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Linking LADM with BIM/IFC standards for mobile-based 3D Crowdsourced Cadastral Surveys

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Key words: Crowdsourcing, 3D Cadastre, BIM, IFC, LADM

SUMMARY

The ongoing urbanization has led to the emergence of several complex constructions and multi-dimensional property rights. Traditional cadastral procedures cannot meet the demands of this new reality, leading to increased costs and long delays. Exploiting the capabilities of the latest technologies, mobile services (m-services), Building Information Models (BIMs), 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 Cadastres, is feasible. The utilization of crowdsourcing techniques for the implementation of fit-for-purpose 3D cadastral surveys, utilizing the currently available 2D geospatial infrastructure, has already been proved to provide qualitative results. Integrating BIM data with cadastral information derived from crowdsourcing techniques, may significantly speed up the implementation of 3D Cadastres, providing a better visual understanding of 3D property rights. In this paper a LADM-based technical solution for the initial acquisition, registration and representation of 3D crowdsourced cadastral data (re-)using existing BIM and m-services, is developed and presented. A practical experiment is conducted 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 the proposed framework, are discussed and presented.

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1. INTRODUCTION

As the phenomenon of rapid urbanization is growing during the years, it is estimated that by 2050 the two-thirds of the population will be living in cities (United Nations, 2018). This exerts great pressure on the existing urban structures and land uses, forcing the 3D spaces in cities to be optimized into multiple individual property units, with legal and physical subdivisions in both vertical and horizontal dimensions. Buildings with several uses referred to the same building footprint, may present a complex equation of overlapping interests, which must be properly managed. Current 2-Dimensional (2D) Land Administration Systems (LASs) are still based on 2D drawings not being able to cope with this new complex stratified reality. Incorrect registrations, mistaken declarations, misunderstandings and multiple disputes concerning these property rights, are only some of the consequences of the poor management of the increasing multidimensional property rights.

To get closer to resolving these issues a 3D LAS is needed in order to provide Accurate, Assured and Authoritative (AAA) information about the multi-dimensional property Rights, Restrictions and Responsibilities (RRR). With the advent of 3D Cadastres, 3D property RRRs of stratified objects may be described in detail, creating a secure and transparent framework for more effective management and use of 3D space. During the past few years, several 3D Cadastre attempts have been initiated worldwide, including a wide variety of potential solutions and important findings, regarding subdomains such as the data type, data modelling, system architecture and visualization (Vandysheva et al. 2011a,b; Stoter et al. 2012; Stoter et al. 2016). With the emerge of the international standard of Land Administration Domain Model (LADM ISO 19152) in 2012, researchers interest focusing in linking the legal and physical parts of 3D cadastral objects, utilizing several technologies, application schemas and technical models such as CityGML, IndoorGML, BIM/IFC, LandXML, InfraGML, etc. (Thompson et al., 2016; Kitsakis et al., 2016; Atazadeh et al., 2018; Alattas et al., 2018; Gkeli et al., 2018; Kitsakis et al., 2019; Gkeli et al., 2019).

However, the considerable costs and required time, for traditional 3D cadastral surveys prevent the immediate completion of such a property registration system intensifying the current problems and forbidden the well-function of property markets in several countries. A fit-for-purpose approach may constitute a potential solution, ensuring that both the developed and developing countries may appropriately built functional land administration systems within a relatively short time frame and affordable costs, in order to meet the 2030 UN Agenda SDGs (Enemark et al., 2014). Recent research has shown that by utilizing modern Information and Communication Technology (ICT) tools, low-cost equipment, crowdsourcing techniques, web services, mobile services, open-source software, the development of a reliable, qualitative and affordable solution for the initial implementation of a 3D cadastre is feasible (Vučić et al., 2015; Ellul et al., 2016; Gkeli et al., 2017 a,b,c,d; Gkeli et al., 2018; Gkeli et al., 2019; Potsiou et al., 2020a,b; Gkeli et al., 2020a,b; Gkeli et al., 2021a,b). Also by reusing the existing rich content of data models, such as BIMs, may significantly reduce the costs and speed up the processes for the implementation of 3D Cadastres (Oldfield et al., 2017). Linking cadastral information to 3D digital representation of the urban environment could be a promising approach in order to define and visualize both 3D physical and legal spaces. Among 3D data models, Industry Foundation Classes (IFC) file format provides the potential capabilities for modelling legal and physical dimensions of urban properties (Oldfield et al., 2017; Barzegar et al.,2021).

The main objective of this research project is to provide a practical technical tool and a crowdsourced methodology for the initial implementation of 3D cadastral surveys in a fast, cost- effective and reliable way. Thus, through such a solution the initial establishment of a functional 3D cadastre is feasibly in a short time-frame, supporting the government administration to provide an effective and transparent system capable of securing property rights, facilitate property valuation, managing real estate markets in modern cities, as well as other necessary urban reforms. This work explores the opportunities for (re-)using available BIM data as registration background for the initial implementation of 3D crowdsourced cadastral surveys. This attempt is part of the wider context of our effort to develop a technical framework that can be adapted to the available cartographic infrastructure of each country or even it can be implemented reliably in the absence of an accurate basemap.

Chapter 2 presents background information regarding the technical framework of the proposed crowdsourced solution. Chapter 3 describes the proposed crowdsourced methodology for the compilation of 3D cadastral surveys, utilizing the proposed technical framework. Chapter 4 presents the implementation test of the developed system in one multi-story building in an urban area of Athens, Greece. Chapter 5 presents an overall evaluation of the proposed technical solution. Finally, Chapter 6 presents the main conclusions referring to the perspectives, the geometric accuracy, the cost, the duration and the reliability, of the proposed crowdsourced solution as a basis for the compilation of a well-functioning fit-for-purpose 3D Cadastre, as well as some thoughts about our future work in this field.

