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Topology Data Structure and Functionalities in Support of Information System for Management of Multi-Dimensional Land Registration

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Summary

Information management system is now heading toward multi-dimensional, sustainable automatic land registration, which tends to replace the existing 2D management system by integrating height, time and scale dimensions for performing complete cadastral processes, analysis and planning.

This study aims at setting an approach for expanding cadastral management systems from 2D to multi-dimensional (third/height dimension, time and scale). Starting from

defining a data model and creating a database appropriate for storing 3D geometric and topologic cadastral objects, in addition to setting spatial procedures and functionality requirements for supporting the third dimension. Next, proposing a solution for creating 3D models in different time spans and levels of details. Several alternatives for storing time/scale dependent data will be examined.

The research topic is still challenging, as no multi-dimensional management system exists. This study will recommend an optimal multi-dimensional model for land management after testing various combinations of 2D, height, time and scale and set an approach for implementing 5D system.

The full integration of many different dimensions, including all the topological entities that define the dimensions integrated into the same system, will prevent the need for handling special cases in segregated systems, support decision-making and multi-purpose applications. As well as providing the opportunity of sharing geo-data by diverse users through linking data from different sources in one system.

1 Introduction

A multi-dimensional cadastral information system is the framework for defining and understanding the spatio-temporal land management restrictions, responsibilities and rights (RRR) of, among others, land information and ownership over space and time. Nowadays, the need for such system for an effective urban planning and management is crucial, a result of population growth, urbanization complexity, and industrialization.

The existing land management systems handle realities as 2D representations, i.e., 2D land parcels (polygons). Still, complex cadastral objects have also height, representing the whole 3D 'air column' (space) above and below the 2D parcel, where the 3D 'air column' can contain a number of 3D parcels, as depicted in Figure 1. .

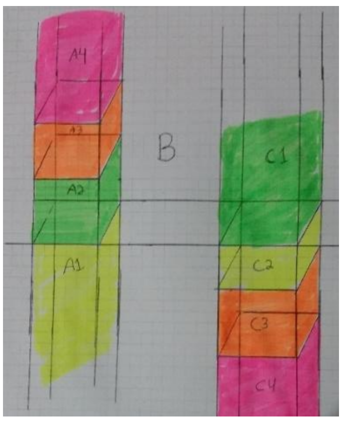

Figure 1. A, B, C are 2D parcels. A1, A2, A3, and A4 are 3D volumetric parcels in the 'air column' of A. C1, C2, C3, and C4 are the 3D volumetric parcels in the 'air column' of C.

Besides the spatial representations, a land property is also represented in time, and can undergo time-dependent changes that are caused either by humans (e.g., transactions, mutation plans) or by natural phenomena (e.g., coastline movements). Which means that a land property does not remain the same, and it is important to recognize when each property was valid in the system. In other words, it is necessary to integrate the time dimension in the land management system since the property's reality is dynamic. In addition, cadastral information systems serve highly diverse users and applications, everyone with his/hers specific needs and purposes, meaning that the data should be presented and queried in different Levels of Details (LODs) in order to fit for different usages (fit-for-purpose), i.e., integrating the scale dimension in the cadastral systems is a requisite.

Efforts are being made to transform the existing 2D land management systems into multi-dimension 5D ones (i.e., integration of all dimensions - space, time and scale). Several studies focused on this issue (e.g., Doner et al., (2013); Seifert et al., (2015); Doulamis et al., (2015); Aien et al., (2012)), still, no such system exists for a large scale management, where the aforementioned studies are limited, presenting only prototypes and pilots. One of the reasons is that the suggested methodologies for dealing with 5D require high computations and construct new systems, based on photogrammetric techniques, rather than utilizing the data in the existing 2D systems.This research is advocated towards setting a complete technological approach for uniformly and smoothly expanding cadastral management systems from 2D to multi-dimensional while preserving the principles of the 2D systems, which is different from the approaches of most of the previous research in this field and is expected to eliminate the need for establishing new and separated cadastral systems for storing, managing and analysing every dimension independently. Constructing 5D land management system provides full reference to space, time and scale (which eliminates the need for dealing with special cases) and enables creating time-scale-dependent databases, performing time-scale-based queries, 5D search (i.e. time and scale are search parameters). These promote the performance of multi-purpose geo-information systems and decision making applications that serve for different fields such as transportation, geodesy and urban planning.

The major steps of the research are: Defining and constructing data structure, topology (geo-database) and functionalities. Followed by data collection and 3D database creation. Then, giving definitions for time and scale dimensions, implementing and comparing various approaches for doing that. The steps would be based on registration rules and RRR in Israel as a case study; however, the research is directed towards providing a global solution, and the proposed approach could be adjusted for other land management systems.

2 Research Objectives

Previous research has proven the usefulness of adding height dimension to the 2D cadastral management system. Still, the appropriate software, data structure, functionality, systematic implementation, database, queries and guidelines for managing 3D cadastral data have not been determined as it involves a large variety of organizational, technical and legal aspects, and needs to be deeply investigated. Besides, land properties have temporal and scale-related components, which has been lately referred to in research. Questions about the need and efficiency of integrating those two elements (time and scale) in the cadastral system have been raised, and not equivocally answered. My research will examine these topics within local real-estate data, starting from the height dimension, then the time and scale dimensions. Giving recommendations and setting an approach for expanding cadastral management systems from 2D to multi-dimensional (third/height dimension, time and scale) while preserving the principles of the 2D systems are the objectives of my planned research.

My research is directed toward a solution that would eliminate the need for establishing new and separated cadastral systems for storing, managing and analyzing every dimension independently. Instead, I aspire to develop a 3D data structure as an expansion to the 2D data. I believe it should save a lot of computational and practical complexities, as well as money, time and human resources; however, efforts are demanded for ensuring that the transfer from 2D to 3D (height extension) is uniformly and smoothly achieved, as well as making sure that there exists a proper way for defining and applying 3D topological relationships in the same system, which is very critical in the field of land management.

