Proposal for the Development of a 3D Hybrid Model for the Hellenic Cadastre

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Key words: 3D Cadastre, Hybrid Model, SDBMS, 3D-GIS

SUMMARY

Cadastral registration based on a two-dimensional parcel representation of space (2D cadastral unit) was adequate for several decades. However there has been an active and increasing use of space above and below the land surface with a fragmented legal status (various properties, property rights, right-holders). Thus, encouraged by the recent technological developments the use of three-dimensional approaches in cadastral systems (3D-cadastral unit) is investigated. The spatial databases, 3D GIS and CAD applications can be effectively used for 3D modeling, spatial analysis and visualization of cadastral objects.

Greece has rural areas of intense relief with various autonomous properties at various levels (parcels, single family houses, mines etc), with overlapping property projections in a 2D-unit system. In the highly urbanized areas, too, there are autonomous properties like condominiums, metro, motorways, utility networks, etc, which have overlapping projections in a 2D-unit system. The technical specifications of the Hellenic cadastre (HC) require the creation of a 2D-unit cadastral GIS; there are no provisions for a 3D-cadastral unit reference for the legal rights and the other cadastral information. This paper proposes a smooth transition from the existing HC 2D-GIS to a 3D hybrid model, so as to preserve the existing 2D-unit system but also integrate 3D representations of the physical objects.

An application of a 3D cadastral process is developed for the island of Kimolos, in which typical examples of special real property objects exist, such as settlements carved into the rocks with overlapping projections of the private properties, and/or settlements with buildings arching over the alleys with overlapping projections of the private and public properties. Aerial and terrestrial images of the island of Kimolos, and the existing cadastral map are combined with the descriptive information of the cadastral records and entered into the spatial database system. The development of the three-dimensional cadastral system is approached by three different methods. In the first two methods the cadastral registration of objects is implemented in the SDBMS of Oracle Spatial, which is linked to a Geographic Information System (ArcInfo) and AutoCAD Map 3D, respectively, so that the properties are visualized in three-dimensional level. In the third method, the registration and 3D representation of cadastral objects are implemented in the environment of ArcGIS, while for their 3D modelling Google SketchUP is chosen, because of its capability to incorporate 3D models to ArcGIS.

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1. INTRODUCTION

During the last century the urban population density and the expansion of the urban areas has increased significantly. Already since 2007, for the first time in history the world's urban population reached 50% of the total global population and it is increasing since then. This trend has led to an increasing interest in land, making the determination of land use zones the need for cadastre intense and necessary. In the past for protection purposes but also recently for economies of scale and with the support of the technology there has been an increasing activity and a compact and dense use of the space above and below the surface of the land parcel. In the large urban centers land uses and ownership rights vary significantly not only between the buildings but also within the same building. The increase in population and vehicles on road networks has led to constructions of modern transport facilities such as underground subway, highways, railways, etc., which necessitates constructions above and below the ground surface, in order to avoid congestion problems, facilitate residents and generally promote a healthy lifestyle in big cities. This multiple use of space leads to complex situations that can be described better by a three dimension documentation.

Despite the fact that properties are mostly depicted in two dimensions and that traditional cadastral registration based on a two-dimensional parcel representation has been adequate so far, there is an ever growing need for a 3d cadastral registration. So the important question is how sufficient are the traditional tools to meet the current requirements or whether cadastral systems need to explore three-dimensional approaches (3D-cadastral unit). 3D Cadastre is defined as a system which sets out the rights and restrictions on 3D property units that exist above and/or below the land surface (Stoter, 2004).

The development of the existing 2D Cadastre into a three-dimensional system is being encouraged by the development of the technology. The spatial databases (SDBMS), the three-dimensional Geographic Information Systems (3D GIS) and the CAD applications can be effectively used for 3D modeling, spatial analysis and visualization of cadastral objects.

Obviously for the registration and management of 3D properties and the overall development of a three-dimensional system, a collection of three-dimensional information of the existing two-dimensional cadastral records is required. This transition entails a quite lengthy and expensive process as it requires replacement of all the coordinates of records so as to add the third dimension (Z). This affects both the remodeling of the database where the cadastral records are stored, and the reproduction of cadastral diagrams which will now show the volume of properties and not the two-dimensional projections, when it is necessary. Moreover, a complete 3D cadastral system can only serve if it is harmonized with the legal framework of each country. The Greek legal framework already secures the existing various legal rights above or underneath of the same land parcel. However, some newly created cases need to be included.

The term "3D Cadastre" can be interpreted in various conceptual models, such as a full three-dimensional system that supports 3D (volume) rights and properties or a simple traditional system which is restricted to minimum information about three dimensions (Stoter and Salzmann, 2003). This happens because the solutions implemented by various countries for the registration of proprietary objects vary according to their current legal status and afterwards the expertise that exists in each country.

In particular, a full three-dimensional system introduces the concept of the 3D property as a reference and registration unit, while it removes the concept of the 2D parcel which is the basis of the traditional 2D Cadastre. In this conceptual model, the legal framework, the real estate transactions and the cadastral records take into account the establishment of individual property rights which refer to a three dimensional space (3D rights). Although some countries have set an appropriate legal framework for the establishment of 3D properties, no country has yet developed a full 3D cadastral registration system.

The intermediate case is a hybrid form of a cadastre, in which the 2D registration system is maintained and any three-dimensional representations of properties or property rights are integrated in the existing two-dimensional system. This results in the preservation of the legal framework, which is referred to the two-dimensional properties and the simultaneous registration of three-dimensional information of cadastral objects. Such a conceptual model is recommended for most countries that have as reference unit the land parcel. Examples of countries that are experimenting the hybrid cadastre are The Netherlands (Stoter and Van Oosterom, 2003), Norway, and Israel (Shoshani et al, 2005), having developed individual cases of technically advanced three-dimensional properties. Countries that have established a legal framework for the consolidation of the three-dimensional properties without been implemented at a technical level are Sweden and Canada (British Columbia). Australia (Queensland, Victoria) (Aien et al, 2011) belongs partially to the latter case, but is in a more advanced stage both legally and technically, having developed individual applications in order to establish a full 3D cadastral registration system.

The third conceptual model is the least intrusive alternative of the above two and is applicable in many countries, which have not particularly dealt with the issue of three-dimensional cadastre. Specifically, this solution is based on the existing two-dimensional registration system, while in cases with overlapping properties, an attachment or a link with the necessary information is added to the cadastral records.

The objective of this paper is to propose the smooth transition of the existing Hellenic Cadastre 2D-GIS into a 3D hybrid model of cadastral registration, so as to preserve the existing 2D-unit system but also integrate 3D representations of the physical objects. An application of a 3D cadastral registration process has been developed for the island of Kimolos, in which typical examples of special real property objects exist, such as houses carved into the rocks (called ‘yposkafa’) causing an overlap of private ownerships’ projections, and buildings arching over alleys causing an overlap of private and public properties' (e.g., roads) projections. The development of the three-dimensional cadastral system is approached by three different methods. In the first two methods the cadastral registration of objects is implemented in the DBMS of Oracle Spatial, which is linked to a Geographic Information System (ArcInfo) and AutoCAD Map 3D, respectively, so that the properties are visualized in three-dimensional level. In the third method, the registration and 3D representation of cadastral objects are implemented in the environment of ArcGIS, while for their 3D modelling Google SketchUP is chosen, because of its capability to incorporate 3D models to ArcGIS.

