LADM-based Crowdsourced 3D Cadastral Surveying – Potential and Perspectives

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Key words: 3D Cadastre, LADM, Crowdsourcing, 3D Modelling, Visualization, 3D Spatial Data, Data Capture

SUMMARY

The rapid economic and social transformation over the last several years, has led to multiple rearrangements regarding the land administration procedures. Vertically growing cities, complex infrastructure, subdivision of three-dimensional (3D) space through several uses and overlapping property rights have increased the demand for establishing modern land administration systems, able to manage various types of rights in a uniform, standardized and reliable way, both above and below the land surface. Since 2012, the Land Administration Domain Model (LADM ISO 19152) constitutes the international standard for cadastral data modelling. Although LADM offers several representations for 2D and 3D cadastral data the definition of the acceptable 3D cadastral object representations and the corresponding 3D geometries are still under investigation. In recent years, many countries have developed legal procedures and prototype systems for the registration of rights on 3D property units, resulting in interesting approaches concerning the acquisition and visualization of such data. However, these approaches are in high demand in terms of required time and cost. In the meantime, significant progress has been achieved in developing 2D cadastral surveying procedures to minimize time and cost, utilizing modern techniques and technological achievements.

In this paper an innovative cost-effective technical framework is designed and proposed, in order to provide a modern technical solution for the initial acquisition, registration and representation of 3D cadastral data, based on international standardization (LADM). The architecture of the proposed technical framework consists of two connected complementary parts: the server-side and the client-side. The first refers to the webserver and therefore to the Database Management System (DBMS). The second refers to the communication between the server and the data capturing tool. For the server-side, a prototype system based on model driven architecture practices and LADM is developed. For the client-side an open-sourced self-developed mobile application for the acquisition of 3D crowdsourced cadastral data, 3D modelling and visualization of the 3D property units, as block models (LoD1) on a mobile's phone screen at real-time, is developed. The scope of this study is focused on investigating technical aspects of integrating legal and physical objects as well as assessing the quality of the produced geometric results in terms of accuracy and reliability. A detailed study of legal issues is outside the objective of this research. The proposed crowdsourced framework is tested for a multi-storey building in an urban area of Athens, Greece. The main conclusions refer to the usability, the perspectives and the reliability of crowdsourced data in designing an affordable and functional procedure for an initial implementation of a fit-for-purpose 3D cadastre.

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1. INTRODUCTION

The growing dominance of multi-dimensional infrastructures in the urban environment increases the complexity in land administration procedures introducing new challenges in recording, managing and visualising the spatial extent of vertically stratified cadastral objects. The vertical subdivision of three-dimensional (3D) space through several uses and overlapping property rights have increased the demand for establishing modern land administration systems (LAS) able to manage various types of rights in a uniform, standardized and reliable way, both above and below the land surface. The importance of such systems is underlined and put in a global perspective with actors as UN-Habitat, the Food and Agricultural Organization of United Nation (FAO), the UN Committee of Experts on Global Geospatial Information Management (UN-GGIN) and the International Federation of Surveyors (FIG) (Lemmen et al., 2015).

The Land Administration Domain Model (LADM) (ISO-TC211 2012) is one of the first spatial domain standards, providing a flexible conceptual schema as basis for the development of 2D and 3D cadastres based on a Model Driven Architecture (MDA). LADM establishes a shared ontology, enabling the 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). The Unified Modelling Language (UML) and the Object Constraint Language (OCL) has been defined from the Object Management Group (OMG) (Oriol et al., 2014) in order to determine the conceptual schemas as well as to model and design the constraints of the information systems. Such standardized model may be implemented through Geographical Information Systems (GIS) and database technology, supporting data maintenance activities and the provision of elements of the model. The transformation between the conceptual and the technical model is of great importance. The most-known tools capable of utilizing such an automated conversion are the SWISS standard of INTERLIS language and the Enterprise Architect UML modeling tool from Sparx Systems.

While LADM provide a generic framework for 3D cadastres, the identification of the acceptable 3D geometries and representations for the 3D cadastral objects are still challenges (Ying et al., 2015). The utilization of already existing 3D data sources (BIM, CityGML, etc.) may facilitate the registration of buildings as 3D spatial units (Thompson et al., 2016; Oldfield et al., 2016; Atazadeh et al., 2018; Alattas et al., 2017; Alattas et al., 2018). The main disadvantage is their limited availability, failing to cover all possible implementations. Nevertheless, in recent literature numerous 3D data sources appeared, capable to describe the 3D aspect of the cadastral objects including lidar data, aerial, terrestrial or space-borne optical data, topographical data, terrestrial laser surveys, and data derived from crowdsourcing or volunteered geographic information (VGI) (Goodchild, 2007a;b). In recent years, VGI and crowdsourcing techniques have become more and more popular, while they constitute cost-effective, efficient and time-effective methods for 2D and 3D data acquisition. Crowdsourcing techniques have already been used in 2D cadastral surveys (Basiouka and Potsiou, 2012a;b; Mourafetis et al., 2015; Apostolopoulos et al., 2016; Gkeli et al., 2016), while in the last few years the research has focused on the investigation of the potential use of crowdsourcing in 3D cadastral surveys (Gkeli et al., 2017a;b;c). The first results seem to be very promising, providing the basis for the implementation of a fit-for-purpose (FFP) 3D cadastre.

As the most of the existing approaches are costly and time-consuming, they are not appropriate to serve the needs of the countries with limited financial resources, as well as the needs of the rapidly growing cities of the developing world that lack basic geospatial infrastructures. In this paper an innovative crowdsourced approach is designed and proposed, in order to provide a modern technical solution for the initial acquisition, registration and representation of 3D cadastral data. The proposed approach explores the potential integration of the legal cadastral information with the physical 3D cadastral objects, based on international standardization (LADM). The main interest of the proposed framework is focused on investigating the technical aspects of integrating legal and physical objects. The detailed study of legal issues is outside the objective of this research. In Chapter 2, the main characteristics of LADM together with the results of the recent research referring to the 3D aspect of LADM, are presented. Chapter 3 investigates the potential use of crowdsourcing for the implementation of 3D cadastral surveys. Chapter 4 presents the proposed framework describing its technical and methodological parts. Chapter 5 presents an implementation test of the developed system in a multi-story building of the National Technical University of Athens (NTUA), as well as the results of the overall procedure. Finally, Chapter 6 presents the main conclusions referring to the perspectives and the reliability of the proposed crowdsourcing framework as a basis for the compilation of a well-functioning fit-for-purpose affordable 3D Cadastre.

2. 3D ASPECT OF LADM

The Land Administration Domain Model (LADM) is composed of three main packages: the Party package, the Administrative package and the Spatial Unit package, forming the core elements of a multipurpose land administration system (MLAS) (Figure 1, left). One of the most critical parameters concerning the utilization of LADM for the development of an efficient 3D cadastral system is the creation of the 3D cadastral geometric objects. The Spatial Unit package and the Spatial Representation and Survey sub-packages include several representations for 2D and 3D cadastral data (sketch, point, text, unstructured line, polygon and topological based spatial unit). According to LADM, a “true” 2D representation of a spatial unit consists of boundary face string, known as LA_BoundaryFaceString, while a “true” 3D representation of a spatial unit consists of arbitary oriented faces, known as LA_BoundaryFace (Figure 1, right). A real 3D cadastral object may be defined as a valid volumetric object that can be represented by one closed polyhedron, refined by a set of connected faces (Ying et al., 2015). However, the identification of the acceptable 3D geometries and representations for the 3D cadastral objects is still challenging (Ying et al., 2015).