2. BACKGROUND INFORMATION

2.1 Related Work

Nowadays, the main source for 3D building information of new buildings is Building Information Model (BIM). BIMs present the geometry of the complex physical buildings' spaces (rooms, corridors, walls and floors), used mainly for planning, design, construction, maintenance, etc. BIM data in combination with IFC data structure, can provide input to 3D cadastre for both each individual property as well as its surrounding properties, allowing the obtainment of clearer picture regarding properties RRRs. Until now, several researches regarding the use of BIMs in 3D cadastres have been made.

The potential use of BIM and IFC as a future data source for 3D Cadastres, is stated by Oldfield et al. (2016). IFC data structure may support the requirements of cadastral legal spaces, while it can be enriched with additional attributes describing the necessary characteristics of legal spaces. As BIMs are widely used and already existed in several fields, their (re-)usage may reduce the cost of the cadastral procedure and speed up the process for the implementation of 3D cadastres. Towards this objective, Oldfield et al. (2017) developed a workflow trying to establish a connection between BIM/IFC and GIS, aiming to incorporate the information of 3D spatial ownership RRRs as input data for the land registry in the

Netherlands. Sun et al. (2019) present a similar approach, investigating the potential integration of cadastral information, BIM/IFC data and GIS, aiming to set a link between physical and legal spaces for cadastral visualization on building level in urban environments. BIM data have claimed a place as an important and detailed data source for the establishment of 3D spatial units. Janecka (2019) highlights the importance of transforming mechanisms between BIM data in the GIS (Geographic Information System) projects, especially regarding the smart cities. It states that within the ongoing international standardization activities, there are activities focusing on 3D Cadastre and BIM, confirming the significance of such connection.

El-Hallaq et al. (2019) proposed a different approach, trying to present and analyze the current capabilities and situation of modern cities and formulate a future vision. They developed a GIS web-based 3D database, including city elements such as buildings, services and other facilities. The main objective of this investigation is the development of a 3D geometric and descriptive database facilitating documentation, transparency and help in the decision-making process. A similar web-based cadastral-oriented approach, is proposed by Andrianesi and Dimopoulou (2020). The main objective of this investigation is to combine BIM and GIS, for the effective management of 3D cadastral information and building data. A web-based application is developed while the IFC standard is used for the exchange and linkage of the 3D spatial information between the two systems. Finally, one of the most recent investigation is presented by Barzegar et al. (2021), trying to resolve the weaknesses of IFC files, concerning the differences between geometry of 3D data in IFC and in a spatial database. To support required spatial analysis, they development an IFC-based spatial database for 3D urban land administration purposes.

2.2 Crowdsourcing in 3D cadastral surveys

During the past few years, crowdsourcing has emerged as a valuable and reliable tool for cadastral data acquisition. The active participation of citizens and more specifically of the right holders, in cadastral surveys, can minimize the time, costs and the gross errors, as they know better than anyone else the boundaries and location of their properties. As this field is newly emerging, the range of the existing investigations is limited. The majority of these researches is based on the identification and delimitation of 3D cadastral objects, on existing 2D cadastral maps, orthoimages and architectural floor plans. Modern technological achievements gain the role of data collection tools by managing and delivering all the necessary proprietary information into the cadastral systems.

An interesting crowdsourced approach for 3D cadastral data capturing, is developed and presented by Vučić et al. (2015). A mobile device is utilized, for the submission of the necessary geometric information regarding the property unit's attributes, such as the height, the reference point and the surface relation. These data are combined with existed 2D official information about the property's premises, allowing the partly establishment of 3D cadastre and its' visualization. Ellul et al. (2016) follow a different approach, trying to implement the cadastral registration procedure by simplifying the recognition and selection of the situations in which the land and property ownership situations belongs to. Utilizing a web-based application, citizens may select their situation through several different groups presenting different types of land ownership. The different ownership situations are sketched by the research team, enabling citizens to comprehend the form of their case.

Besides the descriptive and indirect determination of the 3D cadastral objects, it is important to determine and create their geometry in the 3D space. In Gkeli et al., 2017d it is stated that the utilization of parametric modelling techniques (Model-driven methods) may be the best option to proceed with 3D modelling of real properties, allowing the rapid implementation of 3D crowdsourced cadastral mapping, in a cost-effective, reliable and simple way. Model-driven methods are characterized by high robustness and maintenance of topology and can be adopted by people/citizens without any specific photogrammetric skill. With that in mind, Gkeli et al. (2018) proposed a LADM-based cost-effective technical solution for the acquisition of 3D cadastral data and the visualization of the real properties, as block models (LoD1), both above and below the land surface. They developed a cadastral mobile application able to process the inserted geometric data and provide the block models of the declared real properties, following a prototype modelling algorithm. The key step of the proposed framework is the digitization of property units' 2D boundaries on the available basemap, and the declaration of important geometric descriptive information regarding the height and the floor where the studied property is located, through the developed mobile application. A similar but more sophisticated approach is presented in Gkeli et al. (2019). The mobile application is upgraded. More functionalities are added, while the crowdsourced methodology is enhanced by upgrading the role of team leaders in the overall registration process.

As satisfactory these approaches may be, it should be emphasized that they are based on ideal conditions of accurate basemap availability. In the absence of an accurate basemap, other mechanisms and technologies may be used. The utilization of the smartphone's GPS sensor, with an accuracy of a few meters, or the utilization of external support GNSS (Global Navigation Satellite System) tools and resources, achieving high positioning accuracy, may constitute a potential solution supported by some researchers (Molendijk et al., 2018; Cetl et al., 2019; Potsiou et al., 2020a). However, the efficiency and effectiveness of such systems is reduced significantly as we move towards the interior of buildings. To overcome this limitation, Gkeli et al. (2020b) followed an alternative approach, utilizing a mobile application enriched with multiple geometric tools, enabling the identification of properties boundaries. Furthermore, a more innovative approach is proposed by Potsiou et al. (2020b). This investigation explores the potential combination of mobile services, Bluetooth technology and innovative machine learning techniques for indoor cadastral mapping. Aims to automatically provide the position of indoor cadastral spaces and create a plan-free solution for the initial implementation of 3D indoor cadastral surveys, mainly in urban areas.

