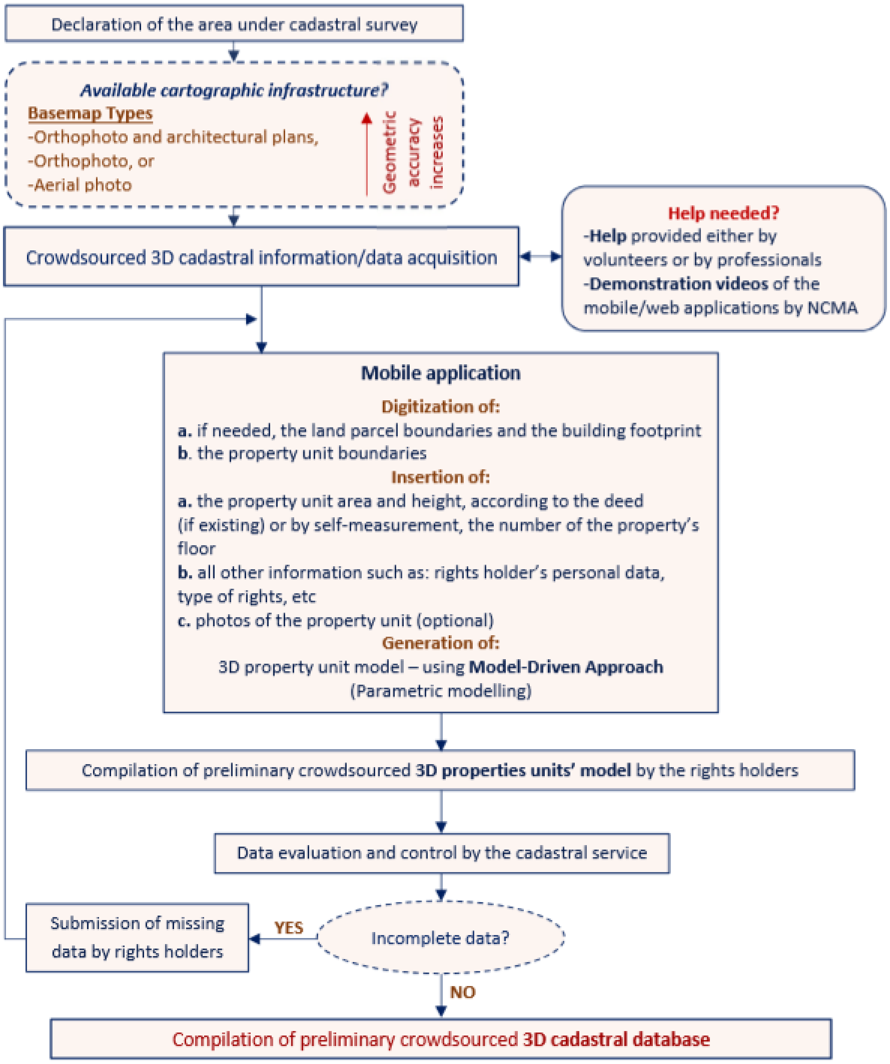

Figure 4: Proposed crowdsourcing procedure for 3D cadastral surveys (Gkeli et al., 2018).

In the third phase, the collection and submition of the cadastral information may be conducted by the right holders, through the cadastral mobile application. The National Cadastre and Mapping Agency should be responsible to provide the right holders with a mobile cadastral application similar to the one developed by the authors. Using the mobile application, right holders may ‘visit’ their property, delineate the boundaries (land parcel and building unit) on the basemap, attach photos or files and other available legal documents proving their rights. In case that right holders are unable to use the mobile application, NCMA should provide them with demonstration videos with detailed instructions for how to use the mobile application, as well as with professional staff - local trained volunteer or local professional surveyor – able to help the right holders in order to procced with the registration procedure.

By the completion of this phase the NCMA will have a draft 3D building and property unit database compiled by the rights holders. In the fourth phase, the cadastral agency should evaluate and control the cadastral database and publish the cadastral data, aiming at the preservation of transparency and a better correction of errors. Finally, in the last phase, the submission of objections for corrections identified by the rights holders together with additional data should be accepted, leading to the compilation of the preliminary crowdsourced 3D cadastral database (Gkeli et al., 2018).