Adding the time dimension and scale to land management and asset registration systems is not a simple process and involves many legal, organizational and technical issues. Before the integration of time and scale, my research will investigate the interaction between these three issues and determine how and to what extent a multi-dimensional cadastral can be applied legally, organizationally, and technically. It will also recommend whether to integrate the time aspect within the three-dimensional cadastral system or to separate it. Both approaches have pros and cons. On the one hand, it is argued that a separated spatial registration system (without the time element) can represent all available practical cases, its technological implementation is much simpler, while "for support for true 4D geometry and topology further R&D activities will be required" and "just adding one simple time dimension might not be sufficient to represent complex temporal situations and therefore the integrated 4D model alone will not be sufficient." (Oosterom et al., 2006). On the other hand, an integrated space and time system will enable efficient and integrated four-dimensional queries, shifting many parent-child relationships into generic neighbouring queries. To offer a conclusion, my research will investigate relevant topics, such as: Can temporary information be obtained from existing cadastral registration systems? Is it necessary to use four-dimensional principles to implement temporal-spatial division? If not, what measures and tests should be made for determining whether cadastral data distribution is a temporary spatial or it is some other kind of division. It will also make a definition for the term "time dimension" and its semantic meaning, along with determining a useful spatio-temporal model in the land registration system. A time dimension can describe many different things, and a clear and uniform definition of the concept will effectively contribute to the implementation of adding this dimension.

Although visualization is not an objective of this research, it will examine various options for representing information on a variety of scales, while maintaining consistency, efficiency, and uniformity in the transition between different scales. The study will recommend one of the two approaches taken in this regard: either storing the most detailed scale and generalizing it to other scales as needed in real time or store in advance some separated databases, each of which represents a different scale. The LODs term gets its importance mostly in the visualization process, which is an integral part of the land management system. In visualization, there is always the need to display the same scene from different distances, which means different scales. Since this research is designed to achieve a complete multi-dimensional cadastral system, it will investigate managing data in various LODs, and aims at putting the guidelines of the most effective way for holding the data in a manner that it enables seamless transfer from one LOD to another. Most of the existing research related to LODs deals only with natural objects and not with man-made ones, and so are the algorithms. Accordingly, my research will suggest a way for storing and representing different LODs for man-made objects.

Data collection is another topic to be explored. The type of data, its structure, accuracy and the way in which it is collected directly affect how the dimensions are defined and induce the structure of the databases for storing, querying and representing the multi-dimensional information. A problem I encountered in my Master's research is that there is no unequivocal definition of 3D cadastral data, their composition, accuracy, coordinate system, projection parameters, and their level of detail. Thus, my research aims to determine the type of the data to be used for the definition and analysis of the three-dimensional cadastral properties.

To sum, this research will: 1) set a cost and time-effective approach for expanding cadastral management systems from 2D to multi-dimensional. 2) Investigate the interaction between height, time and scale in one common system. 3) Recommend whether to integrate these dimensions into one common system or to keep them separated. 4) Suggest either storing the most detailed scale and generalizing it to other scales as needed in real time, or storing a number predefined LODs. 5) Recommend methods for collecting data as an input to the multi-dimensional system.

3 Research Contribution

3.1 Adding the third/height dimension to real estate management system:

The need for a three-dimensional cadastre is acute today: in the modern era, high demand of land and density of urban construction, especially in industrial and commercial centres, lead to overlap and integration of complex structures in space.

Scientific importance: it is expected to offer an innovative approach for defining and modelling multi-dimensional data, while ensuring the integrity and legitimacy of geometry, topology, and semantics, as well as enabling geometric modifications in the system.

New ideas for integrating additional dimensions into a management system have recently been introduced. However, a complete technological solution for adding the third dimension to real estate management systems has not yet been fully implemented.

The research will set an algorithm for adding this dimension to 2D land management systems.

Engineering importance: it is prospected to set the requirements for an integrated cadastral system to be able to analyse and store 3D data, thus leading to a better management of the urban space and engineering projects.

3.2 Adding the fourth/time dimension to a real estate management system

Real cadastral properties have time element and undergo changes caused by humans or natural phenomenon, which gives big value to integrating time into cadastral systems.

Scientific contributions: the integration of the time aspect should significantly improve the various functionalities of the cadastral information systems among them: effective search in four-dimensional systems, and practical performance of time-based queries (archive, operations, rezoning, etc.). Integrating time dimension in the system would result in creating time-dependent databases, change detection maps, presentations and analysis as a function of time, and enabling time-related inquiries, which are all necessary for effective, optimal and multi-purpose geo-information system that serves for different fields such as transportation and geodesy. In urban planning, for example, adding time dimension enables historical achieving, monitoring urban changes over time and cultural heritages, detecting the past trends of urban development and studying human mobility, understanding changes of land cover and land use. These are all necessary for directing the upcoming urban development in a sustainable manner that will preserve natural resources for future ages.

Engineering contributions: Adding time dimension allows the handling of rights and restrictions that are time-dependent, such as: leases and season dependencies (grazing, gathering vegetation, hunting/fishing, etc.). It would also provide a description that is close to the dynamic reality and enable understanding boundaries and ownership changes. Moreover, the boundaries of cadastral objects are influenced by natural changes and phenomena. The fourth dimension will enable monitoring dynamic objects in general, especially natural objects.

3.3 Adding the fifth/ scale dimension to a real estate management system

Integration of all dimensions - space, time and scale - in one system will enable more efficient management and handling of the data level and the level of accessibility.

Scientific contribution: scale is a search parameter. That is, there are situations where the system should be able to answer scale-dependent queries, and the user will be able to search for spatial entities not only according to location and time parameters/considerations, but also according to scale-dependent definitions. In addition, the full integration of many different dimensions, including all the topological entities that define the dimensions integrated into the same system, produces a formal definition of the "geo-data" term. This combination allows full reference to space, time, and scale, and thus all aspects and cases will be dealt with in integrative routines, preventing the need for handling special cases in segregated systems. This would also enable inputting data from separated databases to one common database, which may optimize operating several applications.

