BIM data as Input to 3D Crowdsourced Cadastral Surveying - Potential and Perspectives

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Key words: Crowdsourcing, 3D Cadastre, BIM, Land administration

SUMMARY

So far traditional procedures have often led to increased costs and long delays in the 2D cadastral surveying procedures, making the completion of first registration difficult or even impossible for many countries. In the meantime, the ongoing urbanization has led to the construction of complex buildings with multi-dimensional property rights even in countries with poor and incomplete 2D land administration systems (LAS). This new urban reality though, requires the establishment of modern 3D LAS to protect and secure property Rights, Restrictions and Responsibilities (RRRs) within the three-dimensional environment. Fortunately, crowdsourcing and VGI have recently claimed a critical role as a reliable methodology with an increased potential for affordable and fast systematic registration of both 2D and 3D cadastral data. It has also become clear that a nation-wide cadastral system may be comprised of various datasets of varying geometric accuracies integrated together in a fit-for-purpose whole.

In the meantime, many cities, regardless of the progress in establishing good land administration systems, are mapped in 3D at various levels of detail and have complex buildings designed, constructed and managed by Building Information Modeling (BIM). Linking cadastral information to the 3D digital representations of the man-made environment could be a promising approach in order to define, declare and visualize the complex 3D cadastral space units. The integration of geospatial information derived from existing BIM with the LAS and the use of crowdsourcing methodology to identify the 3D cadastral objects and declare related rights and other necessary information, may significantly speed up the implementation of multi-purpose 3D LAS. Utilizing the Information and Communication Technology (ICT) tools, low-cost equipment, crowdsourcing techniques, web services, open-source software and BIM, the development of a reliable, qualitative and affordable solution for the initial implementation of a 3D cadastre is feasible.

This research focuses on how BIM information and crowdsourcing techniques can be combined together to improve the compilation process of a 3D cadastre. The main objective is to investigate and discuss how these domains may interact and cooperate to serve the needs of the systematic 3D Cadastral registration. An innovative 3D crowdsourced cadastral procedure which will also integrate available BIM data is designed, tested and evaluated, aiming to save time and funds and

provide a solution for the initial registration and visualization of 3D cadastral data. An open-sourced web application for the visualization and manipulation of BIM data is developed and tested. The user of the application is able to zoom in and out of the scene, make 3D measurements, create vertical and horizontal slices of the building in order to reveal hidden entities, helping him/her to recognize and identify each property unit, and finally insert all the necessary cadastral information, updating the system with new data. The proposed crowdsourced framework is tested on a multi-storey building in Athens, Greece. The main potential, perspectives and reliability of such an implementation are assessed and discussed.

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1. INTRODUCTION

The significant trend of three-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. Property 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, jeopardizing citizens' proprietary rights, restrictions, and responsibilities (RRRs), and complicating the valuation, taxation, planning and control of land use and natural resources procedures (Enemark 2005; Gkeli et al., 2020b). The key step in this new era of smart cities, is the creation of a functional 3D cadastral system associated with a 3D digital city model, expected to provide Accurate, Assured and Authoritative (AAA) information about the multi-dimensional property RRRs, throughout their lifecycle. Although the establishment of such a modern Land Administration System (LAS), is underlined and put in a global perspective from various actors (Lemmen et al., 2015), the compilation of a fully functional 3D Cadastre has not been achieved yet, due to the absence of integration between legal, institutional and technical parties involved (Koeva et al., 2019).

During the past decades 3D Cadastre has been a major topic of interest, as modern developments in computer graphics and 3D modelling techniques, make its implementation technologically feasible. Several 3D Cadastre attempts have been initiated world wide, leading to very interesting solutions, investigting the potential use of semantically rich 3D Models, for the creation of a 3D cadastral database (Alattas et al., 2017; Oldfield et al., 2017; Alattas et al., 2018; Atazadeh et al., 2018; Sun et al., 2019; Barzegar et al., 2021). This brings in line several other developments in this field, such as Building Information Modeling (BIM). By reusing the existing rich content of BIMs based on open exchange standards, like Industry Foundation Classes (IFC), the costs may be reduced and an interoperable result may be provided (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 3D legal spaces. BIM and GIS are considered as 3D digital models that have capabilities to identify property units, represent cadastral boundaries and visualize complex buildings in detail and accurately.