4. 3D Crowdsourced Cadastral Practical Experiment

A practical experiment simulating real surveying circumstances was conducted by a team of trained volunteers. For the case study, the innovative crowdsourced 3D cadastral procedure model and the developed LADM-based technical system, presented in Gkeli et al. (2018), was utilized for the compilation of the 3D cadastral surveys. Our main interest is to examine the usability, quality and the potentials of the proposed system (Gkeli et al., 2018), by interacting with the volunteers/public and receiving their feedback. The practical experiment was implemented using a multi-storey building as subject, located in the center of Athens, Greece. The studied building is characterized by multiple and overlapping property rights, as well as by properties with complex geometries. The main objective of this practical experiment is to identify the polygonal boundaries of each property unit together with some basic descriptive information referring to the ownership, utilizing the developed mobile application presented in Gkeli et al. (2018). Data collection is conducted by properly trained volunteers, who are considered as rights holders. The recording levels include levels above and below the terrain surface, making both the process and the results challenging. The practical experiment consisted of four (4) discrete stages: (i) the initial data gathering, (ii) the volunteers training, (iii) the field work, (iv) the extraction and evaluation of the results.

At the first stage, the collection of the existing geospatial information (aerial photos, orthophotos, architectural plans, etc.), was accomplished. An orthophoto of the test area at a scale of 1:1000 (Figure 5) and the floor plans of the two underground floors, the ground floor and the rest seven (7) floors above the ground, at a scale of 1:100, were utilized as basemaps (Figure 6). For this test, the collected data include the land parcels and the property/building unit boundaries, the height of each property, the floor number and the descriptive information about the building (area code, address), the rights holder (name, role, type of rights) and the property geometric data (floor, height, use, area size, volume).

Figure 5: Orthophoto of the case-study area at the scale of 1:1000.

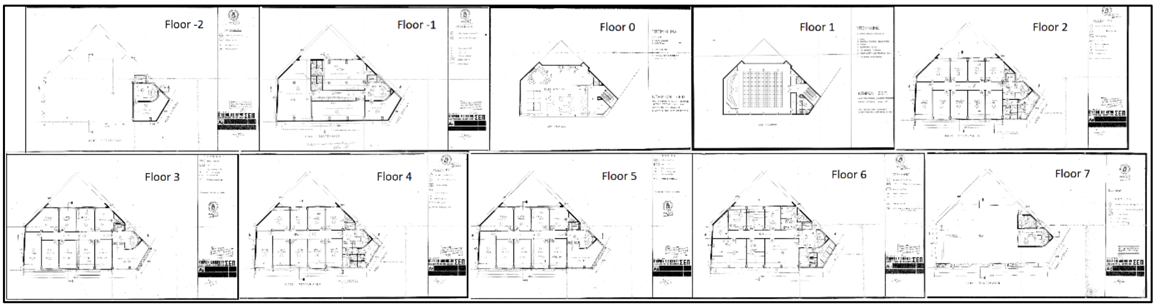

Figure 6: The floor plans of the two underground floors, the ground floor, and the rest seven (7) floors above the ground, at a scale of 1:100.

For the implementation of this practical experiment, a group of volunteers was organized. The volunteers were middle-aged citizens of various levels of education and skills and well enough updated as to the use of smart phones (Figure 7). At first, the volunteers were informed about the main objectives of this project and the functionalities of the developed mobile application. Next, the mobile application was installed in their smart phones, and after a brief training with our scientific coordinator, the volunteers were familiarized with the mobile application, and so the registration procedure could be started. Figure 8 presents a group of volunteers during the training session.

Each one of the volunteers was responsible for the registration of a certain number of property/building units as well as the registration of the building's shared spaces. The procedure starts with the insertion of the necessary descriptive information concerning the land parcel, the property/building unit, the type of the rights, the rights holder's personal data, as well as (in the official cadastral procedure) the insertion of verification images and legal documents, which support and empower the registration process. Next, the identification and digitization of the land parcel polygonal boundaries was conducted, by selecting its corners (as point features) on the orthophoto basemap, utilizing the land parcel digitization tool. Similarly, the identification and digitization of each property/building unit polygonal boundary outline was performed by selecting the floor basemap where the property unit is located, through the selector basemap tool, and then by selecting its corners (as point features), utilizing the building unit outline digitization tool. Figure 9 presents the described procedure. After the insertion of the necessary geometrical data the 3D visualization of the declared land parcel and the building unit, both above and below the land surface, was achieved through the selection of the 3D visualization tool (Figure 10). Finally, the collected data was stored in the developed database in the Cloud of ArcGIS Online, updating the system with the new records and the corresponding 3D property models.