An extension of this technical framework is suggested by Gkeli et al. (2021a,b) trying to integrate BIM in the process for the initial implementation of 3D Cadastres. Through the development of a web-based application, the possibility of (re-)using rich BIM data, as registration basemap for the implementation of 3D crowdsourced cadastral surveys, is explored. The first results are very promising, enabling better communication and understanding of 3D space, while speeding up the necessary cadastral processes. However, the utilization of wireless services in combination with the mobile application, are inclusive and preferable as not everyone has access to a cable internet. Thus, the potential integration of BIM data, crowdsourced techniques, mobile services and LADM standard, for the registration of property's RRR has not been implemented yet, being an interesting aspect for further investigation. The integration of all these factors in a single approach, may expand the range of alternatives for the immediate implementation of 3D Cadastres everywhere.

3. PROPOSED TECHNICAL FRAMEWORK

The proposed crowdsourced approach tends to enrich the previous research on 3D crowdsourced cadastral surveys (Gkeli et al., 2020a,b; Gkeli et al., 2021a,b), aiming to speed up the processes for establishing 3D cadastres, reducing the requires financial resources and increasing the reliability of the collected data. This attempt enhances citizens' role and participation, as right holders are called to be responsible for the identification of their property, either by digitizing its boundaries on an available basemap, or by locating and selecting their property on an existing BIM. The main idea of the of the proposed approach is based on (Gkeli et al., 2020a;b), while it is upgraded by enabling the integration of BIM/IFC data as a potential data source of 3D cadastral information.

The main objective of the proposed technical framework is to provide a modern approach and an alternative technical tool for the future acquisition, management, registration and representation of 3D property rights, mainly in urban areas. It consists of two complementary parts: the technical part and the procedure to be followed. The first part includes the technological sub-systems that need to be developed. The procedure deals with implementation process of the 3D crowdsourced surveys through the developed systems.

3.1 Technical Aspect

The architecture of the developed technical background is composed of two connected parts: the server-side and the client-side. These two parts are communicated through a network connection. The first refers to the web server and the Database Management System (DBMS) where the collected data are stored and maintained. The client-side refers to the data capturing tool, which in this case is preferred to be a mobile device. In order to follow the global directions for the development of 3D cadastral systems, a database schema based on LADM standard is generated. For client-side an open-sourced mobile application for Android devices, is developed, while the storage and management of the collected data is conducted through the server of ArcGIS Online (ESRI, 2021).

3.1.1 Data Model

The proposed DBMS conceptual schema was developed through Enterprise Architect (EA) UML modeling tool from Sparx Systems, which supports the Geography Markup Language (GML) application schemas and the modeling of ArcGIS geodatabases, utilizing Model Driven Generation (MDG) Technologies. EA allows the generation of geodatabase conceptual schemas empowering the development of GIS applications. The developed geodatabase is based on our previous work, presented in Gkeli et al. (2019) following the LADM standard's specification, while some new classes are generated in order to support the BIM/IFC aspect. More specifically, LADM's basic classes of LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit, are preserved (Figure 1). A new class named BuildingUnit3D, is generated in order to function as the receptacle of all potential geometries that can be managed by the DBMS).

According to LADM specifications, a "true" 3D representation of a spatial unit consists of arbitrary oriented faces. As the definition of the acceptable 3D geometries and representations for the 3D cadastral objects is still challenging (Ying et al., 2015), there is a wide range of geometric choices that may potentially utilized. Gkeli et al. (2019) proposed a different geometric approach, based on the fact 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 (Ying et al., 2015).

As BIMs are widely used in modern cities, in many application areas, their (re-)use should be integrated into the future procedures for the implementation of the 3D Cadastres. However, before that happens, some limitations concerning the linking process between BIM and LADM should be settled. BIM consists one of the most detailed and comprehensive object-oriented method of modelling buildings, providing in detail the geometry of the complex physical buildings' spaces, such as rooms, corridors, walls and floors. This may suffice to define the 3D cadastral physical spaces, but not the 3D cadastral legal spaces. A legal space needs to be related with only one space consisting the ownership boundary of a single property, where the corresponding RRRs are assigned (Gkeli et al., 2021b). Thus, for defining the 3D cadastral legal spaces through BIM, a number of physical spaces should be united into single entity, which will describe the legal space of ownership rights. Thus, a 3D spatial representation derived from a BIM may present an apartment which spread across multiple rooms but belonging to one owner (Gkeli et al., 2021b). With IfcSpace entity, the representation of volumetric cadastral spaces inside a building is feasible. Thus, the interior structural elements can be included into this entity, forming the legal spaces of the cadastral objects, where the RRRs will be assigned.

