DESIGN OF A CROWDSOURCED 3D CADASTRAL TECHNICAL SOLUTION

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ABSTRACT:

Over the last half century, the world has witnessed rapid urbanization which is expected to increase over the near future. Use and property rights are reflected as a complex equation of overlapping interests. A fit-for-purpose approach for the initial registration of such rights is of a great importance both in formally and informally developed urban areas, as it may empower tenure security, improve property management, formalize property markets and enable poverty reduction. In this paper a more generalized framework, adjustable to the available cartographic infrastructure and funding availability in each region, for the simultaneous implementation of 2D and 3D property registration, based on a Mobile Cloud Computing (MCC) architecture, is proposed. A Database Management System (DBMS) based on the Land Administration Domain Model (LADM) standard is used for the management and storage of the collected data, while a prototype open-source mobile application for the collection of 2D and 3D crowdsourced cadastral data, the automatic 3D modelling and visualization of 3D property units as block models (LoD1) on a mobile's phone screen in real-time is developed. A case study for a multi-storey building in an urban area of Athens, Greece, is presented. The first results seem to be interesting and promising. A Strengths, Weaknesses, Opportunities, and Threats (SWOT) assessment of the proposed framework, is conducted. The main conclusions referred to the potential and the perspectives of the proposed technical crowdsourced solution for the initial registration for the implementation of a Fit-For-Purpose 3D cadastral system are presented.

1. INTRODUCTION

While urbanization is rising, 3D space in cities needs to be optimized into multiple individual property units, with legal and physical subdivisions in vertical and horizontal dimensions, above and below the ground surface. Such rights are reflected as a complex equation of overlapping interests. Traditional 2D cadastral systems are challenged to facilitate changes legally, institutionally and technically in the form of 3D systems and functional 3D cadastral systems in most urban areas may be expected to provide Accurate, Assured and Authoritative (AAA) information about the multi-dimensional property Rights, Restrictions and Responsibilities (RRR).

With the emerge of the international standard of Land Administration Domain Model (LADM ISO 19152, 2012) in 2012, a unified and standardized conceptual framework sets the basis for the development of 2D and 3D cadastres based on a Model Driven Architecture (MDA).

The considerable costs and required time, for traditional 2D and 3D cadastral surveys prevent the completion of property registration and the well-functioning of property markets in several countries. Especially for the less-developed regions time and costs for the 3D cadastral data collection are prohibitive. The majority of investigations and developments in 3D cadastres is focused on the developed economies, while the prevalent cadastral development in the less-developed economies is focussed on implementing Fit-For-Purpose (FFP) 2D cadastral systems to increase tenure security, improve land management and enable poverty reduction.

To combat the challenge of 3D cadastre establishment and maintenance, both in the developed and the developing world, more innovative and automated methods are needed. To meet the 2030 UN Agenda Sustainable Development Goals (SDGs) a Fit-For-Purpose implementation methodology for a 3D cadastral system should be designed using modern low-cost Information Technology tools, UAVs, mobile services and crowdsourcing techniques for the 3D cadastral data acquisition; adopting international standards, such as the LADM standard, for data modelling; and introducing automation in data management and 3D visualization.

This paper is part of an on-going research aiming to develop a technical tool and a methodology for the future data collection, management and 3D modelling of cadastral objects. The main objective of this paper is to propose, test and evaluate a more generalized framework, adjustable to the available cartographic infrastructure and financial situation of each country, including even regions that still lack a 2D cadastral data registration. In Section 2 a literature review of several modern approaches for the implementation of a 3D cadastral system, is presented. Section 3 presents the proposed crowdsourced cadastral solution describing its technical and methodological parts. Section 4 presents an implementation of the proposed solution in a multi-story building in the congested area of Athens, Greece, as well as the results of the overall procedure. Section 5 presents an assessment of the proposed cadastral solution, based on a SWOT analysis. Finally, Section 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 fit-for-purpose affordable 3D Cadastre.

2. LITERATURE REVIEW

During the past decades, research in the field of 3D Cadastres has attracted the growing interest of the research community, resulting in several zestful approaches. Several countries have developed procedures and prototype systems to proceed with the registration of 3D property rights and 3D visualization of property units, several of them based on LADM (Góźdź, Pachelski, 2014; Zulkifli et al., 2015; Lee et al., 2015; Stoter et al., 2016). Other researchers, investigate the potential

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exploitation of existing application schemas and technical models, such as CityGML, IndoorGML, BIM/IFC, LandXML, InfraGML, to provide a unified solution for the declaration and visualization of 3D cadastral objects (Thompson et al., 2016; Atazadeh et al., 2018; Alattas et al., 2018; Gkeli et al., 2018; Gkeli et al., 2019a).