2. THE NEED FOR A 3D CADASTRE

The recording of all legal rights existing in the real world and their graphical representation often creates complex situations that can only be described in detail by three dimensions. This happens due to the limited extent of the land surface in many countries, where overlapping properties of different use have been constructed vertically, which misinterprets the understanding of the factual situation, above and below the ground surface. Indicative examples are given below, that necessitate the development of a 3D cadastre (Stoter and Salzmann, 2003):

- overlapping constructions of public use, e.g., intersection of rail and road network
- infrastructure above and under the ground, e.g., underground parking, shopping centers, buildings over roads / railways, subways
- location and ownership of cables and pipes (water, electricity, sewerage, telephone, gas, coaxial cable TV).
- many apartments in one building
- mines, beneath the surface of land parcels
- historical monuments, lying underneath privately owned areas.

In countries like The Netherlands, Australia, Israel and Malaysia there have been made some individual experimental efforts of 3D representations of the established property rights or representations of 3D physical objects or registration of 3D rights and properties. These applications are designed to investigate the possibilities and limitations of utilizing one of the three conceptual models of 3D Cadastre, while giving application perspectives in countries that still have as reference the registration of two-dimensional parcels.

A case of implementation in The Netherlands (Stoter and Ploeger, 2003), Sweden and Malaysia (Hassan et al, 2008) are the apartments, where in Germany, France and most other European countries according to their legal status, each owner apartment has the full ownership of the apartment and the co-ownership of common areas of the building. In a few countries (e.g., Austria, Switzerland, the Netherlands), property rights concern the co-ownership of the land parcel, while the cadastral diagrams do not depict the separate compartments, i.e. proprietary space. In this case delineating the boundaries of the apartments requires vertical separation of the building and horizontal separation of each floor in order to distinguish the different apartments, something that can be dealt only with the three-dimensional representations.

Another example is the overlap between public and private property, as implemented in The Netherlands (Stoter and Van Oosterom, 2003), in a case of a building complex, part of which is built over a street in the town of Hague and its use is divided into three different owners (Figure 1).

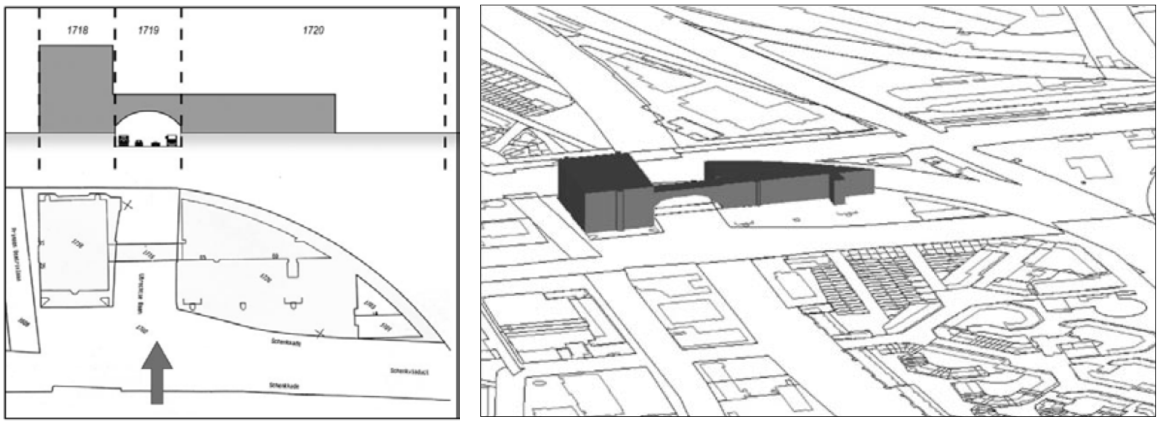

Figure 1. Left: Intersection and cadastral diagram of a building complex. Right: 3D representation of the building (source: Stoter and Van Oosterom, 2003)

A similar situation results from the overlap between a private property and an underground tunnel, case which is represented in the three dimensional space in Israel, where spatial sub-parcels are created in the underground or above-ground space, after the allotment or expropriation of specific parts of the space which are within the vertical boundaries of the surface parcel (Shoshani et al, 2005). Many cases of overlapping public and private properties exist in Greece also, and constitute the main objective of this research, as many complex property ownership statuses that take place both in large cities and picturesque islands, are clearly described better in three-dimensional level. So there is a strong need to develop a hybrid three-dimensional cadastral system in Greece.

3. 3D PROPERTY UNITS IN THE HELLENIC CADASTRE

Greece is a country with an area of 132,000 km^2 and a population of approximately 11,000,000 residents; Greece is covered mainly by rural and forest areas, while more than 15,000 km delineate the sea coast and more than 3,000 islands and islets. Because the rural land is highly fragmented and due to poverty and urbanization, most of the population is attracted in large cities, resulting in the abandonment of rural and mountainous areas.

The goal of the Hellenic Cadastre (HC) is to develop a uniform, systematic and continuously up-to-date information system based on the land parcels of the country, including their geometric description and ownership status, as well as additional information needed for administrative, technical and economic activities. Registration of the cadastral information in Greece is based on the cadastral parcel, a 2D-unit, which forms the basis for their collection, processing and allocation.

2D Cadastre consists of two main components, which are governed by specific institutional context. These are the cadastral maps which contain the geometric description and visualization of the labeled, in a diagram, properties and the cadastral books describing the ownership of each property unit and including data about the owners, location, legal, technical and economic framework, land use, encumbrances, mortgages, etc.

In this phase, the project of the national 2D cadastre has not been completed, but with the completion of the second Main Program, is estimated that all major urban centers will be included in the land registry and 2/3 of the residents will be living in registered areas. The number of property rights, which are expected to have been established by the end of the program is approximately 8,500,000 (PCC, 2009).

Regarding the legal framework of the country, there have not been made any specific regulations for the establishment of 3D properties. More specifically, according to Article 1001 of Civil Code (CC), which establishes the rule of Roman law (superficies solo credit), the owner of the ground parcel is also the owner of the whole upper space (including buildings) and the subsoil. Therefore, the ownership of a land part generally includes all buildings constructed on it (Article 954 CC). Exception to the provision of Article 1001 about ownership, are special cases of customary law, which governs the legal relationships of property rights in several regions of Greece, such as islands (e.g., Cyclades).

Similarly, an exception to the above articles are the establishments of horizontal and vertical ownership due to Article 1002 CC, in conjunction with Law 3741/1929 "on the property by floor" and the L.D. 1024/1971 "on separate ownership," concerning buildings that are built into a single parcel, respectively.

The basic real properties registered by the Hellenic Cadastre are the following (Rokos, 2001):
- Land parcels
- Horizontal ownerships
- Vertical ownerships
- Composite vertical ownerships
- Special real property objects
- Mines.