However, following the traditional cadastral procedures for the implementtion of 3D cadastral surveys and the collection of the necessary cadastral information, influences the time of its completion leading to delays, increasing gradually the costs of the cadastral procedure. As it has been proven at earlier stages of our research, crowdsourcing techniques may be utilized for the implementation of 2D (Mourafetis et al., 2015; Apostolopoulos et al., 2018; Gkeli et al., 2016) and also 3D cadastral surveys (Gkeli et al., 2017 a;b;c;d; Gkeli et al., 2018; Gkeli et al., 2019) providing promising results in terms of cost, time, geometric accuracy and reliability.

Although 2D crowdsourced cadastral surveys have been tested and their pilot implementation is already started in some cadastral agencies (Cetl et al., 2019), the 3D crowdsourced cadastral surveys still need investigation.

In this paper, the potential cooperation between BIM and crowdsourcing techniques for the compilation of 3D cadastral registration, is investigated and discussed. It is now accepted that datasets of variable quality may be integrated in a fit-for-purpose system (Thompson et al., 2018). In this sense, the proposed BIM-based crowdsourced technical solution, combines the current initiatives of the scientific community and produces a modern innovative approach for the initial implementation of 3D cadastral surveys, by setting the basis for the implementation of a Fit-For-Purpose 3D cadastre.

2. BACKGROUND INFORMATION

2.1 BIM and Industry Foundation Class standard

The Building Information Council of the Netherlands (BIR) and the Dutch BIM Gateway (BIMLoket) support that BIM has three different but related meanings. The first is the Building Information Model, describing the digital representation of how a physical building is designed, is constructed and how its finally formed. The second definition is Building Information Modelling, which emphases more on the process both alone and in partnership. The third meaning concerns the aspect of Building Information Management. It focuses on the information regarding the structure, the use, reuse, exchange and share of digital building information during the entire lifecycle of a building (Bouw Informatie raad, 2021). These aspects of BIM, aim to bring in light several threads of different information used in construction into a single environment, and improve the communication between parties.

BIM is considered as the most comprehensive and intelligent 3D digital approach able to manage buildings with composite structures, and enable communication between stakeholders with different backgrounds (Atazadeh et al., 2019). The world of smart cities needs proprietary BIMs, as a clarifying tool, providing a clearer picture with relation to property RRRs. While BIM may be used to provide the geometry of the complex physical buildings' spaces for 3D Cadastre (rooms, corridors, walls and floors), the legal space needs to be related with only one space describing the ownership boundary of a single property. In this legal bounded area, the RRRs corresponding to the property, are assigned. Through binding a number of physical spaces (rooms) or parts of physical spaces (to the middle of the wall space), the legal spaces of ownership rights, may be defined. Thus, a 3D spatial representation derived from a BIM may present an apartment which spread across multiple rooms but belonging to one owner. This could provide a better understanding regarding properties boundaries, ensuing clarity to legal issues and avoiding improper behaviors and disputes between the stakeholders (Oldfield et al., 2016; Shin et al., 2020). The representation of legal spaces can be supported from open BIM exchange models.

The commercial products are increasingly supporting open BIM standards, facilitating the broad utilization and exchange of BIMs. The standard used in this particular investigation is the Industry Foundation Class standard (IFC), which constitutes one of the most widely used standards. The IFC is a set of object definitions and exchange formats that promote interoperability between different platforms and define buildings elements, presenting the spatial relationship among them (Borrmann, 2018; Building Smart, 2021). Among 3D data models, IFC provides the potential capabilities for modelling legal and physical dimensions of urban properties (Barzegar et al.,2021). With IfcSpace entity, the representation of volumetric 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.

2.2 Crowdsourcing in cadastral surveys

Traditional cadastral surveys usually do not include the completion of both 2D and 3D cadastral registration preventing the well-function of property markets in several countries. Especially in cases of less-developed regions, time and costs for the 3D cadastral data collection are prohibitive.