As 3D cadastral systems are more complex than traditional 2D cadastral systems, they require more innovative technical solutions as well as the exploitation of cutting-edge technologies. Shojaei et al. (2015), describes the design and development of a 3D web-based cadastral visualisation prototype based on all the requirements of 3D cadastres, able to manage data in any format or stream data from a DBMS. Višnjevac et al. (2019), proposed an interesting approach for the implementation of 3D cadastral systems, based on the LADM standard. A NoSQL database and a Cesium JavaScript web-based application for the storage and 3D visualization of cadastral data, is designed. This approach requires the existence of data sources such as floor plans, cross-section plans, land parcel plans or other available geospatial information, in order to proceed with 3D registration. The desired 3D reconstruction of the cadastral object is provided through manual processes or automatic procedures based on the complexity of the studied object. However, these approaches are both time consuming and expensive, delaying the implementation of 3D Cadastres.

Practical experience has demonstrated the significant benefits in crowdsourcing geodetic measurement from multiple organisations (Haasdyk, Roberts, 2013). Web-based and mobile-based crowdsourcing solutions, have already been used in developing 2D cadastral surveying procedures in order to minimize the time and cost of the required surveys (Basiouka, Potsiou, 2014; Mourafetis et al., 2015; Basiouka et al., 2015; Gkeli et al., 2016; Basiouka, Potsiou, 2016; Apostolopoulos et al., 2018; Celt et al., 2019; Potsiou et al, 2020; Potsiou et al., 2019; Mourafetis, Potsiou, 2020). The existing 2D experience should be exploited in 3D cadastral surveys, providing a fit-for-purpose solution for the initial implementation of reliable 3D Cadastres. Vučić et al. (2015) proposed a LADM-based crowdsourced solution for 3D cadastral data acquisition. A mobile device is used for the delivery of the property height, reference point and surface relation. By combining the inserted data with already existing 2D (official) information regarding the partition of the real property, the establishment of a part of the 3D cadastre and its' visualization is possible. Ellul et al. (2016) proposed the development of a web-based crowdsourced application for the identification of the several land and property ownership situations. The contributor is asked to select his/her situation from several groups presenting different types of land ownership, sketched by the research team. In Gkeli et al. (2017) a more integrated 3D crowdsourced cadastral solution is proposed. A prototype mobile application for 3D cadastral data acquisition and 3D visualization of the real properties, as block models (LoD1), on a mobile's phone screen at real-time is presented. The application aims to automatically produce 3D building models through the digitization of property units' 2D boundaries on the available basemap. A more sophisticated version of this approach is presented in Gkeli et al. (2019a). The mobile application is upgraded enabling the management and visualization of 3D property models both above and below the land surface. The experience gained by these researches is used to update the developed mobile application (Gkeli et al., 2017; Gkeli et al., 2019a) and establish a LADM-based database and an appropriate methodology, in order to proceed with 3D property unit registration and visualization exclusively through the developed application (Gkeli et al., 2018; Gkeli et al., 2019b).

Up till now the 3D cadastral system presupposes the existence of a complete and functional 2D cadastral system. 2D cadastral and architectural floor plans seem to be the basis for the development of a functional 3D Cadastre (Vučić et al., 2017; Gkeli et al., 2017; Gkeli et al., 2018; Gkeli et al., 2019a; Gkeli et al., 2019b). In the absence of complete 2D cadastral systems and therefore of available geospatial information, such as cadastral maps and/or architectural floor plans, the implementation of 3D cadastral surveys becomes difficult. Main objective is to provide a technical framework and a crowdsourced methodology, able to adjust to the minimum available cartographic infrastructure and funding for each region, for the simultaneous implementation of 2D and 3D cadastral surveys.

3. CROWDSOURCED 3D CADASTRAL TECHNICAL SOLUTION

The proposed technical solution follows a crowdsourced methodology for the compilation of 3D cadastral surveys from scratch, arguing the simultaneous implementation of 2D cadastral surveys, where required. Main objective is the development of a methodology for the initial registration for a 3D cadastral system, in the absence of pre-existing accurate basemaps. The architecture of the developed technical system follows the Mobile Cloud Computing (MCC) motive, based on the previously developed technical solution by Gkeli et al. (2019b). A Database Management System (DBMS) based on the LADM standard is used for the management and storage of the collected data, while an upgraded and enriched version of the prototype open-source mobile application presented in Gkeli et al. (2019b) is used as a data capturing tool.