Obviously from the above categories, all the real property objects, except the 2D land parcels, have a three-dimensional registration status and should be included in a full 3D cadastral system.

As mentioned before, this paper is mainly based on the special real property objects (houses carved into rocks, arches). In particular, special real property objects are by the common law relationships of separate property, under which the owner on the ground parcel is not necessarily the person who owns the buildings, which constitute separate property objects. In such cases, ownership of a building under this legal status does not mean co-ownership to the land parcel (Rokos, 2001).

The special real property objects are not necessarily registered by the Greek Cadastre. The objects of great interest which constitute cadastral records for certain areas, either spatial or descriptive, are those with polygonal form (dug-in houses, above constructions, arches) with a different cadastral ID from the ground parcel, to which they are related (Figure 2). However, in some cases the information on the 3D properties is being recorded in a descriptive way in the cadastral database, which is not sufficient for the correct and precise representation of the real situation.

Figure 2. Up left: Dug-in houses on Milos island. Up rirght: Construction above an arch. Down: private real properties underneath the bridge in the city of Arachova

Greece is undoubtedly one of the countries with a need to create a fully three-dimensional cadastral system as it has rural areas, including villages and small towns, of intense relief with different autonomous properties, parcels, single family houses, mines etc, with overlapping property projections in a 2D-unit system. Also, in highly urbanized areas numerous autonomous properties like condominiums, metro, motorways, utility networks, etc, as well as in several other cases which are greatly occurring both on the islands or the mainland have overlapping projection in a 2D-unit system. The various cases of complex property and ownership status are the following:

- Multilayer constructions of services and utility networks, e.g., tunnel with constructions above it
- Subway
- Electricity cables, water pipes, etc

- Overlapping public and private properties, such as: underground parking, building complex, properties over buildings / roads / roadside arcades or arches
- Overlapping private properties, e.g., properties over buildings with different owners (Figure 3)
- Houses carved into rocks with different owners in the area above the ground
- Condominium ownership rights
- Right of implantation to a separate property
- Mines.

Figure 3. Overlapping ownership projections on Santorini island

Some of the peculiarities of the Greek territory, which impose the need for future, probably long-term, motivation towards such a venture, are (Papaefthymiou et al, 2004):

- The complexity and difficulty of implementing the Greek legislation on the registration of the cadastral information. In particular, the existing legislation does not regulate situations which existed before its establishment, such as the existence of settlements with a complex ownership status, as well as when they were under foreign occupation for many years.
- The intense terrain relief led to the construction of complex infrastructure, multilevel buildings and areas with different property ownerships.
- The finding of older or archaeological structures while conducting excavations for new constructions, which is probably due to the fact that most of the modern settlements were built on the ruins of ancient cities.
- The special real property objects which result from the overlap of multiple uses and properties, discontinuities and separations of parcels and buildings.

4. TECHNICAL ISSUES FOR THE APPLICATION OF 3D CADASTRE

Given the increasing use of space above and below the land surface with a fragmented legal status (various properties, property rights, right-holders), the development of a three-dimensional cadastral system was necessitated, so as to cover the cadastral references to a three-dimensional level and not at the level of a 2D-unit system. The technical issues to be addressed are the representation of 3D physical objects based on two-dimensional projections of the properties.

As mentioned above, spatial databases, three-dimensional GIS as well as CAD systems can contribute effectively in order to create, spatially analyze and represent 3D models, in a properly designed three-dimensional environment. Although a few years ago these technological means were supported by only two-dimensional applications, their upgraded versions now support 3D coordinates, advanced 3D models and specific toolkits for their processing and spatial analysis. Therefore, for the effective management and development of a three-dimensional system, the combination of these different methods is required, so as to integrate spatial and qualitative - descriptive information in a uniform system. Moreover, although these different systems offer the capability of interoperability, i.e. the import, processing and export data from one system to another, a major drawback is the fact that the advanced functions which are supported individually by these systems, are not necessarily supported through the connection to other systems that support only basic functions. For this reason in this application connection of individual programs will be attempted, in order to explore the capabilities of the most widely used and developed technologies in the recent years.

The development of the 3D cadastral system is investigated by three different methods. In the first method the spatial DBMS (SDBMS), Oracle Spatial 11gR2, is connected to AutoCAD Map 3D 2011. Thus, the spatial database for the registration of the ownership of objects is used, in three dimensions, which then is connected to AutoCAD Map, providing a more advanced 3D modeling of both the property and its surroundings according to the users' needs.

It is worth noting that the use of SDBMS for the registration of properties in cadastral applications is indicated in comparison with traditional DBMS, as it is a software module that integrates spatial and descriptive information in the table of an entity and their components include spatial data models, spatial data types and operators, spatial query language, processing and optimization more similar to the specifications of the OpenGIS Consortium (OGC). The new version also supports data types of a three-dimensional geometry such as surfaces, multi-surfaces, solids and multi-solids. Unfortunately these types of geometric data as well as the topological relations between them are not supported when connecting the database with AutoCAD Map.

In the second method under investigation, Oracle Spatial 11gR2 is combined with 3D GIS and more specifically with the environment ArcScene 10 of ArcInfo ESRI, which offers more capabilities regarding the management, processing and spatial analysis of 3D models. GIS software helps users to visualize and analyze spatial data using spatial analysis functions and SDBMS to store, search, query, share large spatial data sets. The procedure of this method is similar to the previous one, beginning with the development of the database of the cadastral data. What differs here is the way that the database connects to the environment of ArcScene, and the opportunities provided for a detailed three-dimensional representation in order to develop a realistic 3D Cadastre. Technically, the 3D physical objects are quite difficult to be visualized, since their geometry is usually more complex, complicating the procedures of spatial analysis (through spatial queries) and topological control when these are treated as single objects.

In the third method under investigation, the registration and 3D representation of cadastral objects are implemented in the environment of ArcScene 10, while for their 3D modeling Google SketchUP 8 is chosen, because of its capability to incorporate 3D models to ArcGIS. Google SketchUp is a software package used for the quick and easy creation of three-dimensional objects. Its toolkits, measuring tools and library materials provide the users with the opportunity to design in detail and accuracy both the outside and the inside of a building and add photo-textures to it. Thus, this software led to a more advanced modeling of the volume properties, adding photo-textures or designed facades to the buildings. Then, each building model was imported into the ArcScene environment, assigning it to the appropriate record of the database, which was created in the internal database supported by the ESRI software. This case differs from the previous as it does not integrate the spatial and the descriptive information of the objects to a spatial database.