Engineering Contribution: it will enable performing more efficient queries in five dimensions. Setting cadastral database that stores the legal status of a network as well as all changes, updates, and movements, based on its physical space enforces consistency in the distribution of borders in various dimensions, which improves the quality of geographical and geospatial data. Moreover, a database at different levels of detail is a very useful tool for improving applications, especially those that support decision-making. In addition, this will enable calculating costs and effectiveness of operating applications upon different LODs and, consequently, recommend on an optimal LOD. For example, Biljecki et al., (2017) refuted the assumption that finer LODs are needed for estimating shadows.

4 BACKGROUND

The complexity of modern land use and management has led to the need of adding the third (height) dimension to land information systems, where several projects have been developed in the area of 3D modelling and reconstruction, especially for land information management (Doulamis et. al., 2015). However, the nature of land utilities is dynamic and have a time component, and it is important to supply answers for time-related questions, for example: “when was an object valid in the database?” (Van Oosterom et al., 2012). The dynamics of man-land relationship is expressed by the “time” aspect. This relationship is dynamic due to the transition of land ownership between people for different reasons (e.g., heredity, sell and buy), and because administrative plans are continuously reshaping the space. Adding the time dimension will enable monitoring the development of cities and villages over time, archiving and storing historical transactions for properties, and tracking statistical changes in land use and coverage, all of which contribute to future planning purposes.

Geo-data have also scale component and the required data resolution varies depending on the application. According to Ioannidis, et al., (2015), an additional dimension, the scale, should be added to complete the digital counterpart for modern urban management architectures. The advantages of 5D modelling, compared with the 4D one, is that the first performs a time-scale geometric model representation, instead of a temporal representation of the 3D geometric properties. The introduction of the time and scale dimensions into 3D Land Information Systems (LISs) will enhance data management in various levels of detail (LODs) without gaps and overlaps in time and space. Despite the fact that both time and scale have always played an important role in LISs, the temporal and scale aspect have been treated quite independently from the spatial one.

3D related spatial cadastre studies were recently carried out, both nationally and internationally (e.g., Aien et al., 2011; Döner et al., 2010; Eriksson and Jansson, 2010; Guo et al., 2011; Karki et al., 2010; Paulsson 2007; Pouliot et al., 2010; Rahman et al., 2011; Stoter et al., 2013). These studies conducted a detailed analysis of various 3D spatial configurations in an attempt to examine and finally evaluate the ability to provide a unified and proper configuration of a spatial cadastral prototype. So far, these studies focused on various aspects of a 3D Cadastre, such as legal and technical issues concerning 3D cadastre with an intention to provide an optimal solution for defining and solving these 3D cadastral solution aspects. A multiplicity of theoretical alternatives for spatial land registry standards of multi-level property has been suggested by these studies. Van Oosterom et al., (2011) and Van Oosterom (2013) conclude that no complete 3D Cadastre system, covering all aspects, is operational. In most cases, spatial cadastral parcels represent only housing units. Still, a number of states investigate the spatial transition to full registration, such as Russia (Vandysheva et al., 2012). Accordingly, it seems that in terms of conceptual and technological maturity, now is the right time to reconsider the required processes in accordance with the preliminary productive steps made during the past decade worldwide.

Only a few researchers studied the time and scale dimensions, among them, are Osteroem et al., 2012; Kang et al., 2014; Doulamis et al., 2015; Seifert et al., 2016 and Makantasiset et al., 2014. However, adding these dimensions to 3D models is significant for contemporary applications, such as: 1) Simulating noise protection (The European Union are obliged to determine and to document noise pollution in cities); 2) Disaster management; 3) Urban planning; 4) Energy turnaround. Required LOD is dependent on the application's needs. So far, the "city-models" were created in Germany for enabling visualization of special applications and received location and 2D building information from the cadastral system, but never became an integral part of the cadastre (Seifert et al., 2016). Expanding cadastral systems to multidimensional is expected to allow multipurpose applications.

5 Literature review

5D Cadastral system is expected to enable efficient management of 5D data upon modern and complex areas so that land ownership rights and responsibilities would be recorded consistently, unambiguously and in an orderly manner with minimum errors. Building such system may enable computerized identification of objects above the surface, below the surface and describe different times and LODs of spatial cadastral data. In general, cadastre management systems should offer these main operations: 1). 5D data collection and organization; 2). Visualization and navigation in the 5D environment; and, 3). 5D analysis, editing, and querying. However, for performing such operations, the technical framework needs to be determined in advance, including data structure, database, software, and hardware.

5.1 Databases

Although useful 3D databases exist, enabling the storing, querying and representing of spatial geometric objects, they usually are not appropriate for managing 3D cadastral-objects, and they need to be improved so that they would provide sufficient tools for handling complex 3D cadastral topological and geometric data models (Zhao et al., 2012). In scientific literature, such databases are called geo-databases. Geo-databases have yet to be developed and expanded, while according to Breunig and Zlatanova (2011) "the integration of 2D and 3D data models and the development of dimension-independent topological and geometric data models" is of a big importance.

Geo-databases could provide the framework to define the geometry and topology of nature-formed and man-made objects in a unified way (Breunig and Zlatanova 2011). In fact, for building and representing complex 2D/3D objects, it is necessary for 3D cadastre management system to provide basic elements, for example: node, edge, face, and body, or, differently: points, line segments, triangles, tetrahedrons, and collections hereof to represent geometry objects. In brief, the data-structure and database would significantly influence the development of the system, the way it is managed and the structure of the functions.

Ioannidis et al., (2016) created an external database that can support both spatial and semantic features of buildings, based on the descriptive metadata model of the Hellenic Cadastre and including: spatial data : 1) 2.5D footprints, refer to properties, buildings and land parcels, and models of 3D COLLADA (with textures); 2) time (period of validity) 3) semantic (cadastral data). The 3D models along with the external database create a 5D Land Information System. The study supposed that land is divided into parcels so that each piece of land relates only to one parcel.