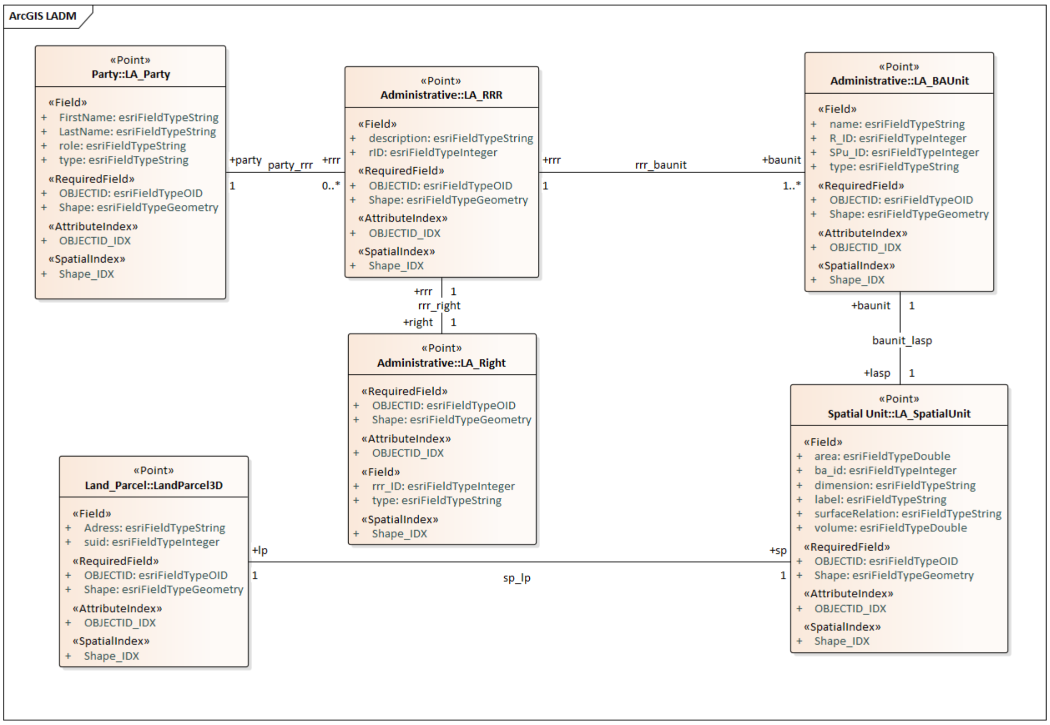

Figure 1: Conceptual DBMS schema of the developed data model, based on the main classes of LADM: LA_Party, LA_RRR, LA_BAUnit and LA_SpatiaUnit

The representation of BIM legal spaces may be achieved utilizing open BIM exchange models, such as the Industry Foundation Class standard (IFC), which is one of the most widely used standard. IfcSpace entity, enables the representation of volumetric (legal) spaces inside a building. With that in mind, a new class named BIM_BuildingUnit3D is created (Figure 2), describing the BIM's cadastral legal spaces. BIM_BuildingUnit3D class is directly linked with BuildingUnit3D class, preserving the necessary information regarding the definition of the volumetric/multipatch geometry of a building unit (property).

Finally, the developed database scheme is exported from EA as a Geodatabase Workspace XML Document (containing the ArcGIS schema) in order to be imported into ArcGIS Pro software. Subsequently, the produced geodatabase is uploaded on ArcGIS Online platform in order to be able to be linked with the rest of the elements of the proposed technical solution.

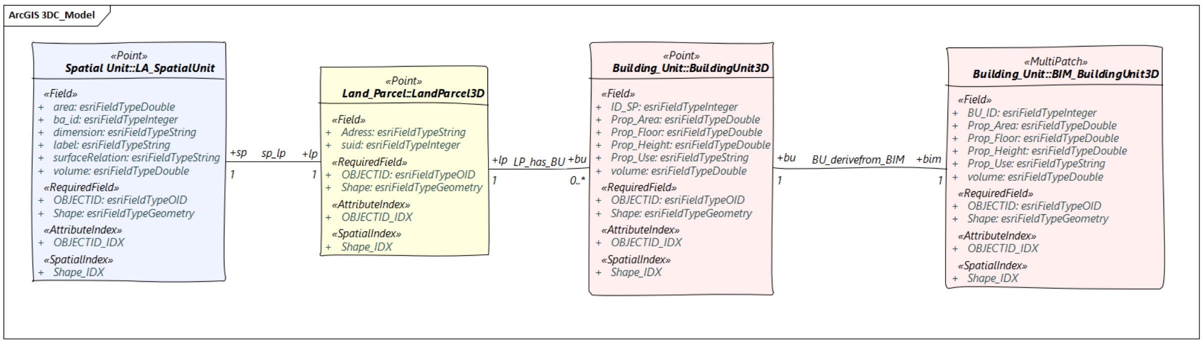

Figure 2: Conceptual DBMS schema of the developed data model, describing the new classes of Land_Parcel, BuildingUnit3D and BIM_BuildingUnit3D; the relationships between them, as well as with the LA_SpatiaUnit class of LADM

3.1.2 Developed Mobile Application

An open-source prototype for Android mobile devices is developed to support the client-side of the proposed technical solution (Figure 6). This research domain is newly emerging, providing promising results for the compilation of a preliminary 3D cadastral database directly by the citizens/rights holders. The developed application is based on the results of earlier stages of the current research (Gkeli et al., 2019; Gkeli et al., 2020a,b), including more functionalities for BIM/IFC manipulation. The mobile application enables the collection of 3D crowdsourced information by non-professionals; the registration of the cadastral data and their relationships within a LADM-based cadastral geodatabase; the automatic generation of 3D property unit models as block models (LoD1), using Model-driven approach; the manipulation of BIM/IFC descriptive data; and the objects visualization in real-time.

For the development of the mobile application a set of software tools were utilized: (i) the Integrated Development Environment of Visual Studio 2013 (IDE); (ii) the Java Deployment Package Oracle JDK 8 (Java Development Kit); (iii) the Android SDK Manager (for API level 19); (iv) 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); (v)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; (vi) the Server of ArcGIS Online (cloud of ESRI), for the storage and management of data (ESRI, 2019); and, (vii) the programming language of C#.

The user interface is simple and appropriately configured in order to lead the registration procedure. It simulates the 3D real world utilizing a Digital Terrain Model (DTM) offered by ESRI. The user may be oriented in 3D space utilizing the GPS (Global Positioning System) of the mobile device. However, the GPS is used only for a rough positioning in order to avoid gross errors during rights holder's orientation in the 3D space. As registration basemaps, the available spatial infrastructure (2D architectural plans, orthophotos, aerial photos, BIM data) may be utilized.