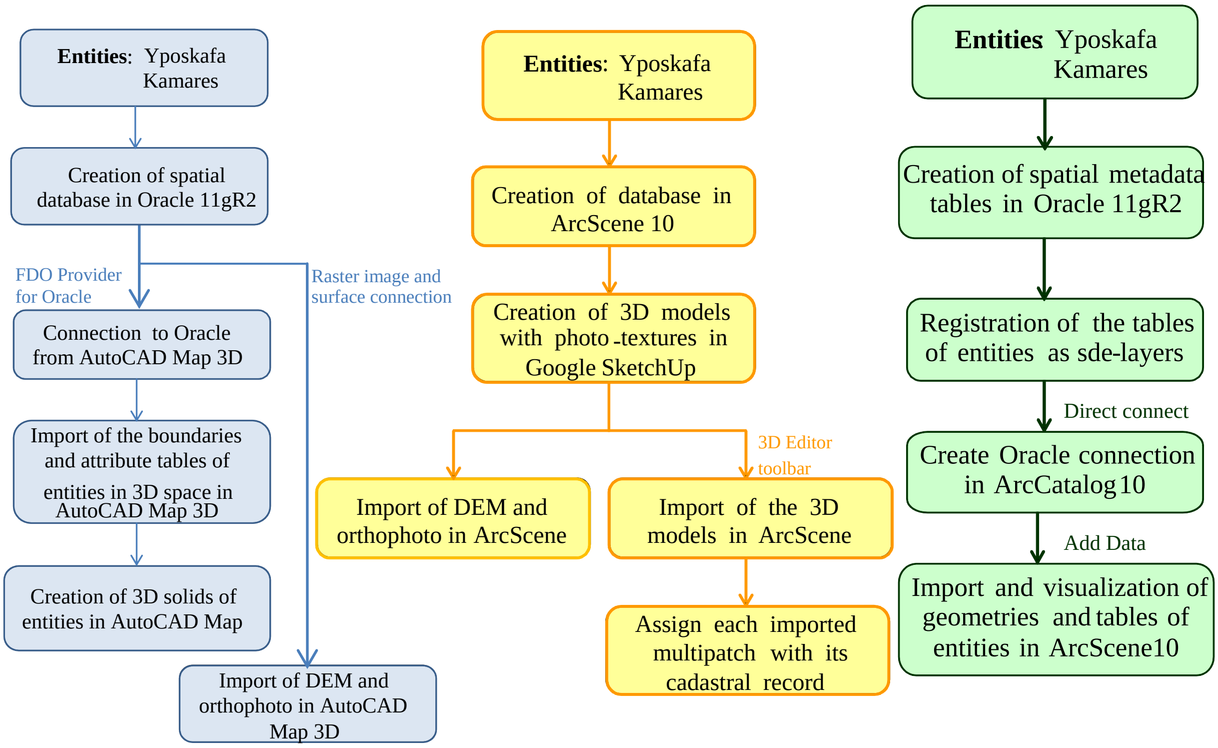

Figure 4. Flow charts of the three proposed procedures/methods

5. CASE STUDY IN KIMOLOS ISLAND

5.1 Application area and data

Kimolos is located in the southeastern Aegean Sea and is part of the southwest Cyclades island complex in the arid line of the western Cyclades. It has an area of 37 km^2 and lies between Milos and Sifnos islands. Kimolos is largely the product of intense volcanic activity, since it is located in the outer zone of the Aegean volcanic arc and its traces are visible everywhere on the island as hot springs and unusual geological formations compose landscapes of rare beauty as well as a variety of rocks, such as the characteristic chalk ("kimolia"). There are many types of complex properties on the island (special real property objects), which constitute the main reason for its selection as the ideal background for developing a 3D registration project on the complex rights and presenting them through a hybrid 3D Cadastre.

Specifically, the cadastral objects of our application consisted of (a) houses carved into rocks, called "yposkafa", causing an overlap between private ownerships and (b) buildings arching over alleys ("kamares") causing an overlap between private and public properties (e.g., roads). The registration of such special real property objects into the HC shows the need for a three-dimensional cadastre. The special real property objects refer to relationships of individual property created by the customary law (later accepted by the Civil Code), under which the owner of such a building may vary from the person who owns the land parcel on which the building lies. Ownership of a building under this legal status does not mean co-ownership of the land parcel. This means that the extent of the specific real property object does not follow the boundaries of the land parcel delineated on the surface of land. It is therefore necessary for the existing 2D cadastral model to provide a solution for registering and representing multilayer property activities in order to better reflect the property rights on land in Greece.

The data used for the development of the hybrid cadastral system are the existing cadastral map, which depicts the boundaries of the properties and land parcels in the 2D level and are provided by KTIMATOLOGIO S.A., the state agency responsible for the compilation of the Hellenic Cadastre (Figure 5). In addition, aerial and terrestrial images of the island of Kimolos are used, which are combined with the descriptive information of the cadastral records and are entered into the spatial database system. In order to determine the height and the volume of the properties, 3D geometric data are collected from the stereo-photogrammetric processing of aerial images of Kimolos. By adding heights to the existing properties, the constructions above or below the surface are volumetrically defined and presented as 3D solids and no longer as 2D projections.

Figure 5. Left: Cadastral map of entity "kamares" - Right: Cadastral map of entity "yposkafa"

For the creation of the background of the study area, a digital elevation model (DEM) and an orthophoto of Kimolos are used. The DEM is created by using the 3D Analyst toolbar of ArcScene environment, using digitized contours of the area, while the final background layer resulted from the process of draping the produced orthophoto, at the scale of 1:2000, on the surface.

The properties represented mainly as plain volumes, excluding the application of the Google SketchUp where photo-textures are placed on their facades, as emphasis is not put on the level of difficulty in creating three-dimensional objects, but on the representation methods and interoperability among the various software packages concerning visualization and data analysis. The following paragraphs provide specific examples of the applied methods.

5.2 Results

The description of the procedures for the application of the first two proposed methods on the test area is given below, together with some typical examples of the products. The application of the third proposed method is still under development.

In the first method under investigation, Oracle Spatial 11gR2 is combined with AutoCAD Map 3D 2011, where it is easy to perform spatial and topological queries. In particular, creating an Oracle connection (Autodesk FDO Provider for Oracle), feature classes ('yposkafa', 'kamares') that created in Oracle, are transferred to AutoCAD Map as layers along with their tables of descriptive attributes. In the same way (Raster image and surface connection) DTM and its draping orthophoto are imported into the AutoCAD Map environment.

A major drawback of this method is that AutoCAD Map 3D does not support complex geometric data types (multi-polygon, multi-surface, solid) which are supported by Oracle Spatial 11gR2. Therefore, when AutoCAD is connected to the spatial database, the outlines of properties are imported in 3D space as rectangular coordinates (X, Y, Z) are given in their corners and afterwards the plain solids of properties are created.

Figures 6, 7 and 8 depict the carved houses (‘yposkafa’) which, due to the intense relief and the steep slopes, are located underneath the ground surface, underneath other buildings while their entrance is located on the ground level and may be either common with that of the overlying building or different. When they overlap with other private properties, they get the same cadastral ID with the respective parcel above the ground, whereas when they are located below a public property (e.g., road), they are registered with the same cadastral ID of the parcel in which the entrance of the carved house is located.

In particular, Figures 6, 7, and 8 depict screen-shots in which a 3D environment in AutoCAD Map 3D 2011 is shown. The DEM, the orthophoto and the 3D solids are imported to AutoCAD Map through FDO Data Connections from the Task Pane which appears on the left of the screen. The user may select the data to be visualized in AutoCAD Map once the connections are made. In this case, the attribute tables of the two entities ‘yposkafa’ and ‘kamares’, in which is also included their spatial information, are selected. The same procedure is followed in order to import the DEM and the orthophoto.