Doulamis et al., (2015) suggested several approaches suitable for visualizing 4D data. One approach is based on GML along with QGIS (i.e., open GIS tool supporting GML) and free user-friendly interfaces, such as Arstoteles3D viewer. Another approach is based on transforming CityGML to other formats which can be displayed more easily in existing viewers, such as KML and X3D, and enable visualizing times changes. Google Earth can be used as a user-friendly interface for viewing KML format and provide the possibility to add other labels, geometry elements, and cadastral data. For viewing 4D data, a building in the database would have two different IDs if it went through changes between two-time instances and one ID if it did not. Besides, start/end date attribute would be added as an external reference. The 4D viewer should be able to highlight changes between two models, display additional semantic data and visualize different time instances.

5.2 Data structure

Defining a data model for storing 3D objects is another aspect to take into account when coming to describe functionalities. Kazar et al., (2008) suggest using Oracle's data model for storing 3D geometries (in general, not specific for 3D Cadastre). In their paper, they present different types and rules for storage, validation, and querying of 3D models. They also show that the GM_Solid representation is unsophisticated in comparison to more topological models, however qualitative enough for describing 3D geometry. In the same context, validation rules are addressed together with examples of valid and invalid geometries. It was noted that actual validation rules are domain dependent. For example, it is unclear if dangling faces (patches) or self-intersection are allowed. Currently, both Oracle and ESRI do not yet support 3D topology structure (Felus et al., 2014). In conformity with the jurisdiction of Queensland, Australia (Karki et al., 2013), a specific set of digital data validation rules in realizing a 3D cadastre is proposed, where 2D parcels are treated as infinite 3D columns containing the volume above and below ground. Processes aim to check and verify different aspects of 3D cadastre are presented, such as verifying 3D encroachments using a cadastral database, disjoint 3D rights, 3D common property and curved surfaces.

5.3 Functions

For providing efficient services, while archiving land rights, restrictions and responsibilities in different zoning plans, the cadastral management system includes diverse functions with varying purposes. Some of which support taxation, property valuation, registering mortgages for future objects (and other fiscal operations). Other functions aim to enable efficient conveyancing, to manage land use planning and land distribution. Well-built functions enable executing changes (derived from new/past land arrangements, such as: subdivision/split, consolidation/union, transfer between lots, expropriation – to name a few).

In general, the existing cadastral 2D procedures and functionalities can be customized so that they would be appropriate for 5D usage with 5D databases, as long as the legal and physical cadastral components are stored properly. Similarly, it is possible to expand and upgrade the previously used 2D queries in different 5D cadastral systems. The implemented 3D queries should answer the user's questions and fulfill his demands, which are analogous, in principle, to queries generally activated in 2D systems. For instance: calculating length and area (or volume) of parcels/buildings, calculating position (coordinates, datum, reference systems), identity and relationship of land parcels within an area of interest (ID, name, ownership, history, tax, value, etc.), 2D and 3D parcels, lots and objects – on- and sub-surface. Besides to time and scale-dependent queries, such as searching objects that existed in specific time span or defined LOD.

In addition to the previously mentioned targets of using functions, they could be implemented for checking the ability to provide permits that approve utilizing land parcels for specific needs and investments conducted by owners, entrepreneur, and public organizations. After checking the submitted data with respect to geometric, topological and public law restrictions, and in accordance with the jurisdictional area and standing zoning plans, the system should provide permits if the request is valid, otherwise, no permit is given. Operating functions should be compatible with the correct spatial units, i.e., enabling survey, measure, visualize and store property in convenient spatial units.

Cadastre systems can be classified in several ways, which are based on different criteria

- primary functions (e.g., supporting taxation, conveyancing, land distribution, or multipurpose land management activities);
- The types of rights recorded (e.g., private ownership, use rights, mineral leases, public law restrictions);
- The degree of responsibility in ensuring the accuracy and reliability of the data (e.g., complete state mandate, shared public and private responsibility);
- location and jurisdiction (e.g., urban and rural cadastres; centralised and decentralised cadastres).

5.4 Time

The time component is necessary for cadastral management system for supporting discrete and continuous property changes. The integrated representation of time should not only support changes at discrete moments, as currently supported by most of the spatio-temporal models via timestamps and versioning, but also continuous temporal changes (Osteroem, 2012). Several studies consider temporal as more than one dimension, as it may represent several sorts of changes, such as geometrical, topological, thematic or other changes related to the features of properties; and since land management systems integrate various types of information, such as financial, architectural, topographical, cadastral, valuation, engineering, of quite a different type and detail (Doulamis et al., 2015).

For adding the time dimension to information systems, the European Union supported the 4D World research aimed at dynamically creating 4D objects from unstructured data acquired from the internet for personal use (Makantasiset et al., 2014). The approach suggested in this research for 3D reconstruction of a cultural heritage object is not suitable for land management systems, because of its low precision Besides, and because it does not integrate semantic data and spatial-temporal properties which are very necessary for land management systems (Doulamis et al., 2015).

Issues and problems in integrating time dimension:

Currently, 4D modelling is implemented by a simple aggregation of independent 3D digital models at different time instances (Doulamis et al., 2015). Meaning that several cases in specific time points are stored, which is not appropriate for managing large-scale environments that undergo continuous changes. However, holding continuous 3D models requires high-cost and efforts. Moreover, temporal data are heterogeneous, which makes managing 4D properties even more difficult. For solving this issue, Doulamis et al., (2015) suggested a selective 4D modelling framework for the spatial-temporal land management system, based on creating change history maps.

Guting et al., (2005) addressed the goal of temporal database as: “to integrate temporal concepts deeply into the DBMS data model and query language and to extend the system accordingly to achieve efficient execution”, they also suggested definition for time dimension: Whereas much different semantics can be thought of, the two most important “kinds” of time are the so-called valid time and transaction time. The valid time refers to the time in the real world when an event occurs, or a fact is valid. The transaction time refers to the time when a change is recorded in the database or the time interval during which a particular state of the database exists.