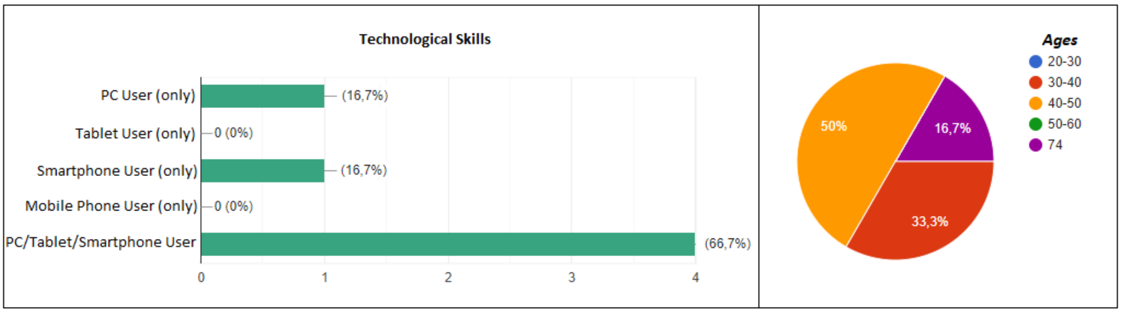

Figure 7: The technological skills (left), and the age distribution of the volunteers (right).

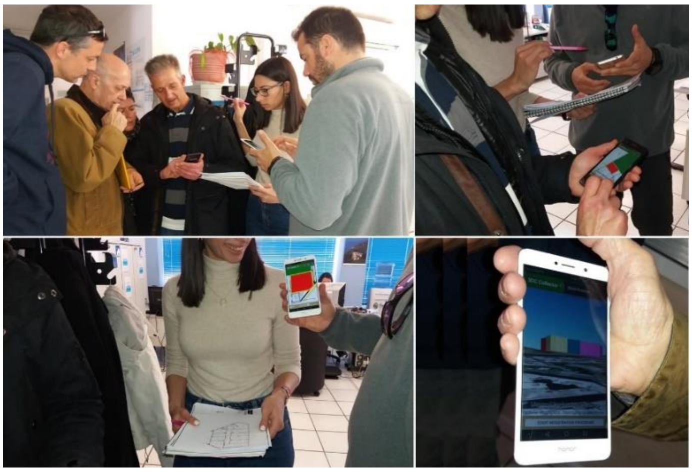

Figure 8: Group of volunteers in cooperation with the scientific coordinator, during the training session.

The registration process was successfully completed through the mobile application; no major problem was encountered. The registration process was quick as the registration of each property lasted about 7-12 minutes (average recording time). The recording time varied, according to the complexity of the boundaries shape and the familiarity of the user with the smartphones devices and the mobile application. The collected data, as well as the relationships between the cadastral objects, were successfully stored in the DBMS in the Cloud of ArcGIS Online. The cadastral information concerning each of the declared properties may be viewed either by selecting the 3D building unit model or by accessing the database and navigating through the relationships between the DBMSs' classes.

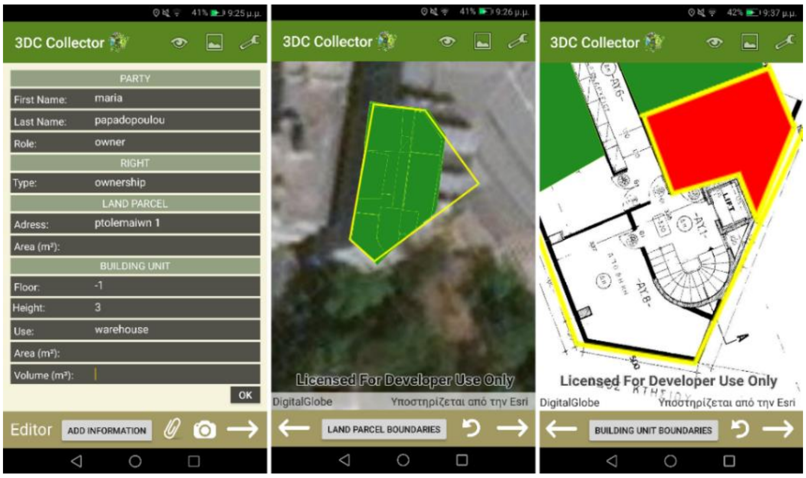

Figure 9: Example of the recording process through the developed mobile application, including (a) the insertion of the adequate cadastral information (left), (b) the polygon digitization on the parcel basemap describing the land parcel (middle) and (c) the polygon digitization on the floor basemap describing the building unit, on the basemap (right).