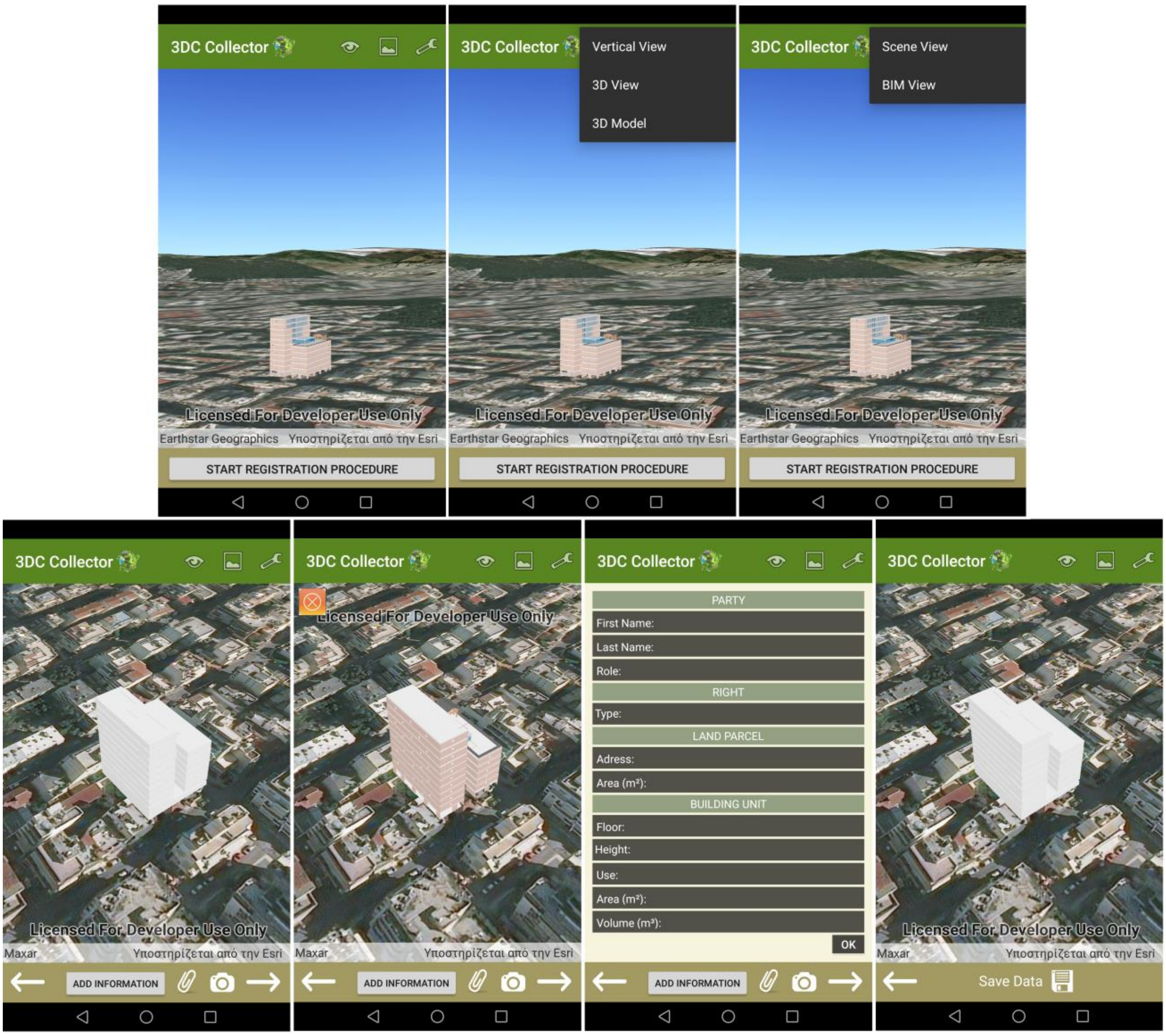

Figure 3: Users interface overview of the developed mobile application

If BIM data describing user's property unit is available, the user may proceed with the cadastral registration process (Figure 3). He/she may navigate throughout the 3D scene, locate his/hers property unit on BIM and select it, by tapping it on screen. Following, the user may enter all the necessary cadastral information included in the information form, which the application will ask him/her to complete. During the registration process, the user may enable or disable the physical (LoD4) or legal view (LoD1) of the property units presented in the available BIM, through the BIM view tool, provided by the mobile application (Figure 3). 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, in the server of ArcGIS Online. It is noted, that in this study we investigate the potential use of available BIM data in order to proceed with crowdsourced cadastral surveys, utilizing mobile devices as data capturing tool. In the absence of BIM data, other methods and techniques may be utilized.

These alternatives solutions have been tested in previous research, leading to satisfying and promising results (Gkeli et al., 2018; Gkeli et al., 2019; Gkeli et al., 2020a,b). A hybrid solution including all the proposed alternatives is tended to be developed in the next step of this research project.

3.2 Crowdsourced Methodology

The proposed methodology for the initial implementation of 3D cadastral surveys, is based on our previous work presented in Gkeli et al. (2020a,b) and Gkeli et al. (2021a,b) (Figure 4). The main objective of the proposed procedure is to reduce time, costs and simplify the most expensive and time consuming phase of cadastral registration process, which is the 3D cadastral data acquisition. By utilizing low-cost technology, (re-)using existing rich data models, and enhancing rights holders' participation during this phase, the collection of the necessary geometric and semantic information concerning the ownership status and other rights, is accelerated with data reliability to be increased. This investigation aims to explore the potential use of BIM data, as a basemap for the initial acquisition of 3D cadastral information, by the rights holders. The visualization of the real properties through BIM, facilitates the identification and selection of the desired property/building unit, simplifying the overall process. As data capturing tool, a mobile cadastral application is suggested to be used.