Currently, there are few studies that have dealt with adding the time aspect to land registration systems. The study by Döner et al., (2010) examined the current state of cadastre in three countries: Holland, Turkey and Queensland (Australia) from an organizational, legal and technical standpoint. The study suggested three approaches for managing time dimension, one for each country, and made comparisons between them. The conclusion indicated that it is possible to implement a four-dimensional cadastral management system in all three cases. In order to integrate the time dimension within cadastral systems, it is necessary to document all changes that occur in parcels or sub-parcels. In Germany, for example, changes are recorded both textually and in surveying sketches (Seifert et al., 2015).

Döner et al., (2010) provided a definition for the two existing approaches for managing temporal-data: 1) In event-based modelling, transactions are modelled as separate entities within the system (with their own identity and set of attributes). When the start state is known and all events are known, it is possible to reconstruct every state in the past by traversing the whole chain of events. 2) In state-based modelling, the states (i.e. the results) are modelled explicitly: every object gets (at least) two dates/times. Their study concluded that "the 3D space and separate temporal attributes approach (state-based model) is sufficient to model temporal changes of utility networks. However, it should be noted that the 4D integrated data type is necessary to model dynamic objects such as parcel boundaries that follow the movements of natural features such as coastlines or river borders. This requires further study". Zaniolo et al., (1997), Part II: Temporal databases declare that about 40 data model for managing temporal databases has been suggested in the literature.

Change history maps:

Doulamis et al., (2015) aims at applying cost-effective solution for representing spatial-temporal land changes and create dynamic change history maps for that reasons, which is based on detecting regions of interest (i.e. regions that underwent significant temporal changes) at the first step.

Change history maps detect regions of interest in the 3D space by combining multiple instances of a 3D model (Doulamis et al., 2015); for producing those maps spatial-temporal analysis was applied to 3D digital models captured at different time instances using automated dense image matching. Only areas with significant changes would be modelled in two instance views:

- Geometric history changes: this approach creates change history maps based on detecting geometric differences between 3D models. The first step in the process is applying Gaussian pyramid filter for smoothing the noise. Next, two examined 3D models at different time instances are aligned. Then areas with significant geometric changes are marked for 3D reconstruction. The required resolution for constructing 3D model increases as the changes increase.

- Semantic history changes: according to this approach, change history maps are created based on changes in semantic information, such as cadastral, financial and architectural rights.

5.5 Scale

So far, two main approaches for storing a data-set of a specific area on a different scale existed (Oosterom and Stooter, 2010). The first approach is to set up separate databases for different scale representations, such that each database stores data on a certain scale. Various national mapping agencies apply this approach and produce maps on previously determined levels of details based on separate databases. This approach advantage is that it needs no real-time process and need only pick-up LOD; however, it is not suitable for drastic simplification where big and small objects exist in the same view. The second approach is to hold only the most detailed data in the system and to generalize these data to a smaller scale in real time if needed, which enables exact specifying of a LOD instead of choosing from a few pre-created options, but yet requires complicated geometric calculations. For efficient data supply in various LODs, it is important to keep consistency while switching between the different scales' display, as well as avoiding conflicts resulted by zoom in/out.

Geometric datasets may be too complex for qualitative representing in small scales, and the solution for that is to simplify the polygonal geometry of small or distant objects (polygonal/geometric simplification in case that the object constitutes of polygons).

Previous approaches for representing data in different LODs, however, are most appropriate for simplifying objects with "non-flat" surfaces (e.g., a human face, an animal (the famous rabbit), a human figure, terrain, molecule structures) and a large number of triangles. Excluding terrain surfaces, the urban GIS entities are mostly man-made objects, often with rectangular shapes, and a small number of surface constructive objects (triangles or polygons). Research on LOD concerning real urban objects can hardly be found (Zlatanova et al., 2000).

Cambray (1993), investigates three approximation levels for man-made objects. The highest level is the minimal bounding rectangular parallelepiped (MBRP) of the 3D object, the second level is the object decomposition into n-parallelepipeds (n=8) and the third level is the faces composing the object. An octree comprises all the levels. The author proposes the approach for data storage and does not elaborate on the computation of the different representations.

Osteroem (2012) suggested an nD approach for data modelling in five dimensions and applied the concept of previous studies in nD storage (Gray et al., 1997; Casali et al., 2003), which used nD modelling for integrating information on multiple thematic attributes rather than spatial and dimensional data. Osteroem (2012) adjusted this approach for managing geometric multidimensional data and created intermediate models for representing 5D models, an example for that is relating time as a third dimension, represented by axis vertical to the plane, for monitoring and recording changes of 2D land property ownership and moving objects, while planar axes x and y represent the 2D properties. According to the study “The deep integration of time with space and scale concepts in an nD approach will fully handle changes upon position, attributes and/or extent of the objects in the unified space-time-scale continuum”

Additional intermediate model is 2D+scale, which is based tGAP concept. The tGAP data structure was implemented for representing multi-scale data by including scale as a separate dimension with the purpose of reducing redundancy, assuring consistency, smooth zooming, and progressive transfer. For this goal, several LODs (distributed upon 1D scale dimension) for a 2D map (2D space) was stored as a 3D cube (Meijers, 2011); every map, in a specific LOD, was represented as one polyhedron. Cross sections of the resulted 3D structure produce 2D maps in different scales without gaps or overlaps. The nD approach applies to 3D+scale by integrating various scales of a 3D model in one 4D data cube. Scale dimension is perpendicular to X,Y,Z axes, which allows continuous representation city at different scales and produce 3D models at different scales by slicing the 4D cube.