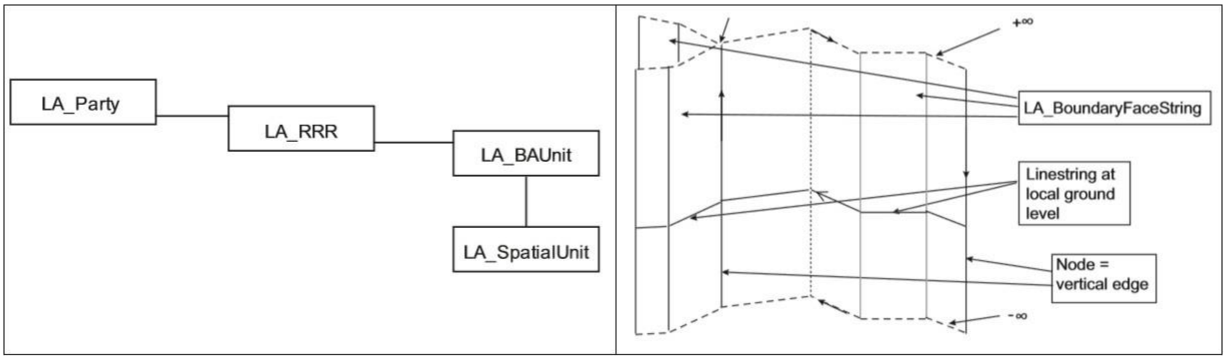

Figure 1. Basic classes of the LADM (left) and boundary face string concept (right) (LADM, 2012)

2.1. 3D LADM-based country profiles

Among various investigations concerning several prototype systems and approaches for the implementation of 3D cadastres only a few are based on LADM standard. Each one of the proposed country profiles handle the 3D aspect according to the current legislation and cadastral background. One of the first pilot LADM-based country profiles was developed by the Russian Federation. The initial cadastral prototype emphasizes the visualization of 3D information of the cadastral objects as polyhedrons, while a web-based browser solution has been developed. The model was adapted to the Russian environment and oriented to five types of property: land parcels, buildings, premises, structures and unfinished construction projects (Vandysheva et al., 2011).

A 3D LADM-based Polish country profile was proposed by Góźdź and Pachelski (2014). For the registration of 3D cadastral objects several new LADM classes were developed by the authors. For the implementation of the proposed model a CityGML-LADM Application Domain Extensions (ADE) was created in order to establish the link between the legal and physical counterparts.

An interesting approach was developed by Lee et al. (2015), who proposed a 3D land administration model for Korea using a cadastral resurvey form, including the representation of 3D physical properties and 3D rights. The new cadastral model supports 3D information as it can contain underground utility and superficies information to present the physical and legal information on both buildings and underground features. New classes added to LADM provide the efficient description and representation of the 3D cadastral objects.

In Kalogianni (2015), a different LADM-based country profile was proposed utilizing the concept of LA_Level. The country's spatial units are categorized and organized in different levels. A new class (GR_Level) is introduced, allowing the efficient managment and representaion of data according to their level.

Several interesting approaches have been proposed for the Malaysian LADM-based country profile in previous years (Zulkifli et al., 2015). The Malaysian profile includes support for strata objects and 3D spatial unit representing building, utility and lot. Rajabifard et al. (2018) proposes strategies for the implementation of 3D Malaysian National Digital Cadastral Data Base (NCDB). The investigation focuses on the processes for upgrading the existing dataset and data collection methods in order to support the 3D digital data and the creation of 3D spatial database based on the elicited user requirements.

2.2 Linking LADM with physical models

Through the last few years several approaches have been proposed to settle a link between the legal and physical counterparts of 3D cadastral objects. As this research domain is newly emerging, the amount of available literature is not very broad yet. The majority of these investigations focuses on the integration between legal and physical data models utilizing application schemas and technical models (CityGML, IndoorGML, BIM/IFC, LandXML, InfraGML, etc.). In Kalogianni et al. (2016), a LADM-based prototype system was developed based on model-driven architecture practices utilizing INTERLIS language and tools. The main purpose of this study is the integration between the 3D legal aspect and the corresponding physical reality of 3D objects (described via CityGML, IFC, InfraGML, etc). While INTERLIS structures describe only 2D objects, an alternative structure for the GM_Solid is proposed. Thompson et al. (2016) explores an integrated method of defining 3D spatial units through an alternative approach of the combined use of LA_BoundaryFaceString and LA_BoundaryFace within the LandXML encoding structure. Oldfield et al. (2016) investigated the potential adoption of existing 3D data sources, as 3D Building Information Models (BIMs), in 3D cadastre. Atazadeh et al. (2018) investigated the potential integration of the legal information modelled with LADM and physical information based on Industry Foundation Classes (IFC) standard, leading to satisfactory results. Other researchers proposed the integration between LADM and IndoorGML. The main idea is to associate LADM with the subdivision of the indoor space based on the right of the user (Alattas et al., 2017; Alattas et al., 2018).

3. THE POTENTIAL USE OF CROWDSOURCING FOR 3D CADASTRAL SURVEYS

In the context of significant technological developments, the role of Information and Communication Technology (ICT) is enchanced. Low-cost equipment, crowdsourcing techniques, mobile services (m-services), web services and open-source software (OSS) sign a new era for the cadastral data acquisition and dissemination procedures, minimizing the cost and the time of the required surveys. The introduction of crowdsourcing in 2D cadastre has been under investigation for a number of years (Keenja et al., 2012; McLaren, 2012; Mourafetis et al., 2015; Clouston, 2015; Apostolopoulos et al., 2016; Gkeli et al., 2016) with positive results. However, the introduction of crowdsourcing into 3D cadastres poses additional challenges in the modelling of the 3D world and the information related to the 3rd dimension. Recent research has proved that low-cost sensors and cameras often available in smartphones enable 3D geospatial data acquisition by non-professional citizens. Thus, each citizen may be defined as potential neo-photogrammetrist (Leberl, 2010), who can collect 3D data and develop models using modern automated 3D reconstruction algorithms and tools.

Through the last few years the research has focused in the investigation of the potential use of crowdsourcing in 3D cadastral surveys (Gkeli et al., 2017a;b;c;d). According to Gkeli et al. (2017d) the utilization of parametric modelling techniques (Model-driven methods) tends to be the best option for a cost-effective and rapid implementation of 3D crowdsourced cadastral mapping, as it is considered to be simpler than the time-consuming and protracted modelling processes. Model-driven methods are characterized by high robustness and maintenance of topology and can be adopted by parties without specific photogrammetric skills. The development of an innovative parametric modelling algorithm appropriate for cadastral

mapping purposes and the utilization of modern IT tools and data collection methods, such as crowdsourcing, may lead to a fast and cost-effective solution for the initial registration, building reconstruction and property units visualization of functional 3D cadastral maps.
Until now, 3D systems focus mainly on 3D modelling of physical real-world objects (building), without paying much attention to their multi-dimensional implementation (Jaljolie et al., 2016). The unified management of legal information and their physical counterpart through standardized data modelling prototypes is of a great importance in order to ensure transparency in land administration procedures. Jones et al. (2017) present a low cost LADM-based approach for the implementation of a post conflict cadastre in Colombia utilizing modern GIS technology. Although this approach refers to the implementation of a 2D land administration system, it presents a different perspective about the usage of LADM in the fit-for-purpose context. In this sense, a fit-for-purpose 3D crowdsourced cadastral surveying approach based on standardized data model as LADM, might be of significant value to speed up processes for establishing 3D cadastres, especially in the densely populated and informally developed cities.