In recent years, crowdsourced data have claimed a place as a reliable cadastral data source, empowering their role in the process for the initial implementation of 2D and 3D cadastre, in both the developed and developing countries (Vučić et al., 2015; Ellul et al., 2016; Gkeli et al., 2017d; Molendijk et al., 2018; Cetl et al., 2019; Gkeli et al., 2019; Potsiou et al., 2020a;b; Gkeli et al., 2020a;b). The active participation of right holders in cadastral surveys, who know better the boundaries and location of their properties, can minimize their time and costs and more important it can eliminate the gross errors. Until now, the majority of research in this field, bases the identification and delimitation of 3D crowdsourced cadastral objects, on existed 2D cadastral maps, orthoimages and architectural floor plans. Right holders are responsible to deliver all the necessary (geometric and descriptive) proprietary information into the cadastral system, utilizing modern technological developments.

Vučić et al. (2015) presents an interesting crowdsourced approach for 3D cadastral data acquisition. The user is invited to submit information concerning the property height, the reference point and the surface relation, through a mobile device. The inserted data are combined with existed 2D official information about the property's premises, enabling the partly establishment of 3D cadastre and its' visualization. Ellul et al. (2016) propose a web-based crowdsourced approach for the identification and declaration of the situations in which the land and property ownership situations belongs to. The contributor selects his/her situation from several groups presenting different types of land ownership, sketched by the research team. A different approach is proposed by Gkeli et al. (2018); they designed a cost-effective technical framework 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. A prototype mobile application able to process the inserted geometric data and provide the block models of the declared properties was developed. The application aims to automatically produce 3D building models through the digitization of property units' 2D boundaries on the available basemap. A similar but optimized approach is presented in Gkeli et al. (2019). The mobile application is upgraded by enriching its functionalities, while the methodology is enhanced by upgrading the role of team leaders in the whole registration process.

However, in the absence of an accurate basemap, other approaches should be followed. As alternatives, 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, is proposed from some researchers (Molendijk et al., 2018; Celt et al., 2019; Potsiou et al., 2020a). However, the utilization of such systems is best adjusted in sparsely structured outdoor areas, while their function in indoor environments is weak. To overcome this weakness, Gkeli et al. (2020b) proposed a deferent approach, utilizing a mobile application with several geometric tools, able to facilitate the registration procedure in adverse cases of weak basemap availability. 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.), user may utilize one or a combination of the provided geometric tools, facilitating the identification and digitization of the desired property boundaries. Furthermore, a more intelligent approach is proposed by Potsiou et al. (2020b). In this approach, mobile and Bluetooth technology, in combination with innovative machine learning techniques, are investigated for indoor cadastral mapping. The main objective of this research is to automatically acquire the position of indoor cadastral spaces and provide a plan-free solution for the initial implementation of 3D indoor cadastral surveys, mainly in urban areas. As it turns out, the integration of BIM in crowdsourced processes for the registration of property's RRR has not been implemented yet, being an interesting aspect for further investigation.

3. RELATED WORK

Nowadays, BIM is considered as the most detailed and comprehensive object-oriented method of modelling buildings. BIM and 3D property are two seemingly different domains but they can interact and get benefits from each other. By having data on each component of a building, BIM can provide input to 3D cadastre regarding each property and its surrounding properties. El-Mekawy et al. (2014) highlighted the need for the establishment of a connection between BIM and 3D property entity for the effective information management. The usage of IFC for addressing 3D ownership information in the Swedish context was investigated. Also, it was stated that BIM or CAD drawings may be utilize as a basis for the identification of 3D cadastral property objects and the presentation of its legal parts, facilitating the 3D cadastral formation process. Oldfield et al. (2016) argue that BIMs, or more specifically IFC, consist a promising data source for a 3D Cadastre. Through properly enriching IFC, it would be able to satisfy the requirements of cadastral legal spaces, enabling the extraction of cadastral data directly from both as-designed and as-built BIMs. Moreover, by (re-)using information from existing BIMs, the cost of the cadastral procedure may be reduced, introducing a cost-effective way for the implementation of a 3D cadastre. Subsequently, Oldfield et al. (2017) designed a workflow aiming to establish a bridge between BIM and GIS in order to derive GIS object from BIM files. In this investigation, the extension of the IFC data structure was examined, intending to incorporate the information of 3D spatial ownership RRRs as input data for the land registry in the Netherlands. Sun et al. (2019) investigate the potential integration of cadastral information, BIM and GIS for the visualization of 3D cadastre in urban environments. The proposed framework utilizes an IFC model in order to link physical and legal spaces for cadastral visualization on building level. The main conclusion is that the integration of the cadastral information, BIM and GIS is possible on both conceptual and data level,
facilitating communication between involved parties.