Considerations in Levels of Details (LODs):

According to Jung et al., (2016), four considerations should be taken to indoor LOD models: 1) Geographical scale issues: generalization of geometric features is based on geographical scale in outdoor LODs, while geographical scale is always large-scale in indoor space; 2) Data capture methods: various methods is implemented for generating data, leading to various data types in the same model; 3) Application issues: the appropriate LOD should be determined based on the application purpose so that it would perform effectively and affordably, e.g., too detailed scale causes using huge data volume and computer resources; 4) Data types: data can be 2D/3D, vector or image data.

Serkan et al., (2012) researched LODs in 3D models for the purpose of managing natural disaster risks and proposed LOD hierarchy that is considered together with CityGML (City Geography Markup Language - an open standardised data model and exchange format to store digital 3D models of cities and landscapes) to improve the existing CityGML of the OGC standard (i.e., a standard that focuses on 3D urban models, which, constitute spatial visualization or analysis environment for many other application areas like cadastre, planning, traffic, etc.). LOD 1, 2 and 3 that were used previously only for outer details in CityGML, were associated with the related indoor definition and notation in the approach suggested by Serkan et al., (2012).

Issues and problems in integrating scale dimension:

- Cartographic issues: symbolised objects may cover geometric areas when switching scale.
- Semantic issues: semantic attributes directly affect the process in the system; for example, when implementing generalization operator, every class should be treated properly, e.g. road should keep being connected and rectangular building remain rectangular. Which means that way of implementing generalization operator depends on the object class.
- Mixed 2D scale issue: mixed scale 2D representation is needed for representing high detailed data close by and less detailed further away from the point of view. (oosteroem, 2012).

Issues in implementing separated scale dimension:

The scale was implemented as a separate dimension in OGC 2008, five levels of details were predefined in CityGML. This approach suffered from several problems, it did not support aggregation because it related only to individual objects and did not relate to the fact that a tree turns into a forest at lower scale for example. Besides, the interior of buildings was included as a level of detail with no unequivocal definition of it, meaning that the interior could be either an inner polygon or another whole world (Zalatanova, 2008). Other researchers, such as Kang et al., (2014), Serkan (2012), Jung et al., (2016), studied indoor LODs hierarchy and the concept of LODs in 3D indoor models and suggested several LODs for presenting indoor data models.

6 Methodology

For implementing the research objectives, mentioned in Chapter 5, procedural steps will be taken. These steps are detailed here, as follows:

6.1 Data structure and topology

a) Data Model and Topological Relationships: the definition of the data model is needed for smooth and uniform transfer between different data levels (0D, 1D, 2D, 3D). The data structure considers 0D, 1D, 2D as special cases of 3D data. For instance, a 2D line is a 3D line with the constant value of z. The challenge in this stage is to offer a data structure that enables performing 3D analysis and editing, while being capable to determine the relationships between entities in different dimensions (e.g., 3D spatial parcels, 3D parcel, and 2D plane), as well as providing the possibility to perform data queries

b) Solving mathematical and topological problems related to 3D analysis. Examples for that are: how to split a 3D parcel (consisting of planes, lines and points) given a 2D splitting plane in the case of simple or complex geometry, how to apply a 3D R-tree sort for the sake of satisfying search in 3D zone, etc., which are much more complicated than the simple 2D problems.

c) Building topological functions based on the data-structure and the solved mathematical problems for performing automatic 3D cadastral processes, e.g. detecting the relation between two 3D parcels.

6.2 Data Collection and Creating Database

The next stage would be the process of implementing the written code. For that reason, a 3D database would be created and will include 3D parcels data that are stored in the data-structure determined in the previous step. In the preliminary implementation, a simple synthetic data (CAD format created in ArcGIS and provided z values) that satisfies 3D assets' attributes would be used. Next, an "object file" and "shape file", exported from a 3D model for Tel-Aviv municipality reign area, built in City-Engine ESRI software, would be used. An attempt of using directly exported files from City-Engine was already analysed, but the structure of exported files in different types did not satisfy the needed data structure, e.g., the points representing any 3D parcels are stored all together, lacking the opportunity of sorting them in planes, which is necessary for defining normal of the planes and performing analysis.

3D reconstruction from existing planar data is preferred upon gathering data from point clouds (the approach applied in many research) for several reasons: it is more important to build multi-dimension integrated system based on existing 2D data in 2D systems, than to use a totally new data, such as point clouds produced by photogrammetric processes or laser scanning; that is because it turns the 2D existing data to irrelevant and worthless. In addition, using point clouds require grouping the digitized points (Zlatanova et al., 2000), which is a complex process to implement whether manually or automatically.

The gathered data should represent different sorts of property, e.g., buildings, pipelines, parks etc. Information about each kind of data would be stored in different tables; tables for holding 3D parcels would also be used, and the previously mentioned properties are part of them. A property could be part of more than one 3D parcel, which means that utility objects are separated from parcels.

Legal and physical objects are not the same, “For example, the rights on the land in which the utility is constructed may give not only the ownership of the utility but also the rights to a certain space, a ‘buffer’ around the utility” (Doner et al., 2011). Therefore, the separation between tables including physical and legal objects is necessary.

6.3 Alphanumeric Data Specification and Setup Script

In this stage, the alphanumeric data needed for practical implementing of the 3D management system is established. This would be done based on the results of the code running process. In addition to writing a final setup script for expanding a 2D management system to 3D.

6.4 Defining "Time Dimension" and Examining Different Approaches

Adding the time dimension would enable related-time inquiries and detecting land properties that have undergone significant changes. This step will first define which legal and physical changes are considered to be recorded, and which are not, and will then implement state-based and event-based models, and suggest which is more suitable for local systems.

Each property object should have two fields declaring its start and end time (object-based), in a case that an object still exists the end time would be empty, in addition to a historical list that contains the shifts it undergo (event-based); this would be optionally applied either by storing all the previous forms of every property as an independent objects in its historical list, or by creating different databases of every particular area, each for representing the situations of all the properties in that area in a specific period of time, which means that the database would have validity date that is determined depending on the amount of alternations that took place in the presented region of property. Two land property data sets, representing different time spans, would be integrated into the system; legal and technical queries would be made in order to check the performance of the integrated system.