4. PROPOSED FRAMEWORK

The proposed crowdsourced approach tends to provide a modern cost-effective LADM-based technical solution for the initial acquisition, registration and representation of 3D cadastral data. The proposed approach consists of two complementary parts: the technical aspects and the procedure to be followed. The technical part refers to the technological background and the sub-systems that need to be developed in order for the proposed framework to be functional. The procedure refers to the way that the implementation of the 3D crowdsourced surveys are conducted through the developed systems.
The main interest focuses on the geometry and representation of the physical 3D cadastral objects (spatial units). The detailed study of legal issues is outside the objective of this research. The main components of the proposed framework are the active participation of the rights holders, the exploitation of modern IT tools, m-services, web services, database manangment systems (DBMS) services, and the development of an innovative algorithm for the automatic 3D modelling and visualization of the spatial units.

4.1 Technical Aspects

The architecture of the proposed technical framework consists of two connected components: the server-side and the client-side. The server-side refers to the web server and therefore to the Database Management System (DBMS) where the collected data are stored. The client-side refers to the communication between the server and the data capturing tool. For the server-side a database schema according to LADM specification was generated. For the client-side, an open-sourced self-developed mobile application for Android devices, was developed. As server for the storage and management of the collected data, the server of ESRI’s ArcGIS Online (ESRI, 2018) was utilized.

4.1.1 Database Management System (DBMS)

The DBMSs conceptual schema was developed through Enterprise Architect UML modeling tool from Sparx Systems. Enterprise Architect, through the use of Model Driven Generation

(MDG) Technologies, supports the Geography Markup Language (GML) application schemas and the modeling of ArcGIS geodatabases. The data structure of the database is based on the LADM standard, while some new classes were generated in order to support the geometry of 3D spatial units. As the developed database schema is about to be imported in an ArcGIS platform, the necessary conversions were connected to the application schema elements of LADM, in order that the final model would comply with the ArcGIS workspace metamodel, which is used by the ArcGIS extension of Enterprise Architect. Figure 2 presents the basic classes of LADM: LA_Party, LA_RRR, LA_BAUnit and LA_SpatiaUnit as well as a new class named LandParcel3D. The insertion of the class LandParcel3D tends to emphasize the basic spatial unit element. LandParcel3D inherits the attributes of LA_SpatiaUnit class, while an attribute defining the address was added.

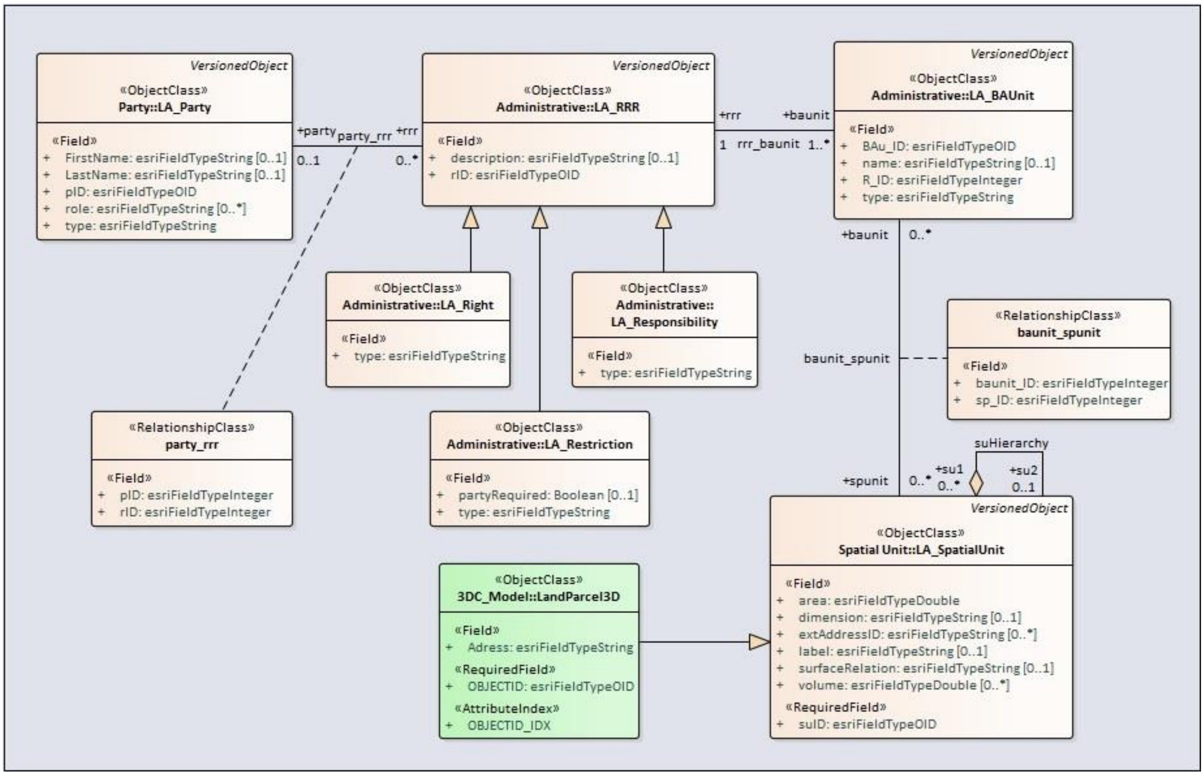

Figure 2. Conceptual schema of the developed data model

Ying et al. (2015) states that a real 3D cadastral object may be defined as a valid volumetric object that can be represented by one closed polyhedron refined by a set of connected faces. A polyhedron may be defined as a 3D solid composed of vertices, edges, faces and an incidence relationship between them (CGAL, 2018). Based on this point of view, the UML diagrams describing the structure of the 3D cadastral objects were created. Thus, a 3D land parcel may be defined as a set of connected polygonal faces, representing a 3D prismatic volume with no upper and lower bound. In Figure 3 the proposed model defining the structure of a 3D cadastral parcel is presented. The class LPBaseParcel includes the geometry of a land parcel in 2D, while the class LP_BoundaryFaces includes the geometry describing the polygonal faces of a land parcel. In order to enable and simplify the representation of the land parcels boundary faces in the ArcGIS platform, a KML object (KMLBoundFaceStrings) defining the

3D land parcel is utilized. The class LP3D_Points includes the vertices of the connected polygon faces, preserving the relationships between them.