3.1 Methodology

The proposed methodology is based on the 3D crowdsourced methodology presented in Gkeli et al. (2019b), expanding its applicability, by minimizing the prerequisite for pre-existing geospatial data and allowing the simultaneous compilation of both 2D and 3D cadastral surveys, if needed. Main objective is to exploit the capabilities of modern low-cost technologies and innovative crowdsourcing techniques, to save time and funds so as the proposed methodology to be applicable and adjustable to any country regardless of the available cartographic infrastructure and funding. The key pillar of this methodology is the enhancement of the citizen/right holders' role, by transferring to them the responsibility for the initial collection of 2D and 3D cadastral data, including the semantic legal and geometric information, as well as to establish an active co-operation between professionals and citizens. A mobile device with an appropriately built-in 2D/3D cadastral mobile application should be provided by the National Cadastral Mapping Agency (NCMA), to be used for data collection. Simultaneously, the NCMA should be responsible for the establishment of a LADM-based DBMS for the storage and management of the 2D/3D collected cadastral data, ensuring data standardization and interoperability. Thus, the reliability of the collected data may be increased, speeding up the processes for the initial registration of 3D Cadastres.

The proposed methodology consists of eight (8) complementary phases (Figure 1). In the first phase, the area under cadastral survey must be declared by the government. All the available cartographic/ geospatial or cadastral information - if existing – should be collected, by professionals, for the preparation of the registration basemap. The type of basemap used for 2D or 3D crowdsourced cadastral surveys is crucial and determines the geometric accuracy of the final product. In countries with well-

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functioning 2D cadastres the parcel boundaries and building footprints are already configured in a 2D cadastral map with reliable accuracies; in such cases a 2D cadastral map may be used as a basemap. In countries with no updated 2D cadastral maps, first a digital 2D cadastral map must be compiled, by identifying the land parcels and the building footprints on it. In this case, an appropriate basemap could be an exciting recent orthophoto, or if not available an aerial photo taken from various platforms (e.g., UAVs), or even the OpenStreetMap (OSM), with gradually descending precisions; a more detailed methodology for 2D crowdsourced cadastral surveying is given by (Potsiou et al, 2020). To simultaneously proceed with 3D cadastral recording, additional information regarding the height of each property unit; the level above or below the ground where the property unit is located; as well as each property unit outline related to the declared rights, should be collected. The architectural floor plans of each building, if available, are the most appropriate basemap option for the 3D cadastral data collection for each floor of the building. In this case, the collected and recorded cadastral information may be classified as Accurate, Assured and Authoritative (AAA) (Williamson et al., 2012; Gulliver, 2015). If professional architectural floor plans are not available, the property unit outline should be identified on a crowdsourced basemap, compiled by the right holders.

In the second phase, the assignment of local team leaders to each sub-region of the area under cadastral survey, is conducted by the municipality. As team leader, a professional surveyor or a trained volunteer may be selected. Local team leaders are responsible assist the overall data collection procedure and help the citizen/right holders to get through any difficulty regarding the process or the used software. Thus, the required time for cadastral surveys is minimised while the reliability of the crowdsourced cadastral data is increased.

In the third phase, team leaders are briefing citizens through the cadastral process, introducing the expected benefits from this crowdsourced project to them. Simultaneously, team leaders are responsible for citizens/right holders training mainly in geometry and legal matters and on the usage of the cadastral mobile application. Apart from the task of the team leaders, informative videos and detailed explanatory documents should also be provided by the NCMA. In order to motivate and recruit citizens to this project, NCMA may provide a motivation reward to the participants, such as a discount rate on taxes or registration fees (Gkeli et al., 2019b), or may utilize gamification techniques (Apostolopoulos et al., 2018).

In the fourth phase, the team leaders should be responsible to collect the available architectural/floor plans - if existing - to be used as basemaps, to georeferenced them - if needed - and to insert these basemaps into the cadastral server in order to be used by the cadastral mobile application for the data collection and registration process.