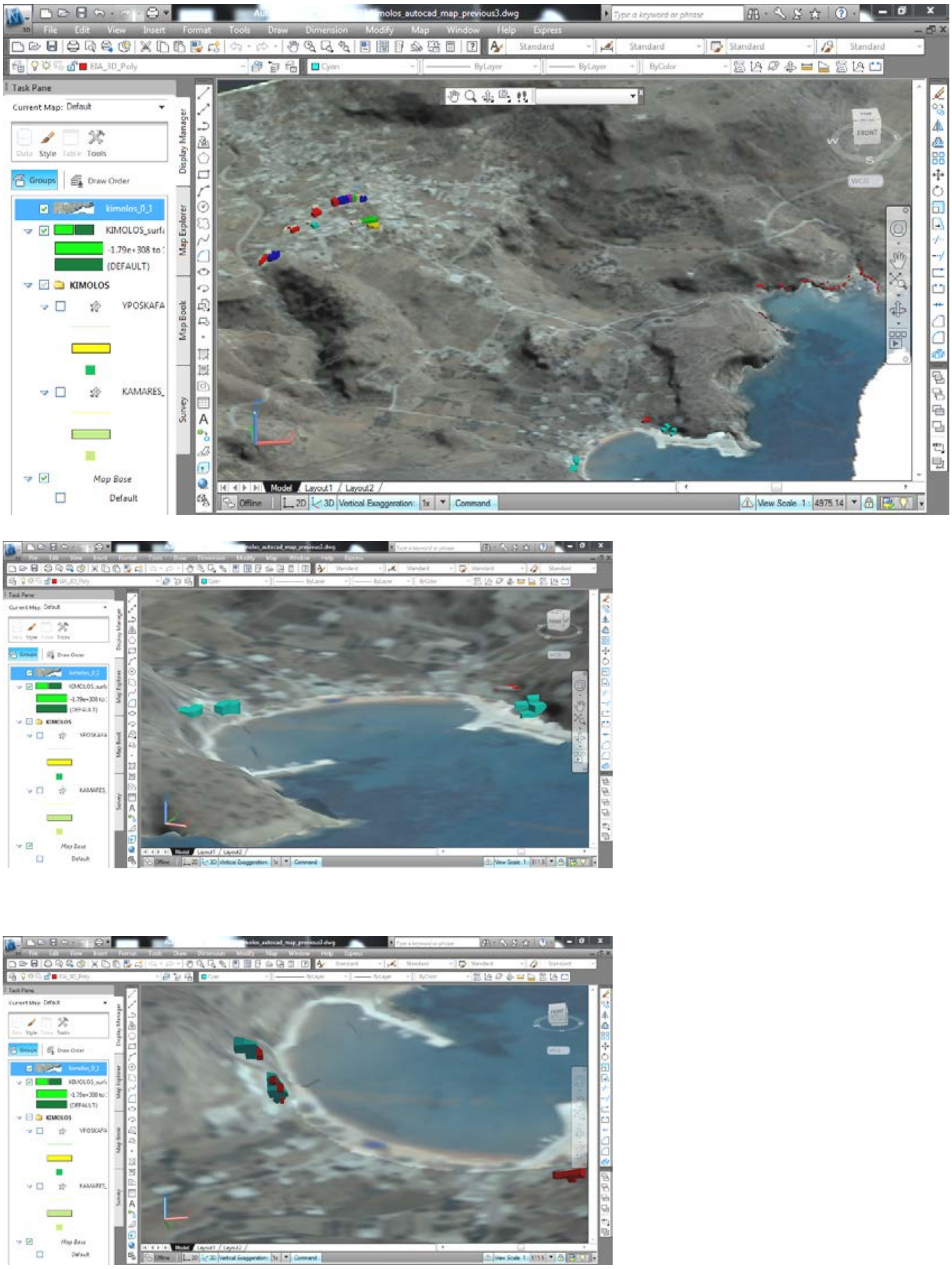

Figure 6. Up: Perspective view of 3D models of entities 'yposkafa' and 'kamares' represented in AutoCAD Map 3D 2011. Middle: Volumes of private properties above the ground surface. Down: Volumes of 'yposkafa' overlapping with private properties below the ground surface

The different layers of the two entities, the DEM and the orthophoto are depicted in Task Pane, where the user can edit them to an extent. By clicking to a layer of an entity, the user can display its attribute data table, where cadastral records are stored. In addition, AutoCaD Map provides the option for analyzing the records of the entities using operators or math, text and geometric functions so as to form specific spatial queries according to the users' need. The entity of 'yposkafa' is depicted in red and cyan colors, near the seaside, while the entity of 'kamares' is represented in the centre of the area with multiple colors. Both entities are modelled as plain solids using as reference their boundaries which have been imported in 3D space in AutoCAD Map 3D.