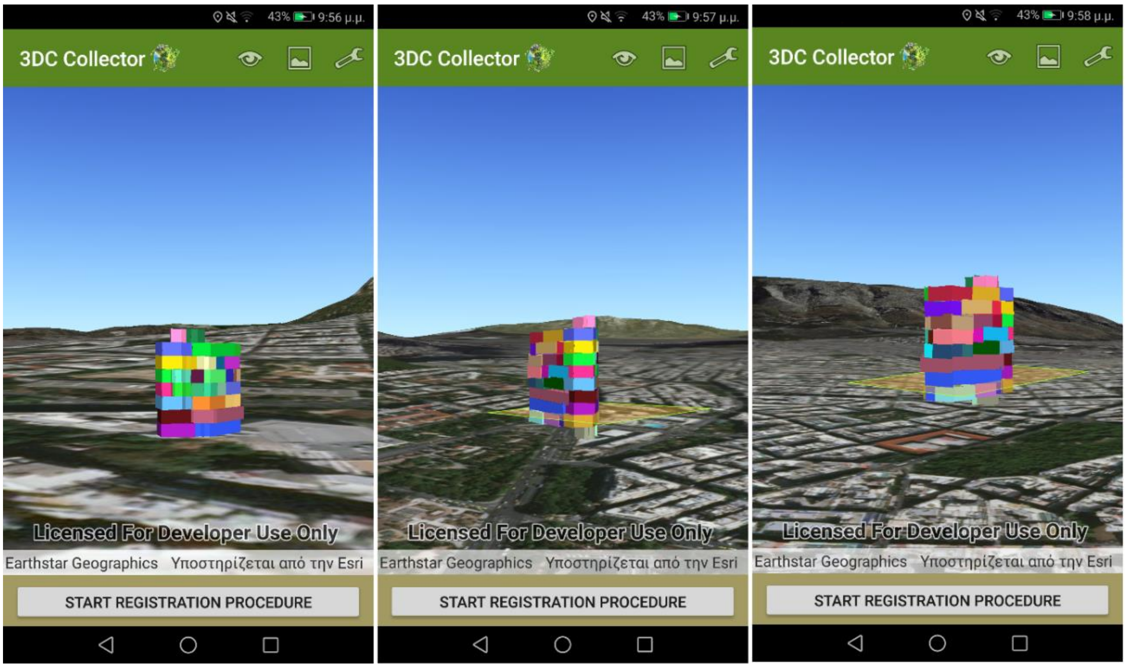

Figure 10: Generated 3D models of the declared properties above (left) as well as above and below (middle, right) the ground surface, using the 3D Model tool of the developed mobile application.