In the sixth phase, the 2D/3D cadastral surveys are performed by the citizens/right holders, through the cadastral mobile application. The application allows citizens/right holders to identify and digitize the boundaries of their property unit and of the land parcel and building footprint, on the available basemaps, even if the available basemaps are not the best option to produce accurate registration outcome. This may be due the absense of 2D cadastral maps and/or the property boundaries may not be clearly visible on the orthophoto/aerial photo. Either way the mobile application should assist and support the registration procedure by providing a set of geometric tools able to determine the location of the land parcel boundary nodes, building footprint and condos outline, by implementing geometric constraints through simple geometric shapes and processes. An example of such mobile cadastral application is presented in Section 3.3. Simultaneously, through the cadastral application, the right holders may submit information regarding the 3D dimention of their property: the property unit height; the area size; the number of the floor (level) on which the property unit is located; as well as other information, such as the right holder/s' personal data and the type of rights they hold; the verification images (photos) of the property unit (optional); and the accompanying legal documents (Gkeli et al., 2019b).This information is fundamental for the description of the 3D cadastral objects and therefore, for the preliminary generation of a reliable 3D parcel, building and property unit cadastral database.In the seventh phase, the evaluation and control of this database is conducted by professionals while additional data together with the collection and submission of any objections for corrections identified by the rights holders should be submitted.

In the last phase, the examination and assessment of objections and the correction of data is conducted by professionals, leading to the compilation of the preliminary 3D cadastral database, by the data collected by the citizens/right holders and evaluated by professionals (Gkeli et al., 2019b).

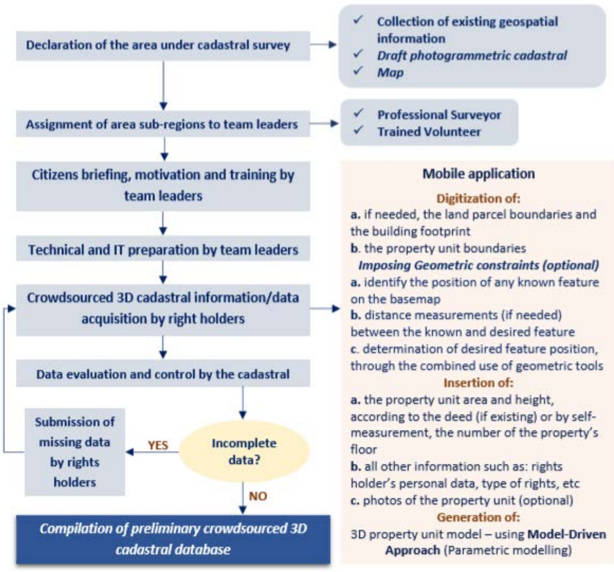

Figure 1. Proposed methodology for 3D crowdsourced cadastral surveys up to the stage of the compilation of the preliminary 3D cadastral maps and data

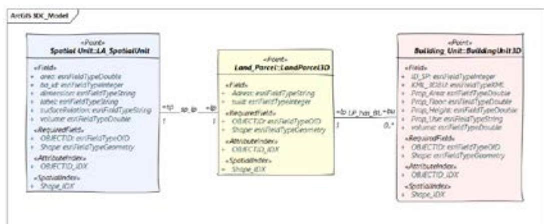

Figure 2. Conceptual schema defining the relationship between the classes: LA_SpatialUnit, LandParcel3D and BuildingUnit3D (Gkeli et al., 2019b)

3.2 Data model

A LADM-based DBMS developed in a previous stage of this research (Gkeli et al., 2019b) is used for the storage and management of the collected 2D/3D cadastral data. The developed DMBS schema is based on the main classes of LADM: LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit, while new classes have been generated in order to substantiate the 3D geometry of the spatial units (Figure 2). The generation of the new classes, that are based on the fact that a valid 3D cadastral object may be defined as a 3D volumetric object formed by polygonal faces, are composed of vertices, edges and relationships between them (Ying et al., 2015; CGAL, 2020). Based on this approach, the geometry of the 3D land parcel and the 3D building unit is supported by the new classes: LandParcel3D, LPBaseParcel, LP_BoundaryFaces, LP3D_Points and BuildingUnit3D, BuildingUnit_Top, BuildingUnit_Base, BuildingUnit_VFaces and Points3D, respectively (Figure 3).