6.5 Levels of Detail

LODs could be related either to visualization or to geometric representation: "The geometric representations meant by the user support the user's tasks and, commonly, are not related to the position of the viewer. For example, buildings represented by their outlines are sufficient for a telecommunications company but insufficient for a utility company" (Zlatanova et al., 2000).

This step aims at determining an optimal way of representing data in different scales/LODs. First, each 3D entity would be stored in the system in various predefined scales. Generating LODs involves simplification operators and algorithms, such as: cell collapse, vertex removal, and edge collapse. The research will examine several algorithms, implement new ones, and measure generalization errors based on geometric values, such as the distance/volume between the original and simplified object, as well as textural errors like color changes. The research will also check whether the simplification process creates distortions or data conflicts, and most of all will monitor the effect of LODs transition on topological relationships, which is of big importance, which is related to geometric representation.

Next, LODs will be implemented as a pre-step for visualization by implementing 3D R-tree, which could be also used for indexing: "Creation of spatial indices is necessary for efficient access to data after the data have been loaded into spatial tables" (Döner et al., 2010). The 3D R-tree would have 3 levels: 1) detailed objects with geometric primitives, such as face and node; 2) bounding rectangle of a 3D object; 3) bounding rectangle of several 3D objects. The option of changing LODs in real time is also planned for investigation.

7 Current Work and Preliminary Results:

To date, the overall aim of my Master's research was to expand the existing state of two-dimensional cadastre treatment - reference to a particular surface and geometry without height information (borders without facades) - to a spatial state of three-dimensional topology. The main achievements were: 1) Defining a topology in a data structure to support three-dimensional cadastral processes (complementary step would be expanding this data structure for 5 dimensions); 2) A comprehensive literature survey; 3) A summary of the CHANIT specification that defines uniform CAD format for all types of plans submitted to survey of Israel (SOI) (similar specifications exist in other national mapping and surveying authorities with minor differences) in terms of mapping the gap between the existing system and the planned one, focusing on supporting three-dimensional cadastral system; 4) Selecting appropriate software; 4) Recommending an efficient approach to defining spatial topology in the database for the construction of a three-dimensional cadastral system; and, 5) Mapping of cadastral processes and functionalities that should be integrated into the system for managing 3D land registration.

A full peer-reviewed paper was accepted and presented at the 11th 3D GeoInfo Conference (held on 20-21 October, 2016, in Athens), which details a systematic analysis of functionality for three-dimensional cadastre of Israel, and another paper is now under review, submitted to a special issue on 3D Cadastre (ISPRS International Journal of Geo-Information)[1].

7.1 The Functions and Process in the3D System

Building 3D management system may enable computerized identification of objects above the surface and below the surface and describe different spatial cadastral processes, such as land transfer, land partition, and land union. In general, cadastre management systems should offer these main operations: 1) 3D data collection and organization; 2) Navigation in the 3D environment; and, 3) 3D analysis, editing, and

[1] Jaljolie, R., Van Oosterom, P., and Dalyot, S. **Spatial Data Structure and Functionalities for 3D LADM System Implementation.** ISPRS International Journal of Geo-Information, Special Issue on "Research and Development Progress in 3D Cadastral Systems" (Under review).

querying. In addition to the processes of 1) Insertion of a new 3D object (3D volumetric parcel); 2) Visualization of 3D objects (via search criteria); and 3) Area analysis for plan and design. These processes were detailed in Jaljolie et al., (2016). An example of a cadastral process workflow is depicted Figure 2.

Besides, the functions involved in the system were also previously listed and detailed, including their input, output, and aims, which vary from supporting taxation to property valuation, registering mortgages for future objects (and other fiscal operations), enabling efficient conveyancing, to manage land use planning and land distribution. Well-built functions enable executing changes (derived from new/past land arrangements, such as: subdivision/split, extrude, consolidation/union, transfer between lots, expropriation – to name a few). An additional target of the functions is checking the ability to provide permits that approve utilizing land parcels for specific needs and investments conducted by owners, entrepreneur, and public organizations, with respect to geometric, topological and public law restrictions, and in accordance with the jurisdictional area and standing zoning plans.

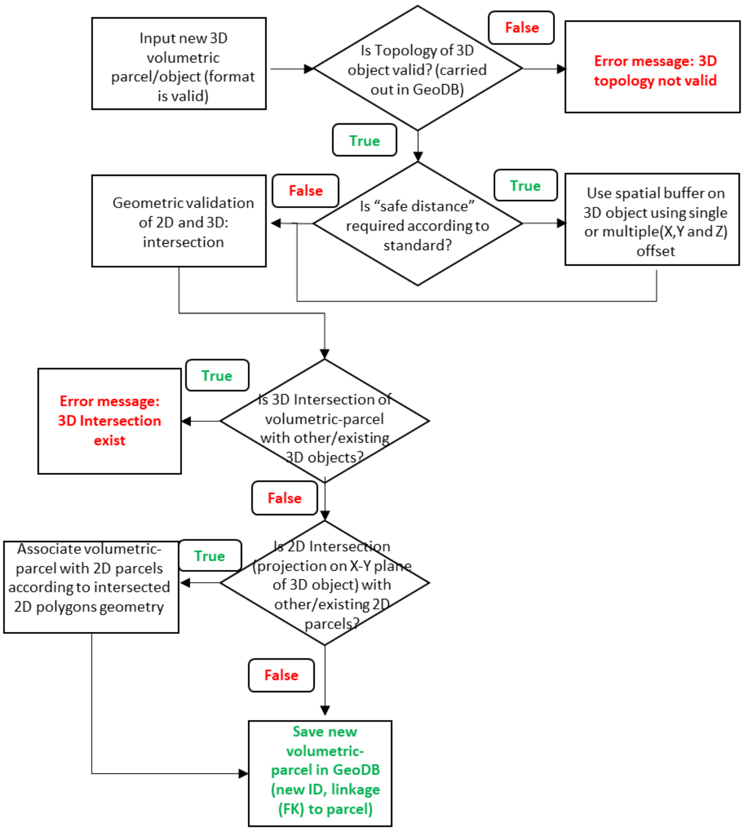

Figure 2. An example of a cadastral process: Insertion of a new 3D object workflow.