Janecka (2019) peruses the ongoing international standardization activities, focusing on 3D Cadastre and BIM, trying to illustrate their connection with smart cities. In this research, the importance of transforming mechanisms between BIM data in the GIS projects is highlighted in order to enable their wider usage in projects dealing with smart cities. As indicated, 3D BIMs potentially can serve well as an important and detailed data source for the establishment of 3D spatial units. El-Hallaq et al. (2019) proposed the utilization BIM and GIS technologies in order to represent and analyze the capabilities of the city, and therefore to define the current situation and formulate a future vision. A GIS web-based 3D model geometric and a descriptive database, including various elements of the city such as buildings, services and other facilities, was developed. 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. In contrast with other studies, Collada file format was utilized for the transformation of data between BIM and GIS systems. Subsequently, Andrianesi and Dimopoulou (2020) proposed similar web-based approach, aiming to combine BIM and GIS, for the effective management of 3D cadastral information and building data in high detail scale within a common platform. IFC standard was used for the exchange and linkage of the 3D spatial information with the two systems, resulting to promising conclusion regarding the potential integration between BIM, GIS and cadastral models after the construction phase. Recently, Barzegar et al. (2021) tried to solve the issues of IFC files, regarding the differences between geometry of 3D data in IFC and in a spatial database. For this purpose, an IFC-based spatial database for 3D urban land administration is developed aiming to support the required spatial analysis in this domain.

4. TECHNICAL FRAMEWORK

This investigation presents a part of an on-going research project aiming to develop a practical technical tool for the management of 3D property rights mainly in urban areas. The proposed crowdsourced approach tends to enrich the previous work on this domain, integrating the available BIM data, as a potential basis, for the initial acquisition, registration and representation of 3D cadastral objects. As it has been proven, the utilization of BIM facilitates stakeholders to better understand the physical environment and identify quickly the boundaries of their property, avoiding gross errors during the cadastral registration process.
A crowdsourced methodology focusing on the stage of the initial acquisition and registration of the cadastral objects/properties defined in BIM is proposed. A web-based application with the role of data capturing tool is developed. As standard for the exchange of 3D spatial information between BIM and GIS environments the IFC standard was utilize.

4.1 Methodology

The proposed methodology is based on the 3D crowdsourced methodology presented in our previous work (Gkeli et al., 2020a;b; Potsiou et al., 2020b). The proposed procedure (Figure 1) 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. The main purpose is to provide a simple, fast, low-cost and reliable procedure for the effective manipulation of existing BIM data, through their enrichment with the necessary cadastral information, aiming to provide an initial 3D cadastral database. The keystone of this methodology is the enhanced participation of the citizen/right holders, by transferring to them the responsibility for the initial collection of cadastral data referring to the semantic descriptive legal information, as well as to establish an active co-operation between professionals and citizens. As data capturing tool, a web-based cadastral application is suggested to be used.

The proposed crowdsourced procedure begins with the declaration of a specific area under cadastral survey, by the National Cadastre and Mapping Agency (NCMA). All the available cartographic/ geospatial, cadastral information and BIM data - if existing – should be collected, by professionals, for the preparation of the registration background (Gkeli et al., 2020a;b). Each sub-region of the area under cadastral survey is assigned to a local team leader, who may be a professional surveyor or a trained volunteer. The team leaders are responsible to assist the overall data collection procedure and help the citizen/right holders with any question or difficulty concerning the process or the used software, minimizing the required time for cadastral surveys and increasing their reliability.

In the next phase, team leaders are briefing citizens through the cadastral process, introducing the expected benefits from this crowdsourced project to them. Also, team leaders are responsible for citizens/right holders training regarding the use of the cadastral web application. Informative videos and detailed explanatory documents should, also, be provided by the NCMA.

The team leaders should be responsible to collect the available basemaps and BIM data, and make the necessary processing in order their insertion into the cadastral server to be used by the cadastral web application. Then, the 3D cadastral surveys are performed by the citizens/right holders, by identifying and selecting their property based on the BIM/IFC represntation and inserting 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.