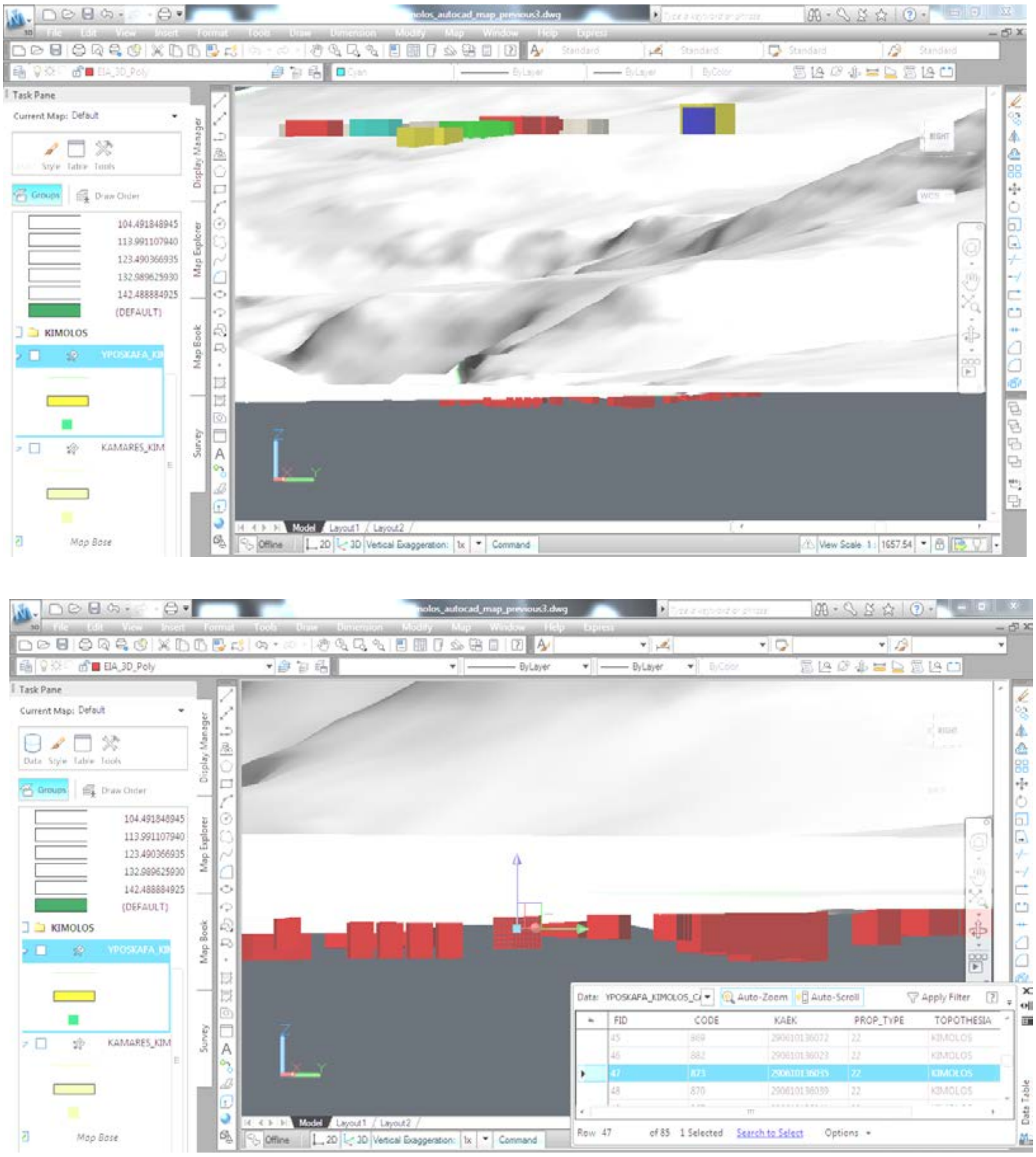

Figure 7. Up: Right view of volumes of entities 'yposkafa' (below the ground surface) and 'kamares' (above the ground surface) in AutoCAD Map 3D 2011. Down: Selected cadastral record of 'yposkafa' with its descriptive information from the respective table of the database

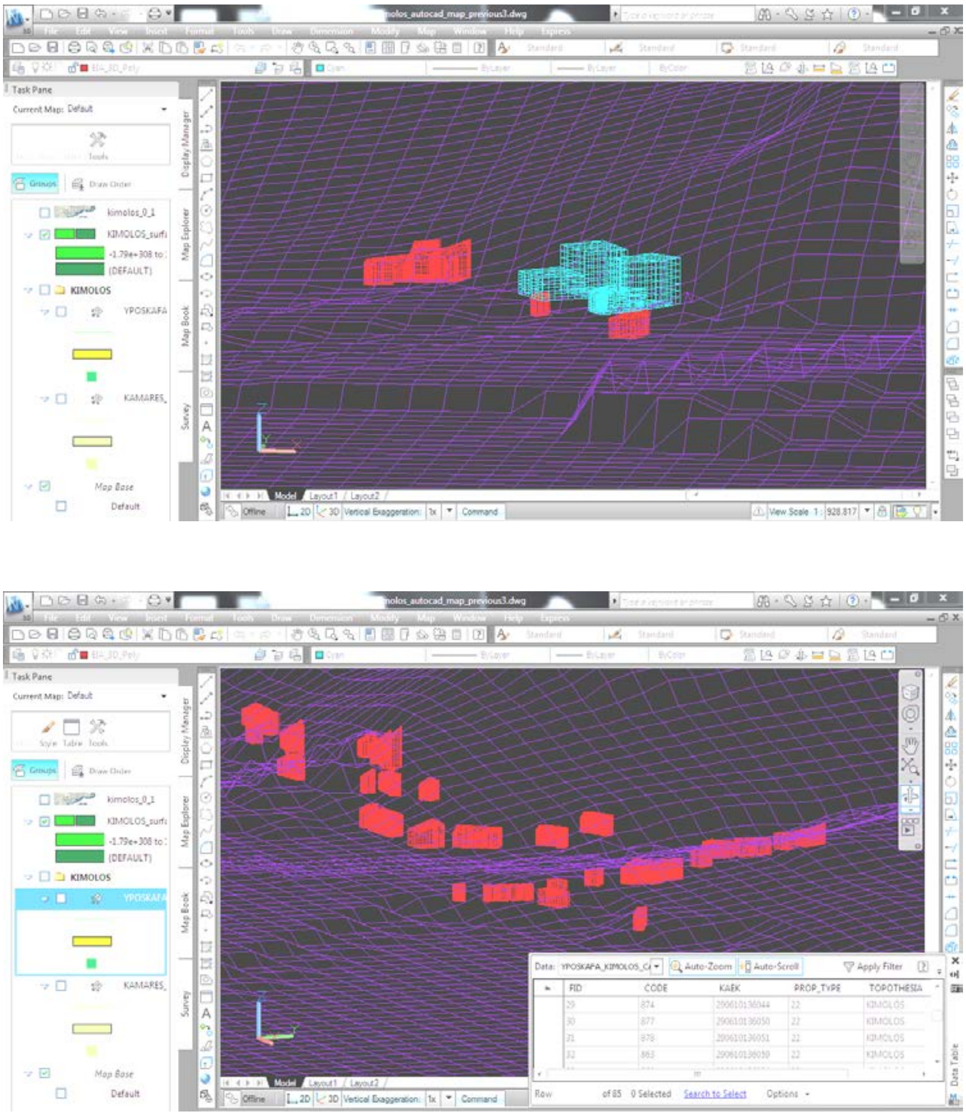

Figure 8. Perspective wireframe view of overlapping private properties (cyan) and ‘yposkafa’ (red) as solids created in AutoCAD Map 3D 2011 after connecting to Oracle Spatial database

Figure 9a depicts building parts situated above arches, which belong to the adjacent properties, to which they are tangent. Particularly, these properties are given the same cadastral ID to the road which they lie on while it is also mentioned that the property is annexed to the adjacent building, which is registered with a different cadastral ID. In the system's screens presented below the buildings located above the arches have the same color as the adjacent property which they belong to.

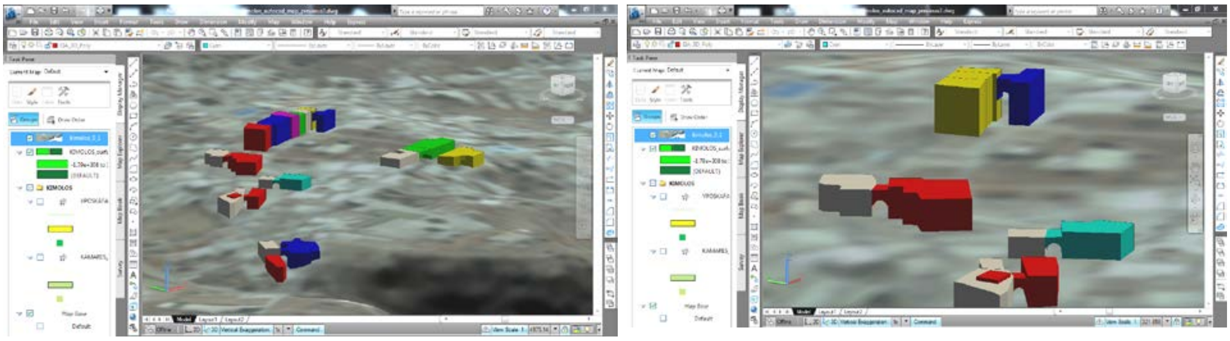

Figure 9a. Perspective views of volumes of entity 'kamares' in AutoCAD Map 3D 2011. The adjacent items with same color consist of the same property