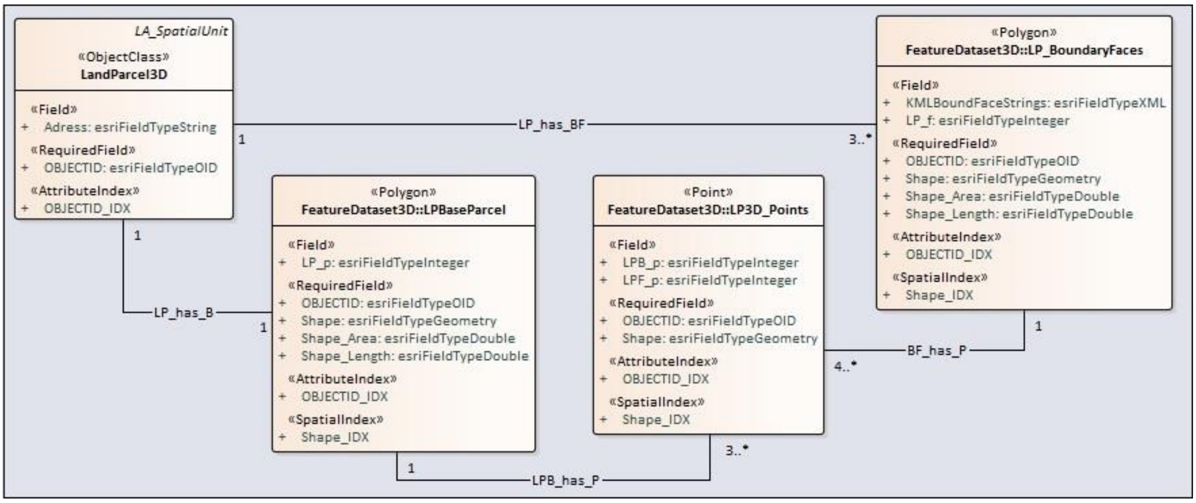

Figure 3. Proposed conceptual schema defining the structure of a 3D cadastral parcel

Similarly, in order to describe the 3D building units a new class named BuildingUnit3D was created. BuildingUnit3D class is directly linked with LA_SpatiaUnit class; it preserves the necessary information regarding the definition of the polyhedron geometry of a building unit (property). As such, the attributes related to the floor, height, area, volume of each building unit were selected. The attribute referring to the current use of a building unit was inserted as a descriptive characteristic. It is noted that the main interest of this research focuses on the specification of the building units as volumes (LOD1) (Gröger et al., 2008) in the 3D space, so that the individual properties can be registered correctly. Thus, a 3D building unit may be defined as a set of connected polygonal faces, representing a 3D prismatic volume with specified upper and lower bound. The proposed model defining the structure of a 3D cadastral building unit is presented in Figure 4. The classes BuildingUnit_Top, BuildingUnit_Base, BuildingUnit_VFaces and Points3D include the geometry describing each one of the building unit's face as well as the relationships between them. Similarly with the class LP_BoundaryFaces, each one of these classes is represented by a KML object in order to simplify their representation in the ArcGIS platform.
The complete database schema was extracted as a Geodatabase Workspace XML Document (containing the ArcGIS schema) in order to be imported into the ArcGIS platform and linked with the rest of the elements of the proposed framework.

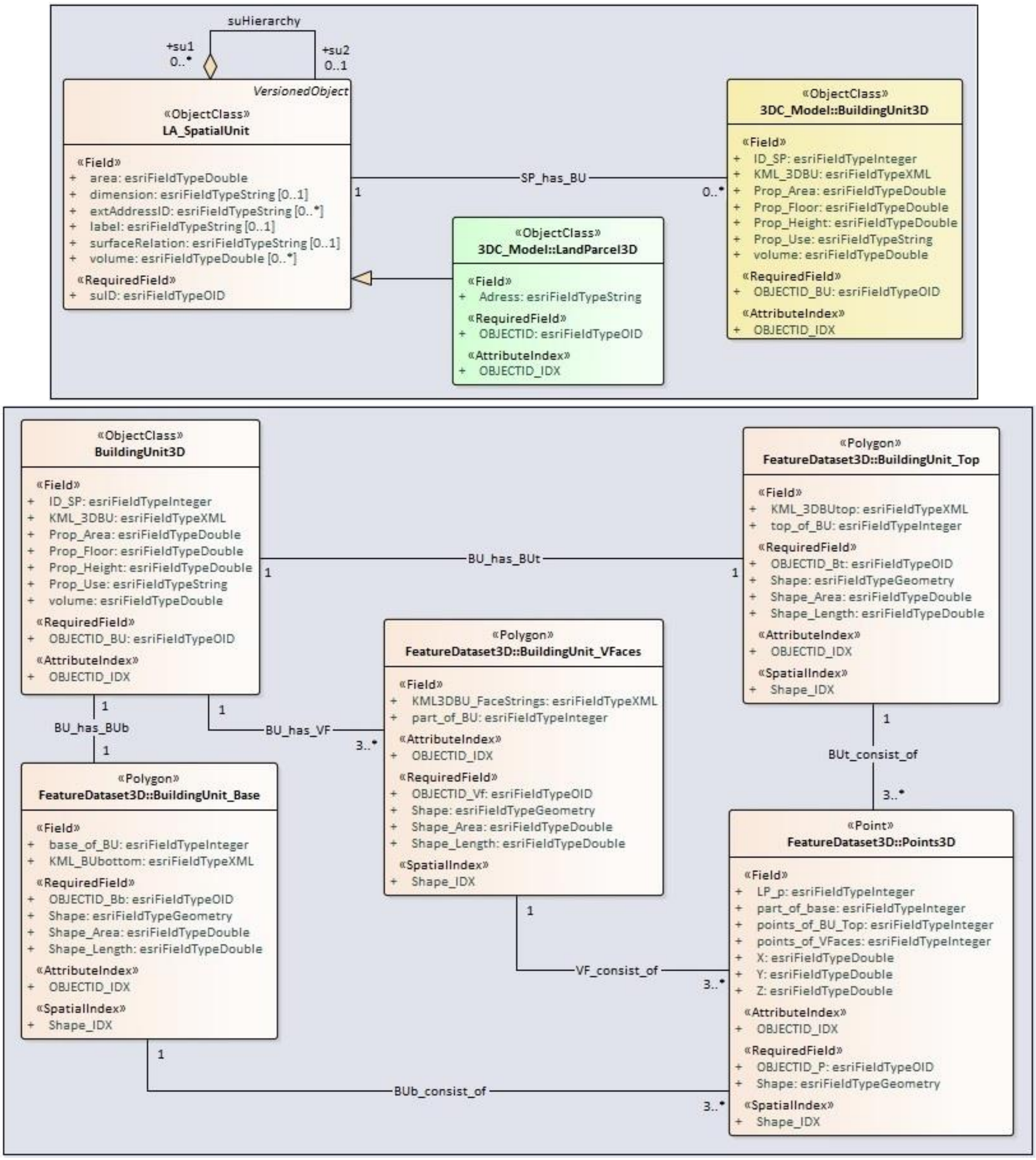

Figure 4. Conceptual schema defining the structure of a 3D cadastral building unit