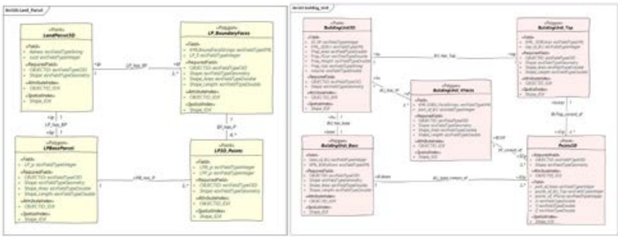

Figure 3. Proposed conceptual schema defining the structure of a 3D land parcel (left) and the 3D building unit (right) (Gkeli et al., 2019b)

3.3 3D crowdsourced cadastral prototype

The cadastral prototype application allows the collection of both 2D and 3D crowdsourced cadastral data by non-professionals; the automatic 3D modelling and visualization of 3D property units as block models (LoD1), using Model-driven approach; the registration and storage of the collected data and their relationships within a LADM-based cadastral geodatabase. The developed mobile application consists an upgraded version of the application presented in Gkeli et al. (2019b), providing a set of additional geometric tools able to facilitate the registration procedure in adverse cases of weak basemap availability (Figure 4).

Figure 4. Users interface overview of the developed mobile application

The application is capable of displaying several different 2D basemaps, and enable the 3D view of the scene, by using ESRI's Digital Terrain Model (DTM). The user may use the GPS (Global Positioning System) of the mobile device in order to avoid gross errors during his/her orientation within the terrain. The identification and collection of the 2D polygonal boundaries - land parcel boundaries, building footprint and condos outline - is conducted on the 2D view of the available basemap (2D architectural plans, orthophotos, aerial photos), through the identification and digitization tools provided by the mobile application. Simultaneously, the application allows the insertion of all necessary proprietary descriptive and geometric information for the declaration of the property rights; the capturing of property unit photos to verify the declaration; and, to attach other useful documents (e.g., plans, deeds etc.). Gometric information regarding the structure of each building unit is selected. The user should provide numeric information through the "Height" and "Floor" fields, defining the height and the number of the floor on which the declared property unit is located. These characteristics are of great importance, in order to proceed with automatic 3D modelling process.

In complex cases where the parcel boundaries are not clearly recognized in the field (e.g., not spotted on the ground, as legal boundaries that are not materialized in the field but are described metrically in the deed), or they are not visible on the available basemap (e.g., due to vegetation, or the hidden parts on the orthophoto etc.), the application provides a set of additional geometric tools facilitating their identification and digitization. These geometric tools implement geometric constraints through simple geometric shapes and processes, utilizing inserted numeric data (in meters), provided by the user. Through exploiting visible basemaps' features, as reference features, and geometric information of proximity, similarity, continuity, enclosure or even symmetry between them and the desired boundary features, provided by existing architectural plans, deeds etc., the gradually identification and digitization of proprietary boundaries is feasible.

Figure 5. Geometrical drawing tools offered by BoundGeometry application. Top (left to right): circle, line, offset to line, vertical lines Bottom: intersection points between 2 circles, 2 lines, a circle and a line

The developed application provides the user with a geometric editor which comprises all the available geometric tools and operations (Figure 4). The developed geometrical tools include (Figure 5): two (2) circle drawing tools; two (2) line segment drawing tool; a parallel lines drawing tool, at a certain distance from a specific line (full offset); a drawing tool of vertical lines of certain length on either side of a specific line; and, three tools for determining intersection points between 2 circles, a circle and a line, and 2 lines. The user may start or pause the cadastral registration procedure, performing any necessary geometric operation, in order to identify features (point or linear) representing the boundaries of his/her property. When the user detects the desired feature through this process, he/she may select it by tapping it on the screen, and then continue with the registration procedure.

Once the data are imported in the application and checked by the user, the 3D land parcel and property unit models are automatically produced based on the inserted geometric and numeric information (height, floor); the respective KML (Keyhole Markup Language) objects are generated; the 3D property models can be visualized on the mobile's phone screen, both above or below the ground, by selecting the visualization tools; the collected data and 3D property models can be stored in the cadastral database, in the server of ArcGIS Online, and pulled back to the application, if needed and if there is an Internet connection available.

4. CASE STUDY

The proposed tool is tested in a multi-storey building in a dense populated urban area of Athens, Greece. Primary interest is to investigate the functionality of the proposed technical tool, and to assess the Strengths, Weaknesses, Opportunities, and Threats (SWOT) deriving from this innovative crowdsourced methodology. Results concerning the geometric accuracy, the cost, the time and the reliability of the collected cadastral data, are of great importance to support and prove the usefulness and valuability of the proposed solution. The experimental procedure consisted of four (4) discrete stages: (i) the initial data collection, (ii) the training of volunteers, (iii) the registration process, (iv) the extraction and assessment of the results.