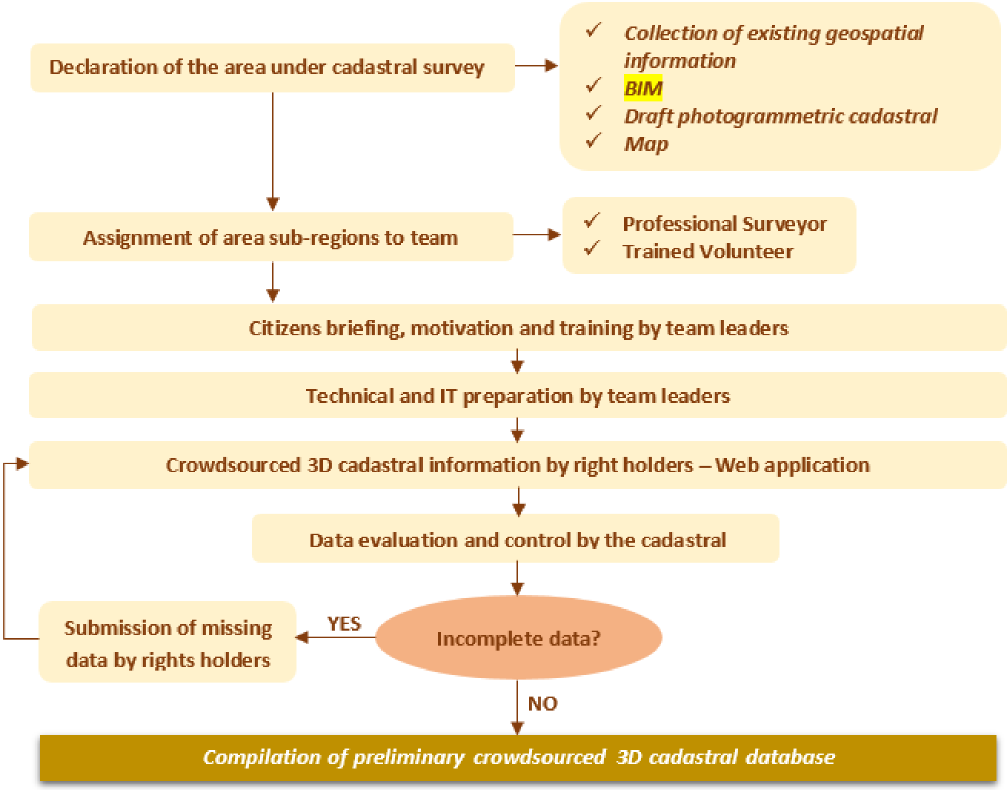

Figure 1: Proposed crowdsourcing methodology for 3D cadastral surveys.

4.2 Web application

To support the proposed technical framework an open sourced web-application was developed by the authors (Figure 2). The application is able to integrate BIM/IFC data into a GIS environment, enabling the acquisition, management and storage of 3D cadastral data, by non-professionals. BIM data are visualized both in level of detail 4 and level of detail 1 (LoD4 & LoD1) (Gröger et al., 2008), facilitating the presentation of the physical and legal spaces respectively. Through observing the virtual scene which is formed by the available BIM data, user can easily be oriented in 3D space and identity his/her property on the model. For the development of the web application, (i) the web development environment of CodePen (CodePen, 2021); (ii) the ArcGIS API for JavaScript 4.18, of ESRI, adding the function of ArcGIS to the application via libraries (with a wide variety of methods and functions); (iii) the HTML and JavaScript programming languages; (iv) the Server of ArcGIS Online (cloud of ESRI), for the storage and management of data (ESRI, 2021), are utilized.

Figure 2: Users interface overview of the developed web application.

Figure 3: Top-row (left to right): the 3D length measurement tool; the 3D area & perimeter measurement tool; and, the layer management tool. Bottom-row (left to right): the building slicing tool; and, the editor tool.