4.1.2 3D – Crowdsourcing Self-developed Mobile Application

To support the client-side of the proposed technical framework an open source prototype for Android mobile devices was developed by the authors (Figure 5) based on the results of earlier stages of their research (Gkeli et al., 2017d). The mobile application may be utilized for the collection of 3D crowdsourced cadastral data by non-professionals; the automatic generation of 3D land parcel and property unit models as block models (LoD1), using Model-driven approach; the generation of the corresponding KML objects; and the objects visualization in real-time. The application allows the identification and collection of cadastral geometric data, exploiting the available cartographic infrastructure (2D architectural plans, orthophotos, aerial photos) as basemaps. The interface is appropriately configured so that descriptive information referring to the property may be inserted, as well. The GPS of the mobile device is used only for a rough positioning in order to avoid gross errors during rightholder's orientation in 3D space. The collected data and 3D models are stored in the cadastral database located in the Cloud of ESRI (ESRI, 2018). The developed application simulates the 3D real world utilizing a Digital Terrain Model (DTM) offered by ESRI. Data are pulled from the application and pushed back into the database in the server if there is an Internet connection. The identification procedure reaches high accuracy requirements as the maximum supported level of scale reaches 1:100. For the development of the mobile application a set of software tools is utilized:

- the Integrated Development Environment of Visual Studio 2013 (IDE),
- the Java Deployment Package, Oracle JDK 8 (Java Development Kit),
- the Android SDK Manager (for API level 19),
- the add-in ArcGIS Runtime SDK for .NET (100.0.0) of ESRI, which adds the function of ArcGIS to the application via libraries (with a wide variety of methods and functions),
- the add-in Xamarin 4.5.0 for Android Support Library that allows developers to build Android, iOS, and Windows apps within the IDE using code completion and IntelliSense,
- the SharpKML library,
- the programming language of C#,
- the Server of ArcGIS Online (Cloud of ESRI), for the storage and management of data.

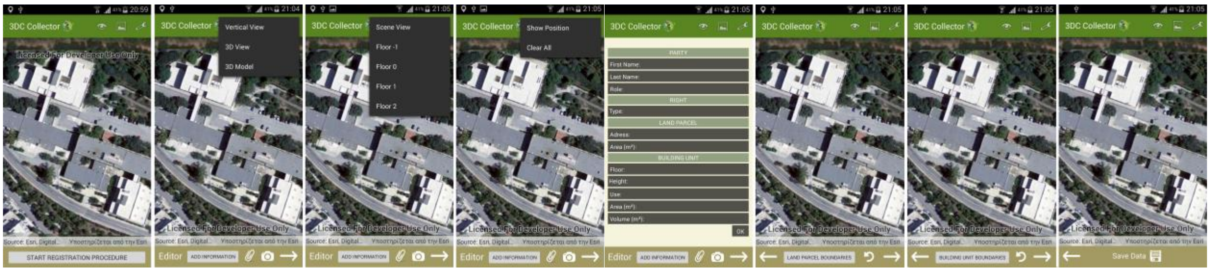

Figure 5. Users interface overview of the developed mobile application

The interface of the application was designed appropriately in order to lead and simplify the registration procedure. The application provides a set of tools for the identification and digitization of the land parcel's and building unit's boundaries as well as the insertion of the necessary proprietary information for the declaration of the property rights. The data collection procedure requires that the user will enter the spatial data values in meters through the "Height" and "Floor" fields, which define the height and the number of the floor on which the property unit is located. The height may be measured with a simple measuring tape from the interior of the property unit or may be assumed to have a default value of about 3m. Once the data are imported in the application and checked by the user, the 3D land parcel model and the property unit model are automatically produced based on the inserted geometric and numeric information (height, floor). Subsequently, by selecting the visualization tool the 3D property models (land parcel and building unit) will be visualized on the mobile's phone screen; the property unit may be located above or below the ground. In addition, the application allows the user to capture photos of the property unit in order to better identify it. Finally, the user can store the collected data in the cadastral database, updating the system with the new records and the corresponding 3D property unit model.

4.2 3D Crowdsourced Cadastral Survey Procedure

The proposed procedure aims to upgrade the current 2D cadastral surveying procedure and to enable a 3D cadastral data acquisition, flexible and adjustable both for the developed and the developing world. As the legislation and the cadastral surveying procedure differs from country to country, in this approach a general framework is introduced in order to save time and funds. The proposed procedure aims to reform and simplify the most expensive and time-consuming phase of the implementation process, which is the 3D cadastral data acquisition including the semantic information of the ownership status and other rights, as specified by the LADM standard. The main purpose is to provide a simple, fast and reliable procedure for the effective manipulation of the declared geometric data (2D and 3D) through an automatic process; the construction of the valid 3D cadastral objects; and, finally, the creation of a preliminary 3D cadastral database, based on international standards. The proposed procedure is presented in Figure 6.

The proposed framework follows an innovative approach for the compilation of cadastral surveys. The responsibility for the initial collection of the cadastral data is transferred to the citizens/rights holders, reducing gross errors. The proposed crowdsourced 3D procedure begins with the declaration of a specific area under cadastral survey. The NCMA should provide a recent basemap for the compilation of the necessary 3D cadastral survey. As the available geospatial infrastructure differs from country to country the selection of the appropriate basemap depends on the options available in each country. A recent orthophoto or cadastral map depicting the area under a cadastral survey, overlayed with the architectural plans of the building units, is the best option to proceed with the 3D recording. In this case, the geometric accuracy according to the specifications can be ensured (Mourafetis et al., 2015). Otherwise an aerial photo may be used reducing the geometric accuracy. In the latter case, the land parcel boundaries and the building footprints should be visible on the basemap. If the parcel boundaries are not readily visible, the GPS sensor of the mobile phone should be utilized so that they may be digitized on the basemap.

In the next phase, the rights holders may be asked to collect and submit information referring to the boundaries of the individual property units for which they have rights together with photos or files of all available legal documents proving their rights. As has been proven in earlier stages of this research, the determination of land parcel boundaries and building footprints may be easily conducted by the rights holders identifying and digitizing them on the available basemap that will be visible on their mobile phone screens (or laptops, or tablets) (Mourafetis et al., 2015; Apostolopoulos et al., 2016; Gkeli et al., 2016). The NMCA should provide the rights holders/citizens with a mobile cadastral application capable to support the 3D cadastral surveys. An example of such mobile application is presented in section 4.1.2. The mobile application allows the rights holder to move throughout the property using the GPS sensor of the mobile device in order to collect directly the necessary information/measurements. It is noted that mobile applications and wireless services are inclusive and preferable as not everyone has access to a cable internet.