At the first stage, the existing geospatial information (aerial photos, orthophotos etc.), regarding the building under cadastral survey, was collected. An orthophoto of the area at a scale of 1:1000 (Figure 6), was used as basemap. The descriptive information about the building (e.g., area code, address), the right holder's data (name, role, type of rights) and the property unit geometric data (floor number, height, use, area size, volume, coordinates of the property unit outline) are the cadastral data to be collected.

Figure 6. Orthophoto of the case-study area at the scale of 1:1000. The studied building is located within the red rectangle

At the second stage, a team that consisted of middle-aged citizens with varied educational background, but with good digital skills, keen with smartphones technology, was chosen. The citizens' team was informed about the objectives of this crowdsourced project and subsequently was trained regarding the technical and the IT preparation, and the function of the cadastral mobile application, by a member of our research team with the role of the team leader. Once, this phase was completed the cadastral registration process started.

The registration process started with the insertion of the adequate descriptive information regarding the declaration of rights and the right holders' data, as well as the attachment of any necessary verification images and legal documents enchancing the current declaration, by the volunteers. One of the most important factors for starting the digitization procedure was the volunteers' orientation in the 3D space and the perception of their respective location on the basemap. This may be roughly achieved consulting the GPS (Global Positioning System) sensor of the mobile device, as the positioning accuracy in the interior space of the studied building was about 2-5 meters. Due to the absence of an accurate registration basemap, such as a cadastral map and professional architectural floor plans, volunteers ought to determine the position of any known building's structural (i.e. building's roof edges) or other features (i.e. fixed ground feature) on the basemap, and then determine the features (points, lines) of the desired land parcel/building unit boundaries by imposing to the known features, several geometric constraints through the geometric tools provided from the developed mobile application. In order to do so, volunteers had to measure - if needed - the distance between the known and the desired features, and proceed with the necessary geometric calculations through the mobile application. Thus, based on these principles, the identification of the land parcel and property unit boundary outline was performed, by selecting features (points) on the basemap (orthophoto) – where they were visible – and implement geometric procedures through the developed mobile application, in order to form the respective boundary polygon. As it is obvious, the determination of the building's interior cadastral units is more complicated due to their complex shapes as well as they are not visible on the available basemap. An example of the described registration procedure is presented in Figure 7, emphasizing on the registration of an indoor cadastral unit. It is noted, that during the whole procedure the team leader is at the volunteers' disposal, to resolve any questions that may emerge. Once the cadastral data are determined and collected by the volunteers, the data are stored in the cloud of ArcGIS Online, updating the system with the new records and the corresponding 3D models. The 3D visualization of the registered properties is achievable by the selection of the corresponding visualization tool (Figure 8).

Figure 7. Example of the registration process through the developed mobile application, including (top left) the insertion of the adequate information, (middle top left) the polygon digitization describing the land parcel and (middle top right, top right and bottom) the registration procedure utilizing the geometric tools for the identification/digitization of the polygon describing the building unit, on the basemap

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The registration procedure was completed successfully, while the identified problems will be discussed in section 5. The developed geometrical tools provided by the mobile application were really useful for the determination and identification of the hidden boundary parts and the interior cadastral spaces, using only an orthophoto as the registration basemap. Training of volunteers regarding the function of the mobile application and the geometrical tools, was very helpful, in order to carry out the cadastral procedure. The registration process was fast as the registration of each property unit lasts about 15-20 minutes (average), depending on the complexity of the boundary shape, the familiarity of the user with the mobile application and the user's understanding about the operation of the geometric tools.

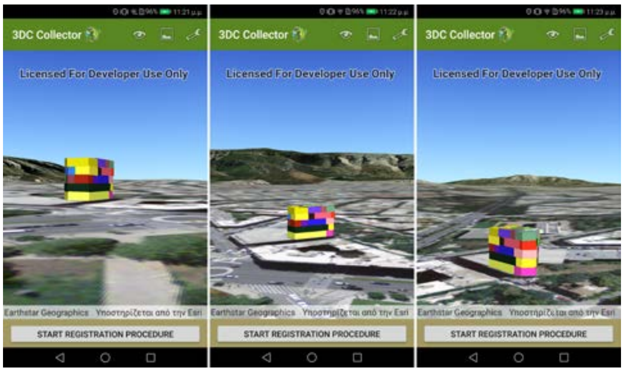

Figure 8. 3D models of the declared properties, using the 3D Model tool of the developed mobile application