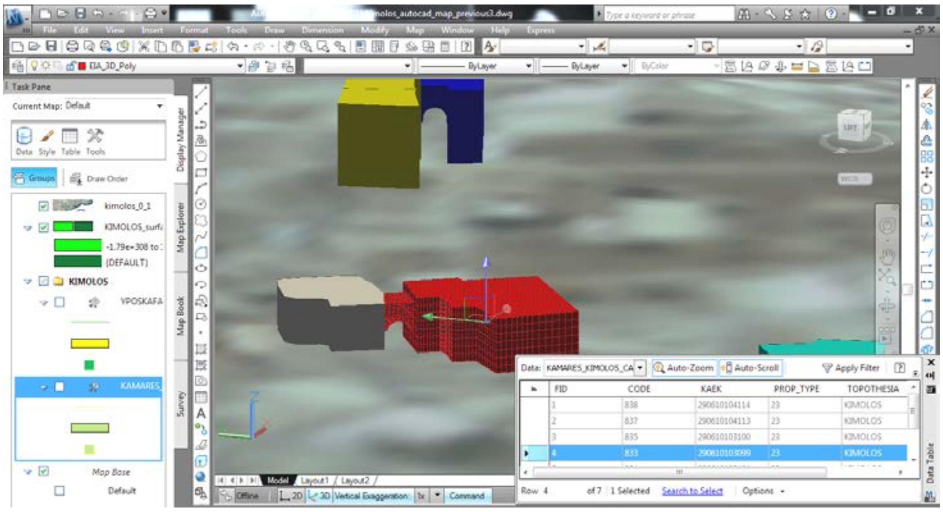

Figure 9b. Selected cadastal record of 'kamares' with its descriptive data from the respective table of the database

In the second method under investigation, SDBMS is not used, as the internal database of ArcScene 10 for the registration of properties was chosen, while the 3D physical objects are designed in Google SketchUp 8, where the models are represented at a higher level of detail by placing photo-textures on the facades of buildings. Each three-dimensional property that is imported into the environment of ArcScene is assigned to the suitable record of the cadastral database that contains its attributes as well as to the suitable feature class which has already been created in ArcScene, as multipatch.

In the following figures indicative examples of the application are depicted. In particular, Figure 10 depicts screen-shots of the 3D environment in ArcScene 10. In the left part of the screen, the layer tab is appeared with the feature class of 'yposkafa' created as well as the imported DEM and orthophoto of the area. The 3D models are imported as multipatch features from Google SketchUp 8, using the 3D Editor toolbar, adjusting, if necessary, their exact position. While importing each multipatch feature, the user should assign to it the suitable record from its attribute table. ArcScene gives also the capability of analyzing or editing the 3D models to a certain extent using ArcToolBox or 3D Editor toolbar respectively.

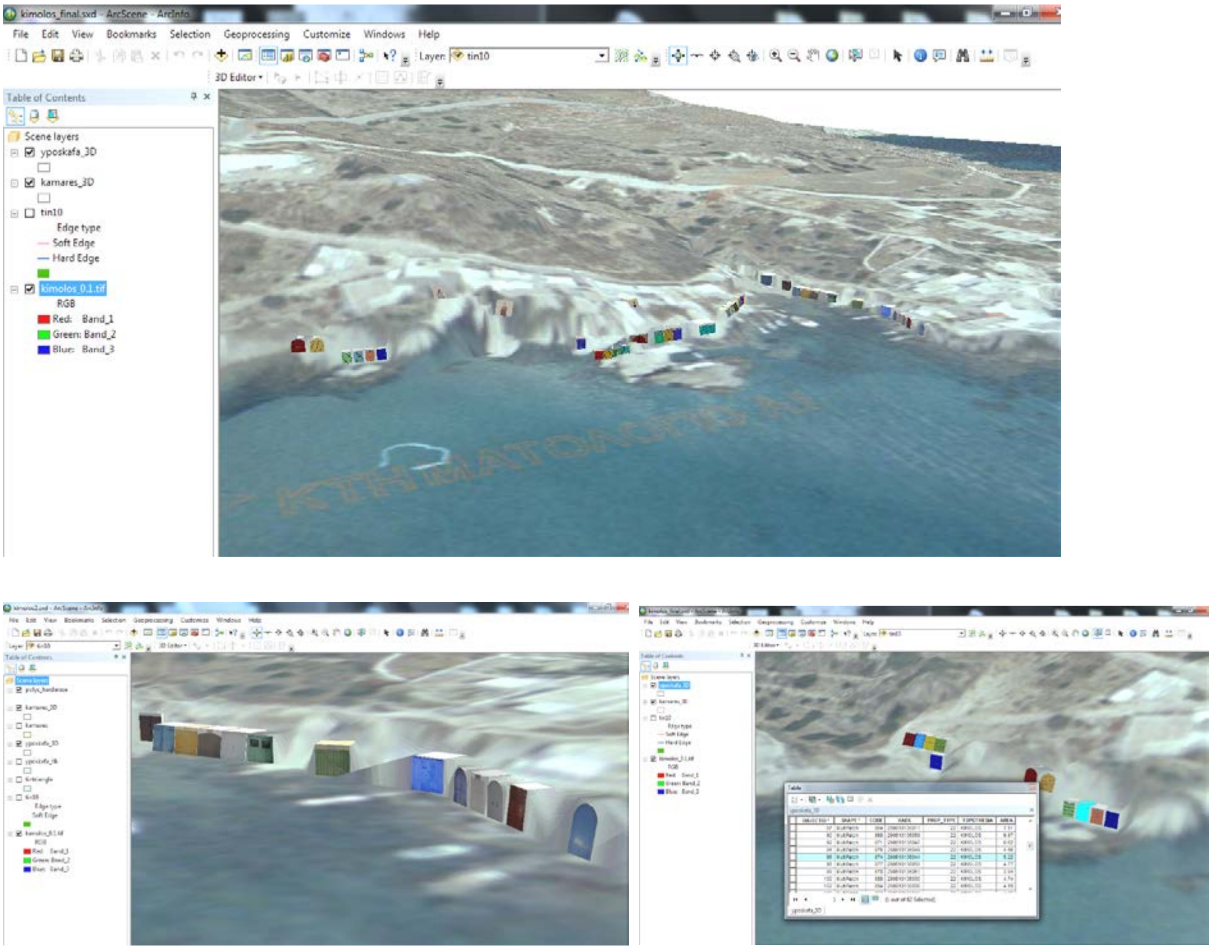

Figure 10. Perspective views of entity 'yposkafa' at a higher level of detail in ArcScene 10. The models designed in Google SketchUP with photo-textures on their facades. Down right: Selected cadastral record of the entity with its descriptive data from its attribute table

Figure 11 also depicts screen-shots of the 3D environment in ArcScene 10. In the left part of the screen, the layer tab is appeared with the feature class of 'kamares' created as well as the imported DEM and orthophoto of the area. Similarly to the above example, the 3D models of 'kamares' are imported as multipatch features from Google SketchUp 8, using the 3D Editor toolbar. While importing each multipatch feature, the user should assign to it the suitable record from its attribute table. As it is depicted the modelling is more advance in this feature class, as it is originally more complex than the other one. In one screen-shot particularly (middle right) we can observe that the arch is a part of the building which is separated in order to cross the underlying alley. Finally, selecting a 3D model, information concerning its cadastral status is displayed for both its legal and technical framework (rights, restrictions, geometry, location, etc), which allows the spatial analysis between the same or different items of the feature classes.