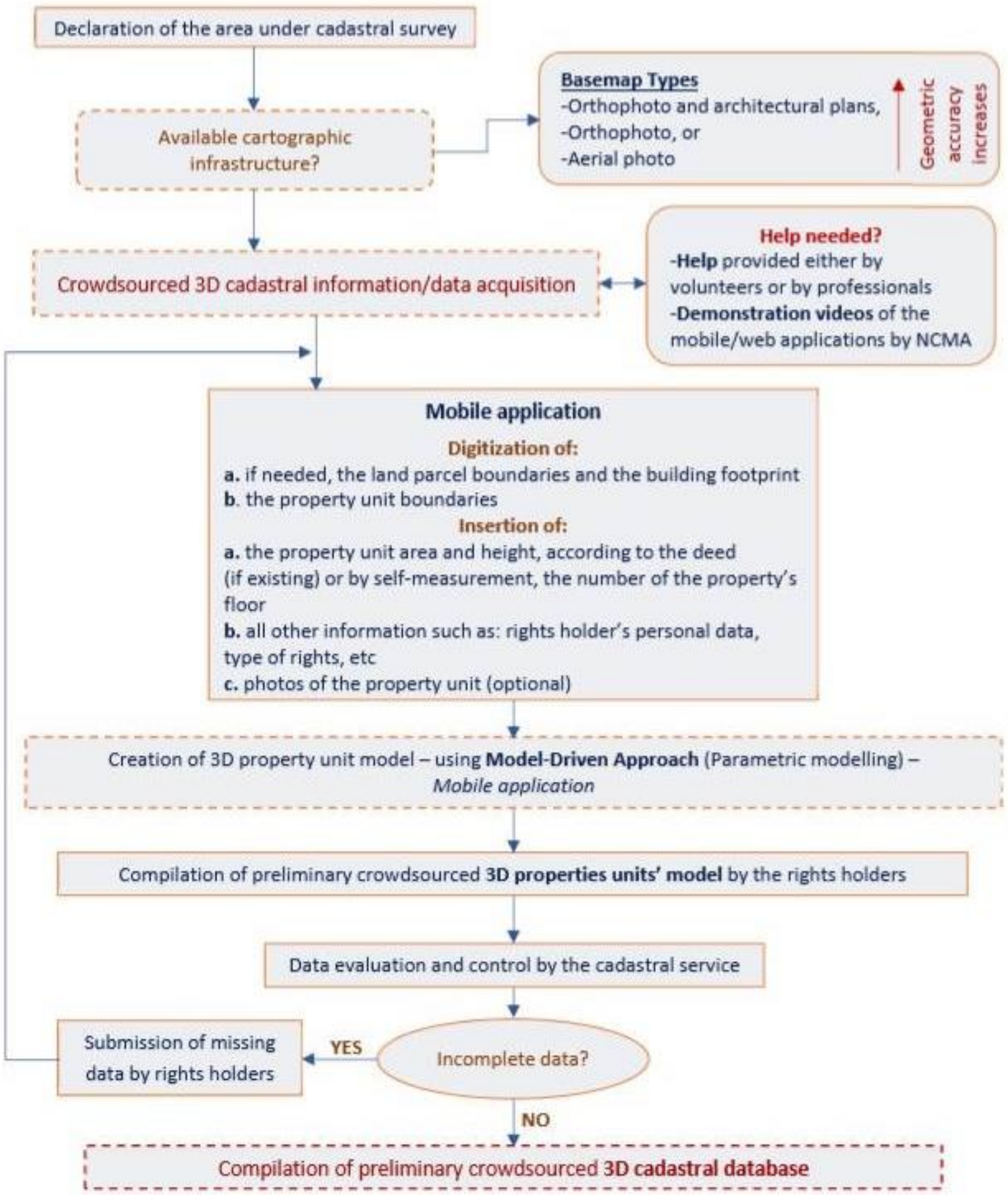

Figure 6. Proposed crowdsourcing procedure for 3D cadastral surveys

Through the mobile cadastral application the identification of the property boundaries on the available basemap may be done by the rights holders. Simultaneously, they may submit information about the property: unit height; area size; the number of the floor on which the property unit is located; other information, such as the rights holder's personal data and type of rights; verification images (photos) of the property unit (optional); and legal documents. The submission of the legal documents and additional evidence about the rights and rights holders may be done directly through the mobile cadastral application by attaching them either as scanned documents or as photos. All this declared information is fundamental to the automatic 3D modelling of each property through the mobile cadastral application and, finally, generation of a reliable cadastral database. In case the rights holders have difficulty or

an inability to use the provided software (mobile application), NCMA may support them with the adequate demonstration videos with detailed instructions for how to use the mobile application. In addition, a local trained volunteer or a local professional surveyor may help the rights holders to complete the declaration cadastral procedure.
By the completion of this phase the NCMA will have a draft 3D building and property unit database conducted by the rights holders. The evaluation and control of this database may be carried out by the cadastral agency and through publishing the collected data, or it may be outsourced. Additional data together with the collection and submission of any objections for corrections identified by the rights holders in the initial data should be accepted.

5. CASE STUDY

To verify the effectiveness of the proposed framework, a case study was perfomed. The developed system was tested for the multi-storey building of the School of Rural and Surveying Engineers of the National Technical University of Athens (NTUA) with the assumption that the building may be considered as a block of apartments and each office room as an indivilual property unit. The main objective is to identify the boundaries of each office room and record some basic descriptive information about the rights and rights holders, utilizing the developed mobile application. The recording levels include levels above and below the terrain surface, making both the process and the results quite interesting.
The type of collected information may vary according to the application and the implementation area. For this case study the collected data include the building- and each room-outline coordinates, the height of each room, the floor number and the descriptive information about the building (area code, address), the room holder (name, role, type of rights) and the room (floor, height, use, area size, volume). The parcel boundaries are the boundaries of the NTUA campus parcel.
For the implementation of the proposed procedure, an orthophoto of the test area at a scale of 1:1000 and the floor plans of the underground floor, the ground floor, the first and the second floor at a scale of 1:200, were used as basemaps (Figure 7). Data collection was performed in cooperation with the employees, who were assumed as rights holders. After a brief training about the functionalities of the developed mobile application they were familiarized with the application. The smartphone's GPS had good signal, even in the interior of the building while the positioning accuracy was about 1-3m. The GPS was used only for the orientation of the user within the case study area, in order to avoid gross errors.
The registration process starts by the insertion of the adequate descriptive information regarding the declaration of rights and the rights holder's data. Verification images and legal documents (in an official procedure) may be inserted, in order to support the registration procedure. Next, the identification of the land parcel boundaries was conducted, by selecting features (points) on the parcel basemap (orthophoto) in order to form the surrounding polygon of each building (as the corresponding land parcel) using the digitazation tool. Subsequently, the identification of each property unit boundary outline was performed, by selecting the floor basemap in which the property unit is located, through the selector basemap tool. Then the user has to select features (points) on the basemap, using the digitization tool, in order to form the polygon of the property unit. Utilizing the mobile's application tools, the user was able to

alter any wrong input data and update the information he/she has entered into the application. The described procedure is presented in Figure 8.