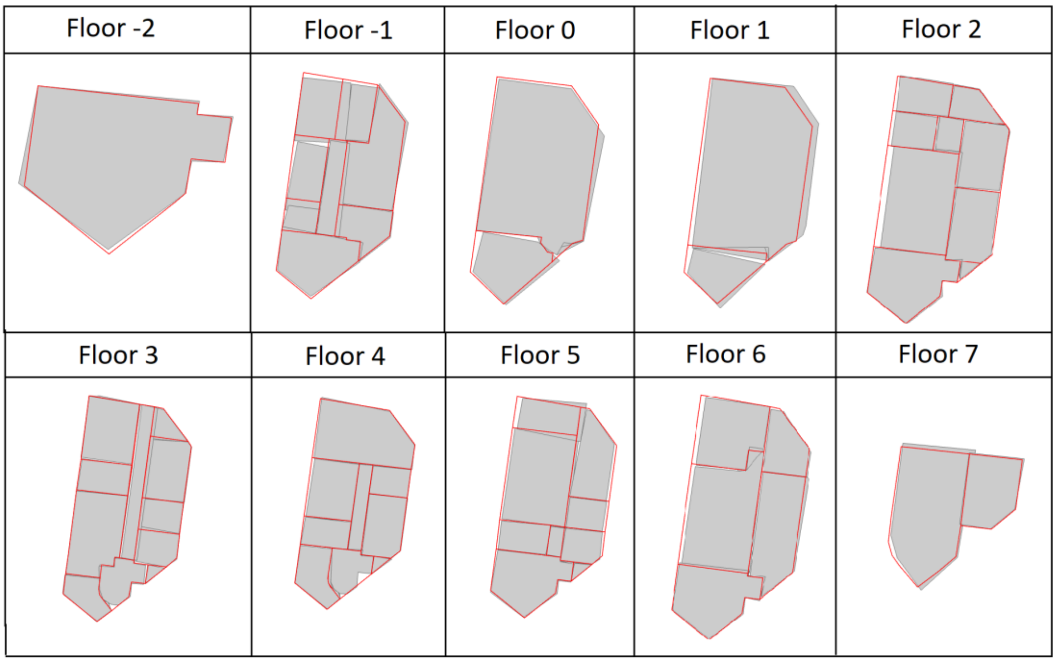

Figure 11: Comparison between the digitized polygons (in gray) and the reference data (in red), for each one of the studied building floors.

For the evaluation of the results in terms of accuracy, quality and completeness, a comparison with the reference data was performed. The architectural plans of each building's floor were utilized as reference data. The comparison was conducted between the reference data and the digitized unit polygons referenced to each one of the building floors. The comparison results were satisfactory; the average accuracy deviation between the compared datasets was 0.34m and their maximum and minimum deviation was approximately 1.17m and 0.03m, respectively (Figure 11). It is noted that the maximum deviation of 1.17m, was detected in the data which were collected by a device with a defective display, strongly affecting the correct selection of the polygonal vertices (point features). Furthermore, the generated 3D models were correctly positioned in 3D space while some small shape defects were caused by the imported errors in the digitization process as well as by errors and elevation jumps in the utilized DTM.

5. Assessment and Discussion

The establishment of a well-functioning 3D cadastral system is directly affected and depends on a combination of several factors that need to be explored in depth. This investigation becomes more complicated in cases where crowdsourcing techniques are adopted for the acquisition of 2D/3D geospatial/cadastral data. Due to the heterogeneity of the contributors both the methodology and the technical system, have to be carefully structured in order to provide a qualitative and reliable outcome. In this Chapter, an assessment of the 3D LADM-based technical solution presented in Gkeli et al. (2018) is presented, based on the practical experiment presented in Chapter 4. Experiments results and contributors' feedback are considered in order to evaluate the crowdsourced 3D cadastral solution, in terms of data quality, usability and reliability.

Data quality is a challenging topic of primary importance for the effectiveness and reliability of a cadastral procedure. Among various quality standards, ISO 19157 (2013) present six (6) spatial data quality elements (completeness, logical consistency, thematic accuracy, temporal quality, positional accuracy, and usability) in order to assess the quality of a product. As the crowdsourced technical framework, examined in this research, is structured based on the international standard of LADM, it turns out that the collected data are well attributed, distinguished and related by logical rules, maintaining the corresponding time stamp regarding the time period of their capture. Also, as the responsibility for the initial data collection process is transferred to the rights holders, who know better the boundaries and location of their properties, the reliability of the cadastral surveys is increased by the elimination of gross errors (Basiouka and Potsiou, 2012a,b; Mourafetis et al., 2015; Apostolopoulos et al., 2018; Molendijk et al., 2018; Gkeli et al., 2016; Rahmatizadeh et al., 2016). Thus, the collected data are characterized by completeness, logical consistency, thematic accuracy, temporal quality and reliability.

Moreover, based on the quantitative results concerning the comparison of digitized polygons with the reference data, it becomes clear that there were no significant discrepancies, with the average accuracy deviation of 0.34m and the maximum and minimum deviation of approximately 1.17m and 0.03m, respectively. As these results concern crowdsourced data, the achieved accuracy is assumed satisfactory. The digitized properties are positioned correctly in 3D space, with relatively small positional errors. However, the results of a crowdsourced procedure are strongly affected by volunteers'/contributors' personal knowledge, interests and willigness. The detailed evaluation of the benefits of the crowdsourced cadastral project and a proper trainning of contributors (rights holders - in our case) by a professional surveyor or a trained team leader, may improve the quality and the reliability of the results (Apostolopoulos et al., 2018; Gkeli et al., 2016).