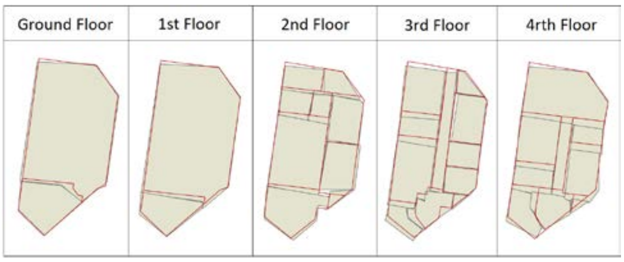

Figure 9. Comparison between the digitized polygons (in grey) and the reference data (in red), for each one of the studied building floors

For the assessment of the derived results in terms of geometric accuracy and reliability, a comparison between the digitized cadastral polygons and the reference data was performed. The professional floor plans of the building, which were not used as registration basemaps in this practical experiment, were utilized as reference data. The comparison results were very interesting approaching the current building reality, with the average accuracy deviation between the compared datasets be about to 0.48m and their maximum and minimum deviation to be approximately 1.71m and 0.07m, respectively (Figure 9). The maximum deviation emerges mainly in cases of incorrect usage of the geometric tools or incorrect features' identification on the basemap. Furthermore, the generated 3D models were correctly positioned in 3D space. However, some small errors presented as shape defects, are caused by incorrect selections of features position on the basemap and elevation jumps occurred in the utilized DTM.

5. ASSESSMENT

In this paper, an innovative cadastral technical solution, is proposed, adjustable to the minimum available geospatial infrastructure and funding situation of each country, for the simultaneous implementation of 2D and 3D cadastral surveys. To evaluate the proposed technical framework and the crowdsourced methodology, we provide a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, based on the volunteers' feedback and the produced results (Table 1).

As it was proven on earlier stages of this research (Basiouka, Potsiou, 2012; Gkeli et al., 2019b), traditional cadastral field surveys require time and funds, that may gradually be increased, complicating or even prohibiting the completion of both 2D and 3D cadastral surveys. The absence of a functional cadastral system enhances right holders' uncertainty regarding their rights, increases risks, time and costs in land and property transactions and mortgages, blocks the real estate market and disables poverty reduction. The indtroduction of low-cost and modern IT tools, crowdsourcing techniques, automated procedures, m-services (mobile services) and international standards, such as the LADM standard, in 2D and 3D cadastral surveys, may speed up the cadastral procedures, reduce costs, enable harmonization and exchangeability of data, and eventually may lead to the immidiate implementation of a functional 2D and 3D cadastral system, everywhere (Apostolopoulos et al., 2018; Potsiou et al, 2020; Mourafetis, Potsiou, 2020; Gkeli et al., 2017; Gkeli et al., 2018; Gkeli et al., 2019ab).

Strengths	Weaknesses
- Various platforms may be used (orthophoto, aerial photo, OSM)	- Depends on volunteer's digital skills, age, knowledge
- Low-cost equipment	- Lower geometric accuracy depending on the basemap used
- Fast implementation	- Dependence on visible cadastral features/boundaries
- Reliable/Crowdsourced data	- Need for a wide screen device
- Immediate data collection/ create up-to-date DBMS	
- LADM standard	
- M-services/ IT tools – easy-to-use	
-Automated 3D modelling	
- Produce preliminary 2D/3D cadastral data	

Opportunities	Threats
- Development of initial 3D cadastres everywhere	- Conflicted expert opinions for the reliability of the derived data in the case of using low accuracy basemaps
- Low investment cost for the commencement of 2D/3D cadastral surveys	- Acceptance of lower geometric accuracy-if basemaps of lower accuracy are used- based on the countries' accuracy specifications
- Potential to reduce property disputes / transparency	- Misalignment with official records or existing systems
- Reliable/Crowdsourced data	