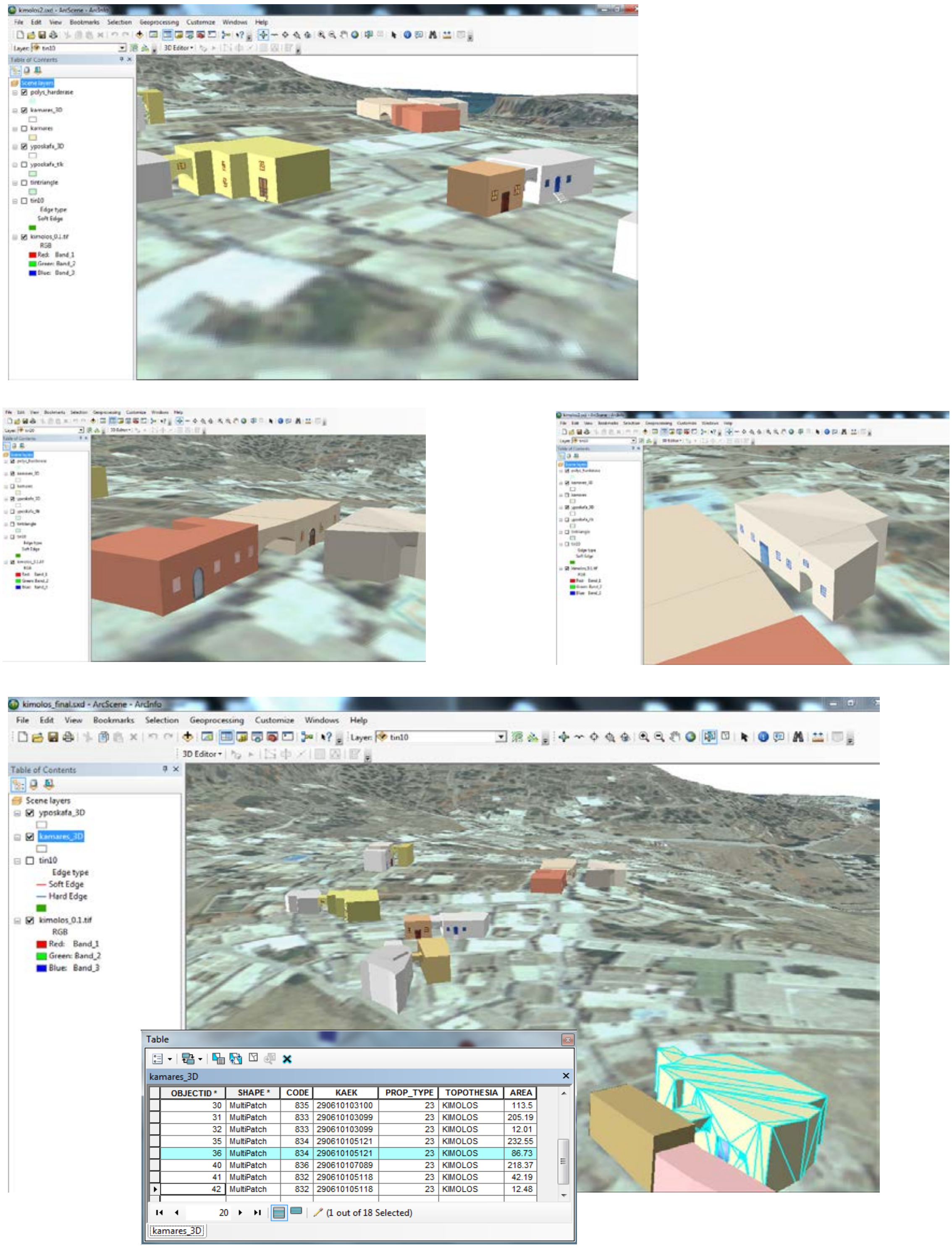

Figure 11. Up and middle: Representation of 3D models of entity 'kamares' at a higher level of detail in ArcScene 10. The models designed in Google SketchUP with photo-textures on their facades. Down: Selected cadastral record with its descriptive data from the attribute table

6. COMPARISON OF INVESTIGATED METHODS – CONCLUSIONS

The development of a three-dimensional cadastral system in Greece is essential due to the complex ownership status in several regions of the country. On the other hand, a full three-dimensional registration system in the short-term future seems to be a difficult and unrealistic task, as it is required the reformation of the existing legal framework or a new regulation that establishes 3D properties and rights. Moreover, although the technological development favours the creation and registration of 3D objects from spatial DBMS, it is still complex and requires the appropriate expertise in order to represent with detail the reality of complicated and overlapping properties. In this paper it is aimed to identify a solution, which is considered to be the best concerning the current state of the cadastral system in Greece.

Three different methods for the development of a 3D cadastral system are proposed and examined, which are based on traditional 2D land parcel-based system and on the representation of 3D physical objects, when these cannot be represented in the existing 2D cadastral map. Generally, this approach is based on the interoperability among commercial software, which are largely used for the management, analysis and representation of two-dimensional and three-dimensional objects.

In two of the above methods SDBMS are used, as they have the advantage of integrating spatial and descriptive information in the same database, which helps users to incorporate all necessary information in the same system. However, spatial databases are not particularly useful in case of three-dimensional geometric data types. Additionally, complex geometric models that are supported by databases are not yet included by most programs that visualize them (e.g., AutoCAD Map, ArcScene) in the level of complexity and detail that is required. For this reason, the level of detail in these methods is not high, as represented in plain volumes. Unlike the above two methods, the third method uses different programs for the registration of cadastral objects and the modeling of 3D objects. So in this case the 3D models are represented in a higher level of detail, approaching better the factual situation. Therefore, although the third method does not incorporate the geometric and descriptive information in the same database, it is easier to register and model the properties. On the other hand, although the final result is integrated on the same system (ArcGIS), the upgrade of existing or import of new records is a time-consuming process, as different programs for each process are used.

To sum up, a hybrid 3D cadastre system will undoubtedly facilitate interested users to understand the ownership status in every aspect of technical, economic, social and legal matters of everyday life, but also will constitute the beginning of a full three-dimensional cadastral era. The system is presented to the various market players for their comments, and for their proposals for further improvements.

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