The first phase of the proposed crowdsourced procedure starts with the declaration of a specific area under cadastral survey, by the National Cadastre and Mapping Agency (NCMA). The preparation of a draft registration basemap is conducted, through collecting all the available cartographic/ geospatial, cadastral information and BIM data - if existing (Gkeli et al., 2020a;b). In the next phase, the area under cadastral survey is divided to sub-regions and each one of them is assigned to a local team leader, who has an auxiliary and organizational role during the process. The team leader may be a professional surveyor or a trained volunteer, responsible to assist the overall data collection procedure and help the right holders with any question or difficulty concerning the process or the used software. In the third phase, team leaders are responsible to inform rights holders about the benefits of the cadastral crowdsourced project and train them on how to use the cadastral web application. Besides that, NCMA should provide informative videos and detailed explanatory documents, describing the necessary processes.

The responsibilities of the leaders also include the collection of the available basemaps and BIM data, the utilization of the necessary pre-processing steps for their insertion into the cadastral server, and therefore, for their usage by the cadastral web application. Next, the 3D cadastral surveys are performed by rights holders through the cadastral web application. Each right holder, identify and select his/hers property based on the BIM/IFC representation and insert all the necessary cadastral information. Finally, 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.

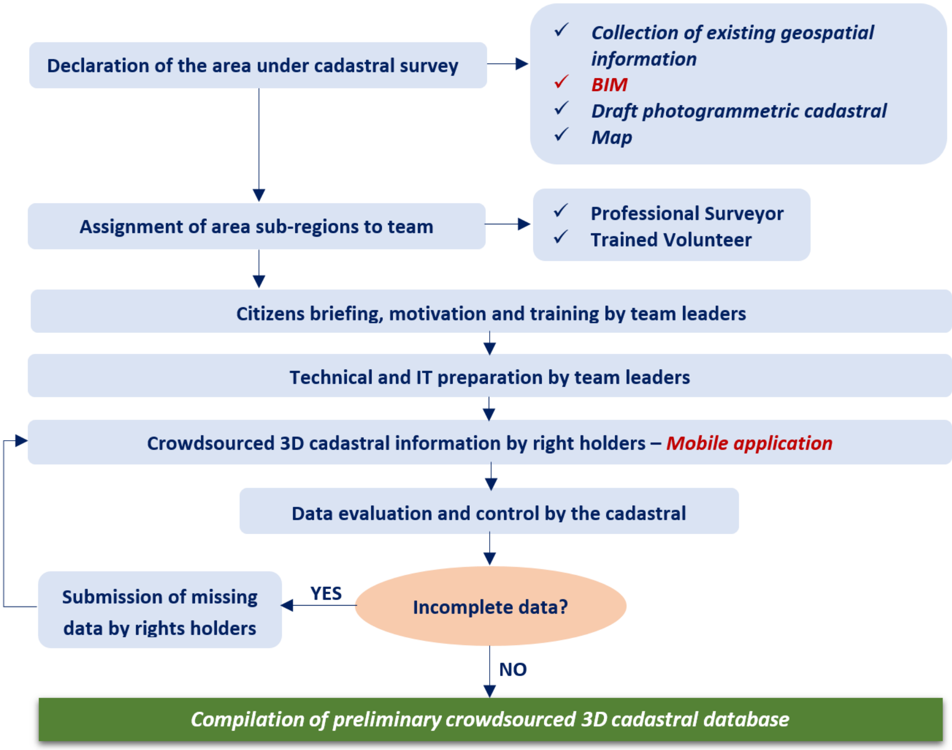

Figure 4: Proposed crowdsourcing methodology for 3D cadastral surveys up to the stage of the compilation of the preliminary 3D cadastral database

4. PRACTICAL IMPLEMENTATION

The proposed technical framework was tested in a densely structured urban area of Athens, Greece (Figure 5). The 3D building models of a building block were utilized as registration basemap. The models were in LoD4, describing in detail the physical characteristic of the buildings' exterior. In this section, a number of pre-process steps enabling the insertion and exploitation of the BIM data into/from a GIS system, and therefore their integration with the generated LADM database and the developed mobile application, are discussed and presented. Finally, the practical experiment is described, and the first results of the proposed crowdsourced approach are presented.

Figure 5. The aerial photo depicting the test area

4.1 Pre-processing steps

For this particular case study, 3D building data available from a previously successfully completed project conducted by a research team of the National Technical University of Athens, were used (Ioannidis et al., 2015). For the creation of the BIMs of the studied area, the Autodesk's Revit software was selected, while a set of available georeferenced floor plans were utilized as reference data. In the first step, the physical spaces were created in LoD4, and then the legal spaces were generated utilizing the Area and Schedule function of Revit. The utilization of Area tool enables the identification of the 2D boundaries for each 3D legal space which is a debatable topic among researchers, as their proper identification varies according to the current legislation of each country. In this investigation, we assume that the 2D and 3D legal boundaries of the studied properties are correctly sited.