Table 1. SWOT results on the proposed crowdsourced technical solution

The use of volunteers' mobile devices as the main mean of 2D and 3D data capture, reduces the cost and time of the overall procedure, as each one may be responsible for the declaration of his/her own properties. During the practical experiment volunteers seemed to be very receptive to the crowdsourced cadastral project and supportive for its implementation in real circumstances. After a proper training, volunteers were able to interact and collect data through the mobile application, quite easily. The most difficult part of their training was the understanding of the geometric tools' operation and the imposition of the geometric constraints. After presenting some examples, the tool operation was understood as it is based on simple geometric processes. These geometric tools expand the range of applications and the perspectives of the proposed cadastral solution, as they also allow the utilization of low accuracy platforms (aerial photo, OSM etc.) as registration basemaps. Especially, in the absence of architectural floor plans, the registration of the interior cadastral spaces is weaker. The utilization of geometric constrains for the identification of hidden features, is indispensable. At this point, right holders' participation is of great importance, increasing the reliability of the collected data, as there is no one more suitable to indicate the property boundaries than its own resident/occupant (Goodchild, 2007a; Goodchild, 2007b).

Data collection process was successfully completed, while no major problem was occurred. The role of the team leader was significant, resolving any questions that volunteers had, saving valuable time. The overall registration procedure was relatively fast as the initial registration of each property lasted about 15-20 minutes (in average), which is hard to be achieved with traditional surveying procedures. The collected data were well attributed, distinguished and related by logical rules following the form of LADM standard, ensuring transparency by enabling the property market functioning within a country or internationally. At the same time, the 3D property models were automatically produced using the declared data, without delay- no tedious manual procedure is required- and then were stored in the 3D cadastral DBMS keeping the system up-to-date. By the end of this procedure the immediate production of preliminary 2D and 3D cadastral data and models, was performed. Such preliminary cadastral data, in order to be used for the creation of a AAA cadastre need to be checked by professionals and follow the publishing and objections submission/examination procedure prior to the legal title provision and the final registration.

The average accuracy deviation -in case no professional floor plans are available- resulted through the practical experiment was about to 0.48m while the maximum and minimum deviation was approximately 1.71m and 0.07m, respectively. The achieved accuracy may seem unacceptable compared to the achieved accuracies when pre-existing floor plans are used. However, the proposed cadastral solution consists a fit-for-purpose solution, where the main purpose is to safeguard citizens' rights, in self-made cities informally developed, with a geometric accuracy which may be improved gradually. This particular research will investigate in the near future new tools to further improve the achieved accuracies.

During the overall procedure a few more weaknesses and deficiencies were identified and highlighted by the volunteers and the team leader. The main group of weaknesses are related to the functionalities of the mobile application. The usage of the mobile application and especially of the geometric tools, depends a lot on the volunteer's digital skills, age and perception of geometry matters. The absence of familiarity with mobile devices, which mainly may refer to elderly people, may have a negative effect on the procedure's outcome. The volunteer's inability to be oriented in the indoor 3D space and identify known features on the basemap, may lead to incorrect point selection, affecting greatly the achieved results. Also, the screen size of the mobile device seems to affect the data collection process. A device with a wide screen, such as a tablet, may facilitate the identification of the property boundaries and make the registration procedure much easier for the volunteer.

The proposed crowdsourced technical solution combines the current initiatives of the scientific community and produces a modern innovative approach for the initial collection of 2D and 3D cadastral data- when needed - even in the most adverse condition of accurate basemap availability. Using low investment budget for the compilation of 2D/3D cadastral surveys, the immediate implementation of a functional 2D/3D cadastral system, is feasible and useful for many land management tasks in decision-making. Through 3D property visualization, several property-related issues may be better managed, ensuring fair taxation, secure ownership, provide access to mortgage and poverty reduction. The presented case study constitutes a practical example in the exploration of the function and results of the proposed framework. The obtained results will be used to further optimize both the technical and methodological crowdsourced frameworks.

6. CONCLUSIONS

The development of functional 3D property registration systems is indispensable for the effective management of land and multi-dimensional overlapping property Rights, Restrictions and Responsibilities (RRR), especially in dense urban regions that still lack a 2D cadastral data registration. This paper presents a part of an on-going research project, intended to provide a pfit-for-purpose technical tool for the fast and reliable acquisition, management and visualization of 3D cadastral units. The proposed framework constitutes a step towards this objective, even in the absence of geometrically accurate basemaps. The proposed crowdsourced solution can provide a reliable AAA 3D cadastral database, fast and with limited funding resources when geometrically accurate basemaps are used. The developed mobile application has several geometric capabilities and potentials, as a 3D data capturing tool, allowing the identification of hidden or non-marked cadastral features on the available basemap. The first experimental results seem to be promising, providing the basis for the immidiate implementation of a fit-for-purpose 3D cadastral system.

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