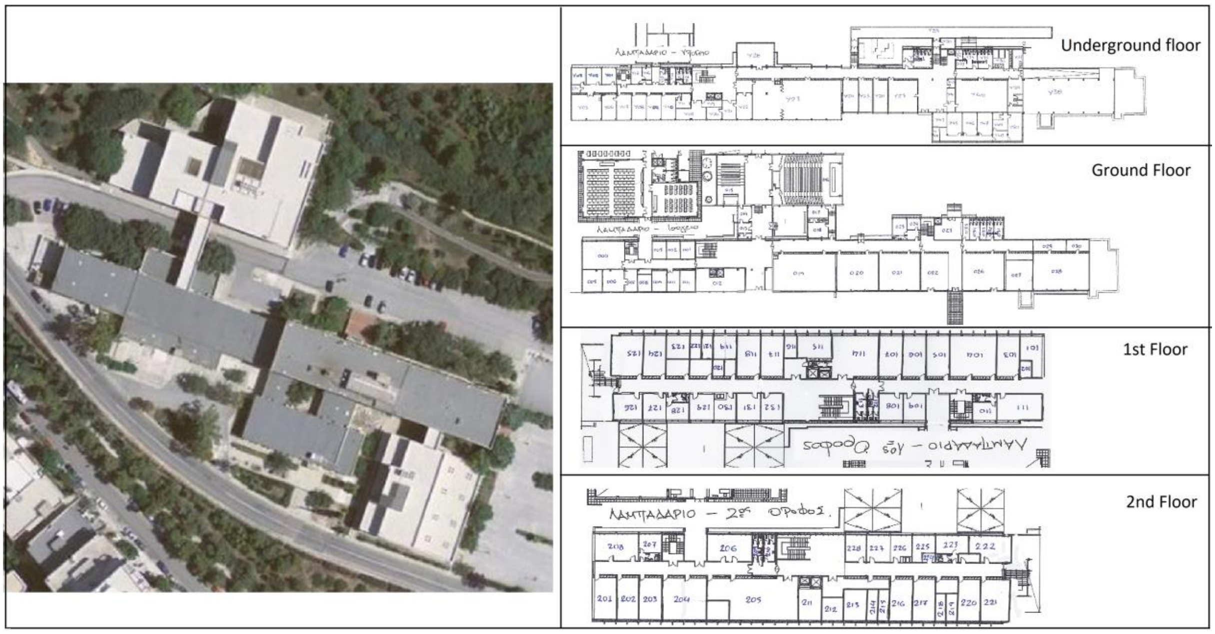

Figure 7: Orthophoto of the case-study area at the scale of 1:1000 (left) and the floor plans of the underground floor (top right), the ground floor (2nd row right from the top), first floor (3nd row right from the top) and second floor (bottom row right)

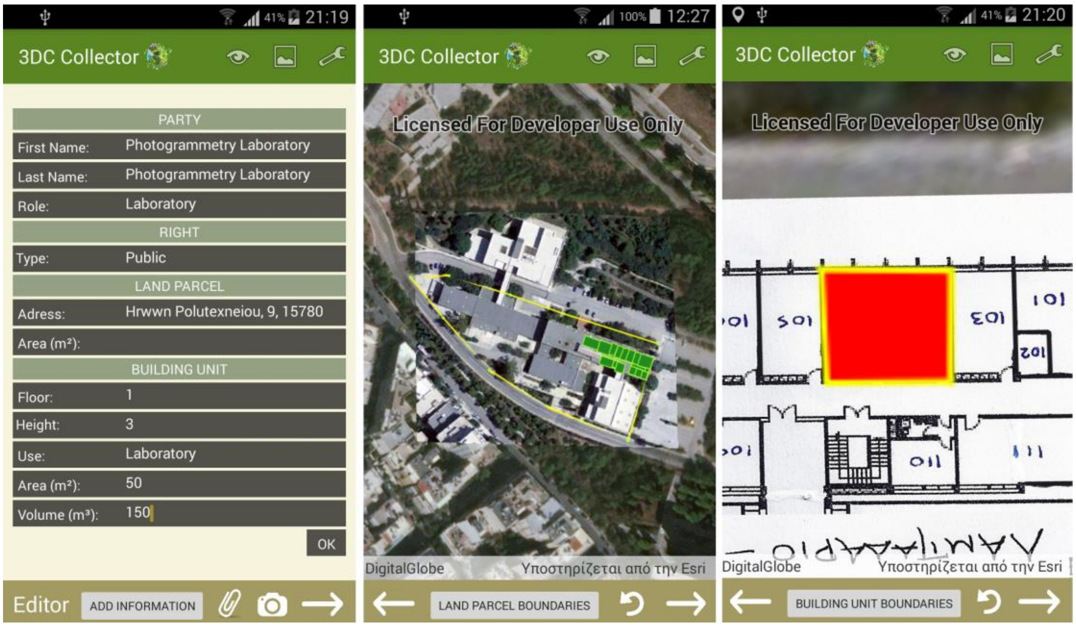

Figure 8. Example of the recording process through the developed mobile application, including (a) the insertion of the adequate cadastral information, (b) the polygon digitization on the parcel basemap describing the land parcel and (c) the the polygon digitization on the floor basemap describing the building unit, on the basemap

Once the data are imported and checked, the 3D visualization tools allow the user to see the 3D property model of the land parcel and the building unit, above or below ground, through the selection of the corresponding tool (Figure 9). In the last step of the registration procedure, the collected data are stored in the developed database in the Cloud of ArcGIS Online, updating the system with the new records and the corresponding 3D property models.
Once the data refering to each room are imported and controlled, the 3D visualization of the registered room was achievable through the selection of the corresponding tool (Figure 8). As the last step of the registration procedure, the collected data were stored in the Cloud of ArcGIS Online, updating the system with the new records and the corresponding 3D models.
During the data collection process, no major problem was encountered. The mobile application was easy to use and the necessary information were successfully collected. The overall procedure was relatively quick as the registration of each property lasts about 5-7 minutes, depending on the complexity of the boundary shape and the familiarity of the user with the mobile application. The existence of an architectural floor plan is really helpful as it clearly presents the boundaries of each room, leading to successful and geometrically accurate results.

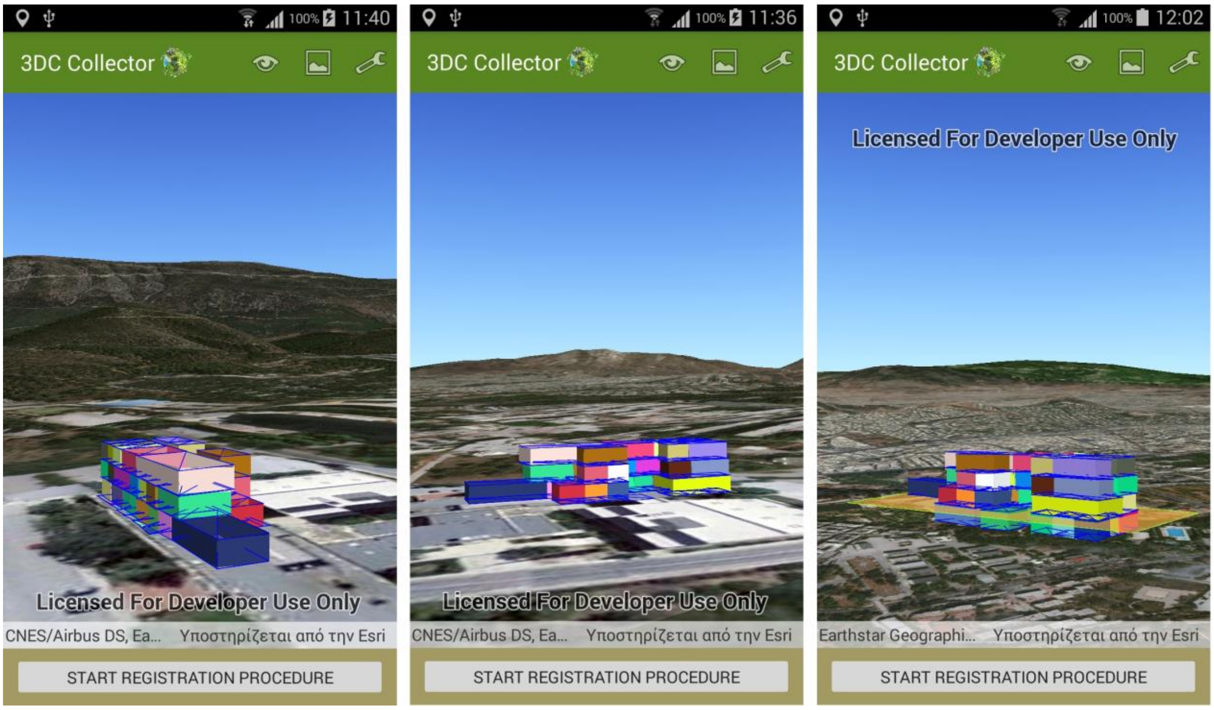

Figure 9.3D models of the declared properties above (left, middle) as well as above and below (right) the ground surface, using the 3D Model tool of the developed mobile application