In the subject experiment volunteers were middle-aged citizens of various levels of education and skills, and suitably competent in the use of smartphones. After they understood the purpose of the 3D crowdsourced cadastral project, they were very willing to contribute to this research. Their interest contributed to a successful outcome of the process. However, public recruitment in such crowdsourced procedures is not easy. The contributors/rights holders have to be motivated in order to participate and produce reliable results. Following gamification strategies, a reward for the rights holders' participation in the cadastral procedure, such as a discount on taxes or registration fees for the most active, may strengthen the rights holders' motives in order to ensure the smooth, robust and efficient implementation of the crowdsourced process (Gkeli et al., 2019). After reviewing volunteers about their opinion on this matter, there seemed to be a positive reaction about establishing such rewards policy.

In addition, as regards the technical part of the proposed crowdsourced framework, the usability of the developed mobile application consists of an important factor for the implementation of 3D cadastral surveys. During the data collection process certain bugs, weaknesses and deficiencies were identified and highlighted by the volunteers leading to correction at the next stage of this research. The main group of errors related to the functionalities of the mobile application. Its major inability was the delay or the forced interruption of the application, during the simultaneous data storage by the users. In this case, data may not be stored in the server of ArcGIS Online, making necessary the repetition of the registration process. However, even with the existence of this error, the registration process was quite fast as the registration of each property lasted about 7-12 minutes (average recording time).

In addition, another deficiency was in the accuracy of the mobile device's GPS. The achieved positional accuracy in the interior space of the studied building was about 1-5 meters, and thus the GPS could only be used for rough positioning in 3D space, in order to avoid gross errors during volunteer's orientation in the test area. The achieved accuracy of GPS strongly affects the overall registration procedure, especially in the absence of architectural plans or/and orthophotos of high accuracy. In addition, another weakness is detected in the screen size of the mobile device. A device with a wide screen, such as a tablet, may facilitate the identification of the property boundaries and make the registration procedure easier for the user.

However, beyond these drawbacks, volunteers agreed that the developed mobile application was easy enough to be learned and used, as its interface was designed appropriately leading to simplification of the registration procedure. Thus, based on the proposed components by Nielsen (2012), defining the usability of user interfaces through five (5) quality components, it turns out that the developed mobile application was distinguished by learnability, efficiency and memorability, but there are some parameters that need to be reconstructed and updated, in order to minimize errors and maximize users' satisfaction during the registration process. These identified shortcomings and weaknesses concerning the overall crowdsourcing procedure, will be taken into consideration, for the improvement and updating of the proposed technical system, in Gkeli et al. (2018).

It is worth mentioning that this research is at an initial stage and the proposed technical solution is evaluated on the basis of ideal conditions, assuming that the necessary spatial data infrastructure/plans are available, which may be the case for the majority of relatively new constructions in developed countries. By making the necessary adjustments in the proposed crowdsourced framework, it may be adopted by various countries utilizing the currently available spatial data infrastructure. Thus, this study presents only a proposal for the implementation of 3D cadastral surveys in the near future. As a next step of this research, a large-scale implementation and a more in-depth investigation regarding the absence of accurate registration basemaps for the land parcel and for the various building levels digitization will be carried out. Therefore, new challenges will be revealed and should be addressed, in order the proposed crowdsourced technical framework to be effective.

6. Conclusions

In an era dominated by vertically subdivided and overlapping property rights, the establishment of a modern land administration system (LAS) able to manage various types of rights in a uniform, standardized and reliable way, both above and below the land surface, is of great importance. While traditional cadastral field surveys often lead to delays, increasing gradually the cost of the cadastral procedure, a cost-effective innovative solution for the compilation of 3D cadastral surveys is needed. The examined crowdsourced technical approach for the initial acquisition, registration and representation of 3D cadastral data, consists of a valid paradigm of such an innovative solution. 3D crowdsourcing may provide an advancement with huge potentials for the fast, economic and reliable implementation of 3D cadastral surveys. With the proper motives, training and briefing of the community/rights holders about the benefits of such a crowdsourced cadastral project, the quality, reliability and relative accuracy of the procedure may be achieved. By implementing the necessary improvments to the examined technical system, the proposed crowdsourced approach may constitute a first step toward the initial implementation of 3D cadastre. In this way, the chances of meeting the Sustainable Development Goals (SDGs) in time are increased what is most important is to secure property rights through the timely completion of cadastral registration utilizing the existing fundings, and not the final geometric accuracy of the 3D cadastral data.

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