The application's interface is user-friendly and appropriately configured in order facilitate the registration procedure. BIM data are translated in IFC format and then converted into a geodatabase, enabling their further manipulation from the web application. The displayed scene simulates the 3D real world utilizing a Digital Terrain Model (DTM) offered by ESRI. As basemap, the available spatial infrastructure (2D architectural plans, orthophotos, aerial photos, Open Street Maps) may be utilized. Data are pulled from the application and pushed back into the database in the server of ArcGIS Online as there is an Internet connection.

The developed application provides a set of tools for the comprehension of the visualized 3D scene, the navigation through the virtual environment, as well as the manipulation, insertion and storage of the require cadastral data into the cadastral database (Figure 3): (i) a scene zoom in/out tool, (ii) a layer management tool, allowing the user to enable and disable building's layers presenting LoD1 or LoD4, in order to identify his/her property on BIM and proceed with the registration process, (iii) a 3D measurement tool, enabling the users to measure length and calculate area on/of 3D objects, (iv) a building slicing tool, allowing the user to create vertical and horizontal slices, revealing information about building interior spaces, and (v) an editor tool, enabling the user to select his/her property on BIM, as it is presented by LoD1 – where the property is presented as a solid entity, of a single ownership - and insert all the necessary descriptive cadastral information, about his/her rights. Once the user enters all the require information he/she may submit their declaration, updating the cadastral database with new records.

5. TEST IMPLEMENTATION

The proposed application is tested in a multi-storey building in a dense-populated urban area of Athens, Greece. The main interest of this test, is to investigate the functionality of the proposed technical tool, as well as the potential integration in the 3D crowdsourced cadastral framework, presented in previous research (Gkeli et al., 2020a;b). Data collection was performed in cooperation with the students of the School of Rural and Surveying Engineers, National Technical University of Athens (NTUA), who were assumed as rights holders. Each property is assigned to a student, who is responsible for identifying the property on BIM, and declare the adequate information through the developed web application.
As a first step, BIM data were processed in order to be converted in a more suitable form, allowing their further manipulation from the web application. The available BIM of the studied building was created with Revit software, while the properties objects - where the rights are referring to - were defined through the '*Schedule*' tool of Revit. This pre-processing step is important for the success of the propose framework, as it integrates all the physical elements consisting the property - windows, walls, rooms, etc.- to a solid surface, representing the cadastral object where the RRRs correspond. Subsequently, BIM data are translated in IFC format, where the cadastral spaces were preserved through the '*IfcSpace*' entity. Finally, IFC model converted into a geodatabase, and inserted to the cloud of ArcGIS Online. It is note that the properties of *IfcSpace* feature class was enriched with more attributes, representing the cadastral information that will be collected through this test. For this particular study, the collected data include the selection of the property entity/volumetric object, and the descriptive information about the building (area code, address) and the right holder (first name, last name, type of rights).

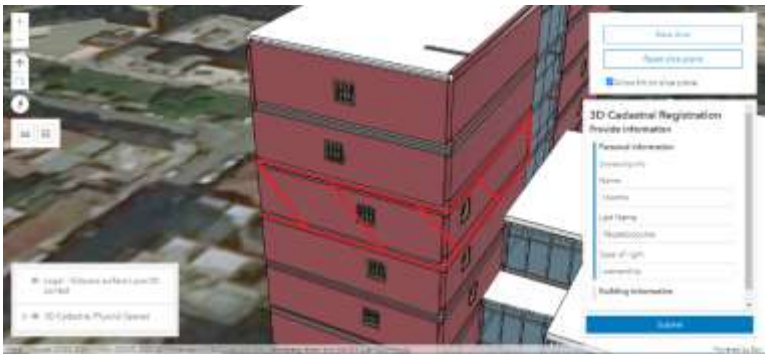

Figure 4: Example of the registration process through the developed web application, including: (top row) the identification of the desired property, (bottom row left to right) the property selection and the insertion of the necessary information concerning the right holder; and, the building.