After the completion of the registration procedure, the LADM-based database was exported from the Cloud of ArcGIS Online, and the draft crowdsourced 3D property models were generated. The collected data were evaluated in terms of accuracy, quality and completeness through a comparison with the reference data. The architectural plans describing each unit on the floor plans were used as reference data. Based on Gkeli et al. (2017d), the comparison was conducted between the reference data and the digitized unit polygons referenced to each one of the building floors. The evaluation of the results shows that there were no significant discrepancies between the compared data (Figure 10). The average accuracy deviation between the compared datasets is 0.17m while their maximum and minimum deviation is approximately 0.49m and 0.03m, respectively. The quality control shows that the achieved accuracy is satisfactory, revealing that the proposed registration procedure utilizing the self-developed mobile application leads to reliable results. The produced 3D models are correctly positioned in 3D space while the small shape defects are caused by the imported errors in the digitization process. The proposed procedure, together with the developed system, have notable potentials. Certainly, the results of a crowdsourced procedure may be greatly improved after a proper training and briefing of the rights holders/ users by a trained team leader or a professional surveyor (Apostolopoulos et al., 2016; Gkeli et al., 2016). It is noted that the presented case study constitutes only a practical example in exploration of the Figure 10: Comparison between the digitized polygons (in blue) and the reference data (in red), for each one of the studied building floors.function and results of the proposed framework.

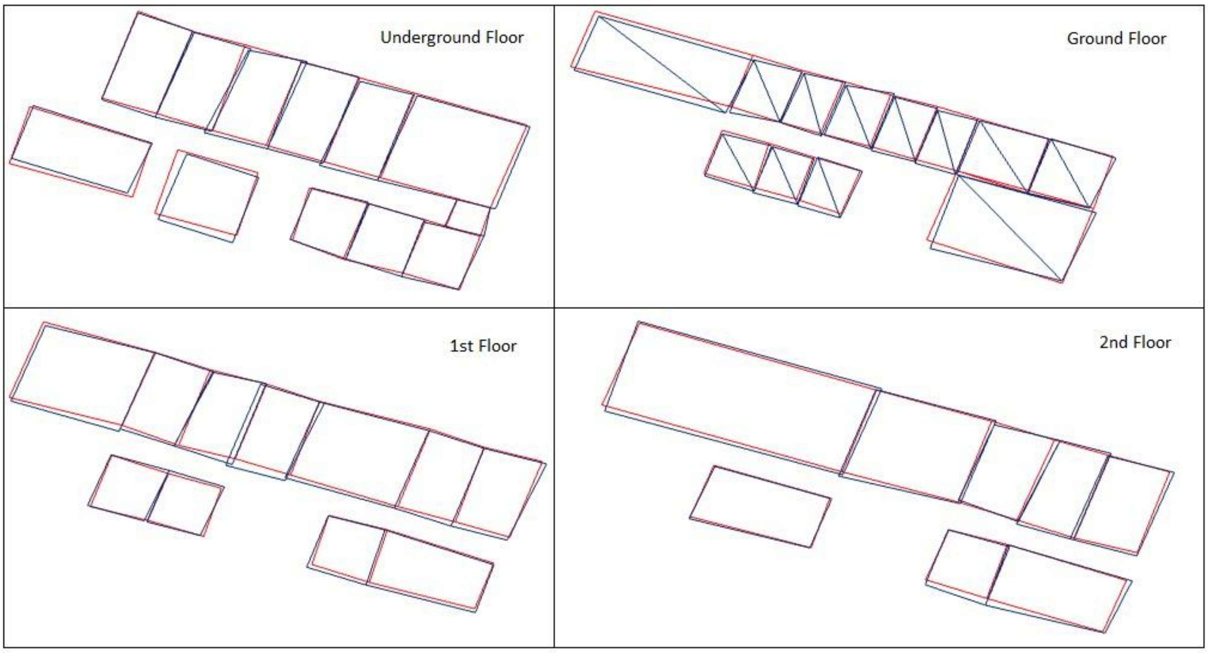

Figure 10. Comparison between the digitized polygons (in blue) and the reference data (in red), for each one of the studied building floors

6. CONCLUSIONS

While the traditional 2D cadastre is inadequate to give clear information about the legal status of real estate in cases of multiple use of space with overlapping and complex property issues, the implementation of a 3D cadastre is essential. In light of the coming urbanization encroachment this situation is only going to get more complex as construction seeks to make best use of vertical and underground space on limited urbanized land.

Due to the difficulty of the traditional cadastral field surveys the exact time of their completion is uncertain leading to delays and the gradual increasing of the cadastral procedure's cost. Thus, a cost effective, fast and reliable solution is needed. As it has been proven at earlier stages of this research, crowdsourcing techniques can be utilized for the implementation of 2D and 3D cadastral surveys providing very promising results in terms of cost, time and reliability. However, what is most important in order to meet the Sustainable Development Goals (SDGs) in time is not the final geometric accuracy, but the completion of the registration of all units and rights as quickly as possible by an affordable and inclusive method, while providing security of rights in the most reliable way according to existing funding.

3D crowdsourcing is an innovative field, with huge potentials for the fast, economic and reliable implementation of 3D cadastral surveys. Combing 3D crowdsourcing procedures with LADM standards new perspectives are emerging for the initial implementation of 3D cadastre. The proposed framework constitutes a first step towards this objective, utilizing modern technological developments, IT tools and m-services, such as smart devices etc., reducing the required time and efforts for the completion of the field work. According to the test implementation, the proposed framework is qualified in order to produce a qualitative, accurate and reliable 3D information model depending on the accuracy of the available basemaps, while the developed application is easy-to-use as users may not have the necessary level of 3D modelling skills in order to contribute to the registration procedure.

The proposed framework aims to develop a more generalized technical framework for the initial registration of 3D crowdsourced cadastral data and the creation of a standardize cadastral database everywhere, exploiting the available cartographic infrastructure of each country and including regions that still lack registration of 2D cadastral data. Thus, the proposed framework may be implemented both in the developed and the developing world. Through proper and brief training of the rights holders, the reliability of the proposed procedure will be increased. Thus, this approach may constitute the basis of an initial implementation of a FFP 3D cadastre.

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BIOGRAPHICAL NOTES

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