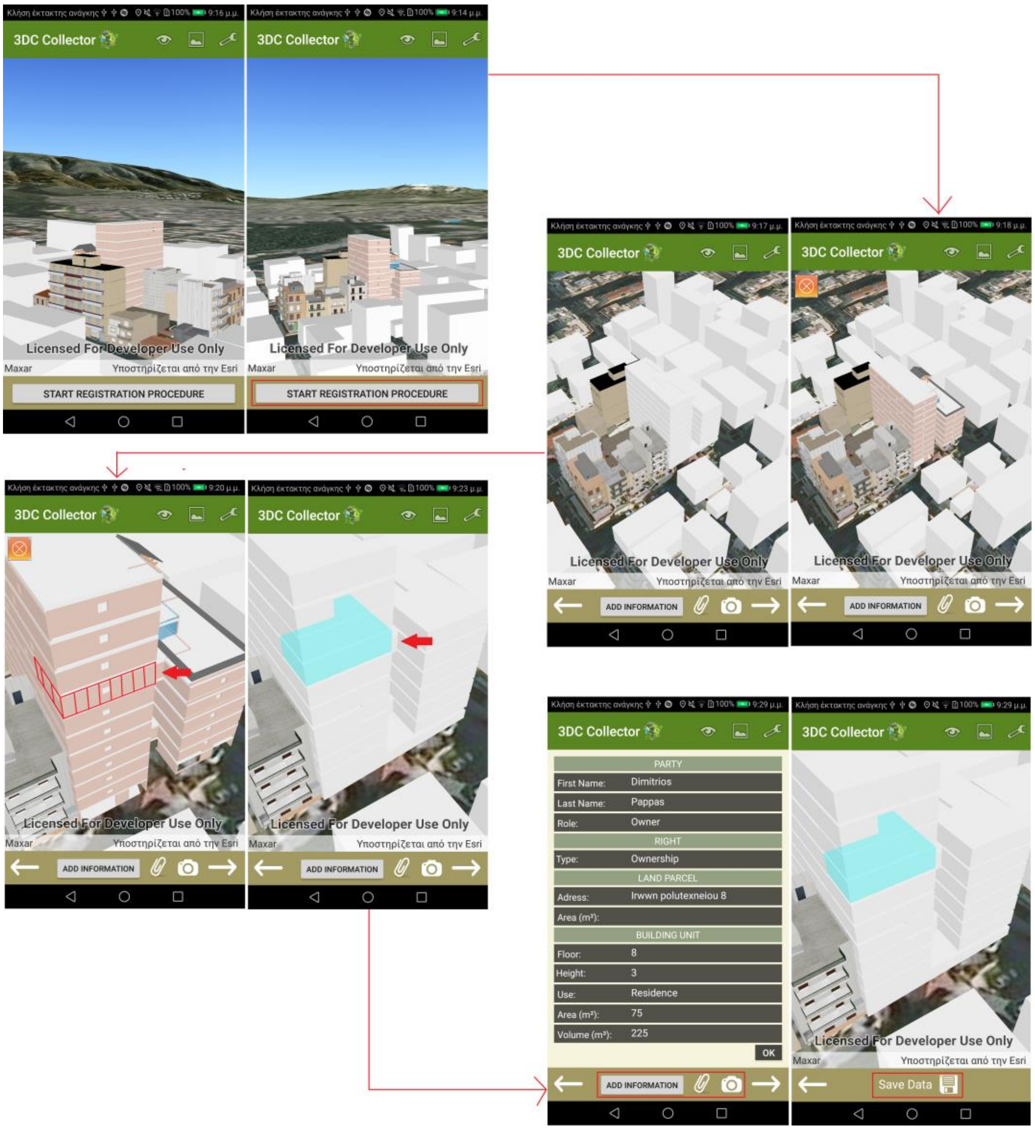

Figure 6. Example of the registration process through the developed mobile application, including: (first row) navigation throughout the 3d scene, (second row) visualization of physical and legal view of the studied building, (third row) the identification and selection of the desired property and (fourth row) the insertion of the necessary information concerning the right holder, the land parcel, the building and the building unit; and the storage of the collected data

The identification of the different types of legal objects is outside of the scope of this study, but will be addressed in the next stage of this research project. Subsequently, another useful tool provided by Revit is Schedule, as it enables the insertion of the necessary semantic information concerning the property's RRRs. Thus, the generated 3D legal objects were enriched with several attributes, describing each one of the necessary cadastral information as they are described through the generated LADM-based DBMS schema, presented in Section 3.1.1. Finally, the created 2D spaces were matched with IfcSpace entity in the exported IFC model, which was selected as exchange model in order to translate the BIMs 3D spatial information into the ArcGIS platform.

In the next step, the generated IFC model was imported into ArcGIS Pro environment, utilizing quick import tool from Data Interoperability Toolbox. Thus, the IFC model was translated into a file geodatabase and then the IfcSpace entity was directly connected with the BIM_BuildingUnit3D class of the developed LADM-base geodatabase, which is now enriched with the necessary geometric information concerning the cadastral legal spaces. It should be noted, that despite performing all the necessary steps during the development of BIM with Revit software, its georeference is not properly maintained when IFC is inserted into ArcGIS Pro environment. This is a common issue in the context of BIM–GIS integration. For this particular study, the IFC2x3 version was utilized, which despite the fact that embedded spatial reference information, mismatches may occur when importing the model to a GIS environment (Zhu et al., 2021). However, this issue is solved in the IFC4 version by introducing a new entity that includes and maintains all the necessary elements for the geo-reference of the model (Gkeli et al., 2021b).

For the purpose of this study the model was horizontally aligned close to its correct position with a fixed offset of 17 cm, while its vertical alignment was incorrect, making it appear to be submerged in the ground. To overcome this problem, the model was moved to its correct horizontal position utilizing the editing tools of ArcGIS Online. By the end of this phase, the developed LADM-based geodatabase may be uploaded to the Cloud of ArcGIS Online, so that it can be utilized for the implementation of 3D crowdsourced cadastral surveys through the developed mobile application.

4.2 Implementation and Results

For the practical implementation the proposed crowdsourced methodology was followed. A team of volunteers consisted of NTUAs' students, were assumed as right holders in order to proceed with the 3D cadastral registration. As team leader a member of our research team was selected, in order to inform the volunteers about the objectives of this research project and train them regarding the functions of the developed mobile application. Once the volunteers were familiarized with the mobile application the 3D cadastral registration process was started. Each one of the volunteers was responsible of identifying a specific number of property units in the BIM and declaring the necessary information through the developed mobile application.

The user was able to navigate throughout the 3D building scene and view the structural and realistic characteristics of the building by enabling the physical view (LoD4) through selecting the respective tool provided through the mobile application. Once the volunteer identified the desired property unit, he/she may close the Physical view and view only the 3D legal objects (LoD1) of the studied building. By tapping on the BIM at the position that he/she assumed that his/her property was located, the 3D volume presenting the legal space where the RRRs are assigned was highlighted. Then, the user was inserted the required cadastral information utilizing the Add Information tool. For this experiment, as inserted data, the descriptive information about the rights holder (first name, last name, and type of right); and the property unit (address, area code, and use), were selected. Simultaneously, the volunteers may attach images and legal documents (in an official procedure) proving their rights, in order to verify their declaration. Once the volunteers collected the required data, they submitted their declarations, which were stored in the cloud of ArcGIS Online, updating the system with the new records. An example of the described registration procedure is presented in Figure 6.