The volunteers' team was informed about the objectives of this crowdsourced project and subsequently was trained regarding the technical and the IT preparation, and the functions of the web application, by a member of our research team with the role of the team leader. After the completion of this phase, the cadastral registration process begun. Each volunteer was navigated throughout the 3D building scene, aiming to identify his/her property. The volunteer has a clear supervision of the scene, the structural and realistic characteristics of the building, enabling the LoD4 layer. The visualization of the building with a form similar to its reality, facilitates and make easier the recognition of a specific property. Once the volunteer identifies his/her property, may disable LoD4 and enable LoD1 layers – utilizing the layer management tool - and select the volume which corresponds to the studied property. Finally, the volunteer may insert the necessary cadastral information, through the editor tool. When the volunteer selects the editor tool, a drop-down list is appeared, where the declared data has to be entered. Once the cadastral data are determined and collected by the volunteers, they may be submitted and 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 4.
The registration procedure was completed successfully, while no major problem has occurred. The web application was easy to use and the necessary information were correctly collected. The registration process was fast as the registration of each property unit lasts about 5-10 minutes (average), depending on the location of the property in the BIM and the familiarity of the user with the web environment.

6. DISCUSSION AND CONCLUSIONS

The establishment of a functional 3D cadastral system is indispensable for the effective management of land and multi-dimensional overlapping property RRRs. Traditional cadastral surveys often lead to delays, influencing the time and increasing gradually the costs needed for the implementation and completion of both 2D and 3D cadastral procedures. The uncertainty of ownership rights blocks the real estate market and the rights holders into a stagnant state. The utilization of an alternative, fast, cost-effective and reliable solution is needed. The shift to the use of innovative data collection methods - such as crowdsourcing - and the (re-)use of powerful representational models - such as BIM - may constitute a potential solution. However, in order to meet the Sustainable Development Goals (SDGs) the most important fact is not the ‘how’, but the completion of the registration of all units and rights as quickly as possible by an affordable and inclusive method, providing security of rights in the most reliable way according to existing funding. As it has been proven at earlier stages of this research, crowdsourcing techniques may be utilized for the implementation of 3D cadastral surveys providing promising results in terms of cost, time, geometric accuracy and reliability. The proposed crowdsourced technical framework combines the current initiatives of the scientific community and provides a modern innovative approach for the initial implementation of 3D cadastral surveys, by setting the basis for the implementation of a Fit-For-Purpose 3D cadastre.

At the same time, BIM has conquered a prominent place in the construction sector, affecting several other private and public organizations/departments, to adopt and proceed their projects, following the BIM methodology for the development of three-dimensional digital models. As BIM consists one of the most detailed and comprehensive object-oriented method of modelling buildings, their (re-)use may be of significant importance for the declaration of the physical and legal cadastral objects in 3D Cadastre. Through binding a number of physical spaces (rooms) or parts of physical spaces (to the middle of the wall space), the legal spaces of ownership rights, may be defined as a solid surface. This surface represent the 3D spatial representation where the RRRs are refer to. By utilizing all the available levels of detail provided from BIM, a better understanding regarding property boundaries is achieved, ensuring clarity to legal issues and avoiding improper behaviors and disputes between the stakeholders. IFC standard empower this objective, as it facilitates and allows the integration of 3D building elements presented in BIM, with 3D cadastral information through an interoperable manner.

The proposed crowdsourced approach tends to enrich the previous work on this domain, integrating the available geospatial information derived from existing BIM, as a potential basis, for the initial acquisition, registration and representation of 3D cadastral information concerning the related rights, directly from right holders. As the test implementation demonstrated, BIM data consist a cost-effective solution that facilitates the cadastral registration procedure, speeding up the implementation of a multi-purpose 3D Land Administration System (LAS). Rights holders have better supervision of 3D space and thus, the identification of their property consists a simple process. The proposed crowdsourced framework along with the developed web application, lead to satisfying results. The use of the web application is simple, enabling the collection of the necessary data in a short time, with the registration of each property unit to fluctuate between 5-12 minutes (average). However, the achieve duration depends on several parameters, such as the location of the property in the BIM and the familiarity of the user with the web environment, that needs to be investigated. For example, if the desired property is located in the interior of the building, without to abut with any exterior wall, its identification becomes difficult, requiring more time and careful observation.

As the volunteers of this experiment were of young age with good digital skills, it is obvious that a further investigation, recruiting volunteers with varying educational and technical/digital background, should be conducted in order to provide more efficient and reliable results. That consists the next step of this research, trying to optimize the proposed crowdsourced framework.

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Member of the management board of the Greek Cadastral Agency (2009-2012).
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