Thus, following this sequence of registration steps, the volunteers were able to complete succesfully the registration procedure, through the mobile application. The mobile application was easy to use, with the registration of each property accomplished in about 7–15 min (on average), depending on the location of the property in the BIM and the familiarity of the user with the application. The collected cadastral data have been correctly assigned to the 3D cadastral legal objects presented through BIMs, and stored successfully in the cloud of ArcGIS Online. The proposed technical solution seems to lead to reliable results requiring less time and financial resources in contrast with traditional cadastral procedures. However, this study consists only a first step towards this objective. A more in-depth investigation is needed in order to highlight any weaknesses or problems regarding the proposed framework and the mobile application itself.

5. DISCUSSION AND CONCLUSIONS

In light of rapid urbanization, the cases of multiple use of the space with overlapping and complex property right are increasing, requiring proper management. The establishment of a 3D cadastral system aims to support the government administration in order to provide an effective and transparent system capable of securing property rights, facilitate property valuation, managing real estate markets in modern cities, as well as other necessary urban reforms. Despite this need, traditional cadastral systems remain based on 2D maps complicating the definition and management of multi-dimensional property rights. At the same time, traditional cadastral procedures are time-consuming and elaborated, delaying or even preventing the completion of field surveys, increasing simultaneously the costs of the required procedures (Basiouka and Potsiou, 2012; Molendijk et al., 2018). This results in an increasing need for the development of modern innovative approaches for the compilation of 2D and 3D cadastral surveys. Until now, crowdsourcing has claimed a critical role as a reliable methodology with huge potentials regarding the realisation of 2D and 3D cadastral registration, both affordable and fast. Gross errors may be reduced as the rights holders can better identify their properties without making assumptions about the property boundaries or the names of the owners (Gkeli et al. 2016; Mourafetis et al. 2015).

BIM consists without a doubt one of the most detailed and comprehensive object-oriented method of modelling buildings. Its utilization and more precisely its potential (re-)usage may be of significant importance for the declaration of the physical and legal cadastral objects in 3D Cadastre. The utilization of BIM for cadastral purposes is very beneficial as provides a realistic view of 3D buildings and therefore of 3D property units, enabling the fast and reliable registration of 3D cadastral objects, minimizing the gross errors which are usually inserted in traditional cadastral surveys due to the misinterpretation of property unit's position and boundaries. Though the exploitation of BIMs and the IFC standard the definition and visualization of 3D legal boundaries in LoD1, is feasible. The visualization of 3D cadastral legal spaces provides a better understanding of properties boundaries as well as of the extend of the RRRs, ensuring clarity and avoiding improper behaviors and disputes between the right holders (Barzegar et al., 2021). As resulted from the test implementation, the registration process using BIMs was enjoyable, increasing the receptivity of the volunteers to perform and complete the necessary steps for the implementation of the 3D crowdsourced cadastral surveys.

Of course, another important factor strongly influencing the effectiveness of the proposed technical solution, is the ability of the user to manipulate the developed cadastral mobile application. In this particular test implementation, the users/volunteers were young adult people with advanced digital skills (engineering or technical skills) as they are students from various NTUA Schools and/or young surveyors, and they are well informed about the use of smart phones. However, as it has been proven at earlier stages of our research such mobile applications or even more complicated mobile applications can be managed by older people with limited digital skills (Gkeli et al., 2021c). Through proper training of the rights holders and real-time support from the team leaders, the effectiveness and reliability of the proposed procedure will be increased and assured.

Beyond these matters, the adoption of an international standard in order to structure the collected data, consist a valuable feature of the proposed technical solution. The adoption of LADM standard, establishes a standardization in cadastral data management and facilitates the communication between the involved parties within one country or between different countries ensuring transparency, cross-border trade, and in general data exchanging in heterogeneous and distributed land administration environments (Janecka et al., 2017). Until now, there are several different approaches presenting a potential integration schema between BIM/IFC and LADM and there is still much room for improvement. So far, the research in this field has been proven that BIMs potentially can serve well as an important and detail source of data for such 3D spatial units. Their connection with LADM and GIS may expand even more their potentials and provide interesting solutions for the fast and reliable implementation of 3D cadastral surveys.

The proposed LADM-based crowdsourced technical approach provides an alternative solution for the initial acquisition of 3D cadastral information, utilizing the rich content of (existing) BIMs. The proposed framework aims to save time and funds, simplify the registration process, enable communication, data exchange, and increase reliability of the collected data, by enhancing the role of right holders during the cadastral surveys. The selection of a mobile application as the main data capturing tool, is very helpful as a mobile device allows the rights holders to move throughout the property using the GPS sensor and oriented in 3D space and 3D visual environment, simultaneously. Also, the utilization of wireless services in combination with the mobile application, are inclusive and preferable as not everyone has access to a cable internet (Gkeli et al., 2018). The developed mobile application enables the collection of the required data in a short time, with the registration of each property unit to fluctuate between 7-15 minutes (average) and leads to reliable and accurate results. Thus, the proposed approach may constitute the basis of an initial implementation of a 3D cadastral system, speeding up the processes for the implementation of 3D Cadastres.

As a next step of this research, the investigation and identification of the different types of legal objects will be carried out, in order to investigate in detail, the weaknesses and challenges of the proposed technical framework and to proceed with the necessary corrections. Also, a hybrid mobile application including all the proposed alternative data and tools for the identification and digitization of properties boundaries (in cases of limited data sources) is tended to be developed in the next step of this research project, providing a more solid technical solution for the initial implementation of 3D crowdsourced cadastral surveys.

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