The algorithms and practical implementation of the functions and processes among real integrated 2D and 3D data are very complicated. Besides, a lot of familiar processed into the 2D systems, such as split and search, turn to long scripts among 3D data, especially parcels that are not simple and have to take into consideration different possible cases. Previous research is detailed in the background chapter, but most deal either with very simple objects and limited operations or based on separated 3D data that are mostly gathered from the point cloud and could not possibly complement the 2D system, which is the main aim of the research. Meanwhile, these functions are being built into Python workspace, which has not been made before in any of the research I have reviewed.

7.2 Mapping Primary Requirements of Information:

The geometric and topological depiction of a parcel is a primary requirement in cadastral systems, including:

- Defining the quality of boundaries and presenting their topology;
- Descriptive data of a plot as defined in the registry (titles) and obtained from survey: coordinate values of parcel's borders, visualization of 3D plots and their associated 2D objects (and vice versa), length(s) of parcels' borders and building lines, information regarding mortgages and eases (if exist), mutation plans, describing plots' boundaries by measured distances/directions and by noticeable objects located nearby (bounds), documents for all the transactions, partitions and deals that have occurred previously;
- Property tax registrations to support claim to land and organization of records and ledgers and land values analytical calculations of boundaries;
- Description of the spatial framework of a parcel, which is datum, coordinate system, reference points, etc…
- Transformations: restoring the transformation parameters and reference points, digitizing existing maps and orthophotos, automation processes for parcel's data;
- Data quality check: accuracy of system's operations and final products should meet the accuracy requirements of a variety of relevant applications. Description, reconstruction and calculation accuracy, together with data quality, the accuracy of data collection and propagation of errors must be appropriate.

7.3 Legal and Technical Aspects of CHANIT Specifications

For the sake of expanding the existing 2D management system, database and functionality gaps in CHANIT specification were mapped. Figure 3 illustrates the topics that the research referred to. A detailed description of these gaps and the modifications that should be done were described in our under-review paper.

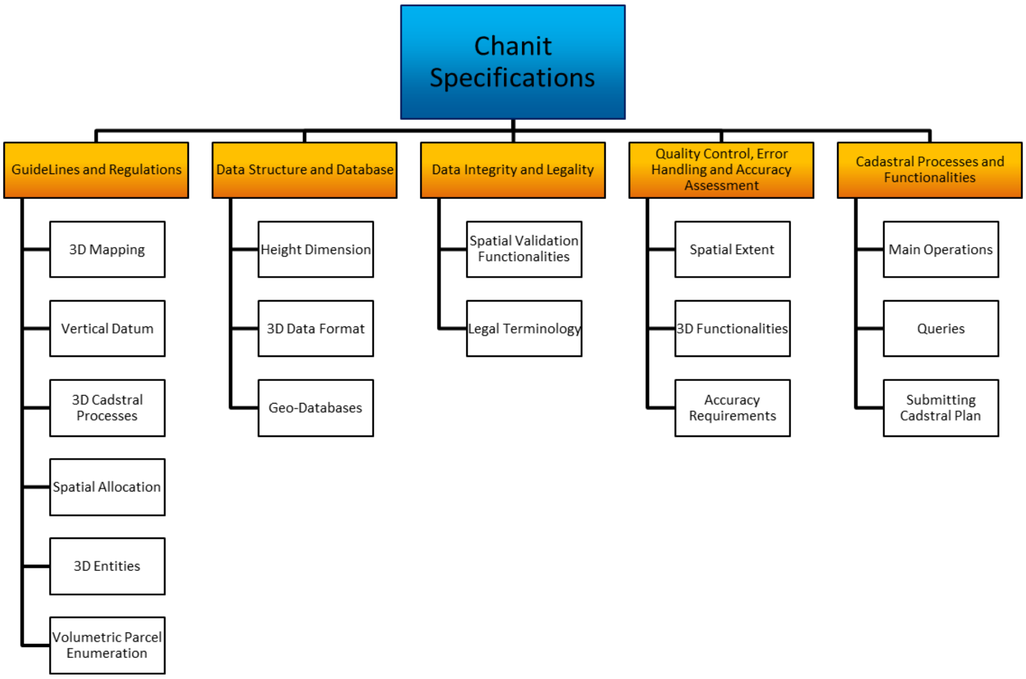

Figure 3. Relevant topics in CHANIT specifications analyzed in this study (extended with respect to 3D cadaster).

The findings of the gap mapping processes included the examination of functionalities, classes, properties, and methods. Recommendations for augmenting and promoting the existing operative 2D cadastral system to be suitable for comprehensive 3D land management are given accordingly in 4.4.

7.4 Data-structure, Fields, and Methods

The main classes existing today in the operative 2D cadastral system are limited to 2D data (e.g. point, line, parcel) and refer to the planar parcel as an infinitive 3D air column. Those classes were adjusted by adding fields for fulfilling 3D requirements and representing 3D reality, such as absolute and relative height (depicted in Figure 4), 3D lines and planes equations in space (make it possible to detect whether an object is vertical, horizontal or diagonal), range field for indicating the range of the coordinates, the extent and location of a spatial object, etc.

Figure 4. Levels with the same orthometric heights (absolute height) could be either above or below ground (relative height).

Besides, it is necessary to define new classes for describing objects that were not relevant in the previous system, e.g. 3D volumetric parcels and 3D polygons (i.e. used for describing facades, floors, and roofs, which could be defined by the coordinates of their corners and by their borders). Figure 5 illustrates the data structure suggested in this research.

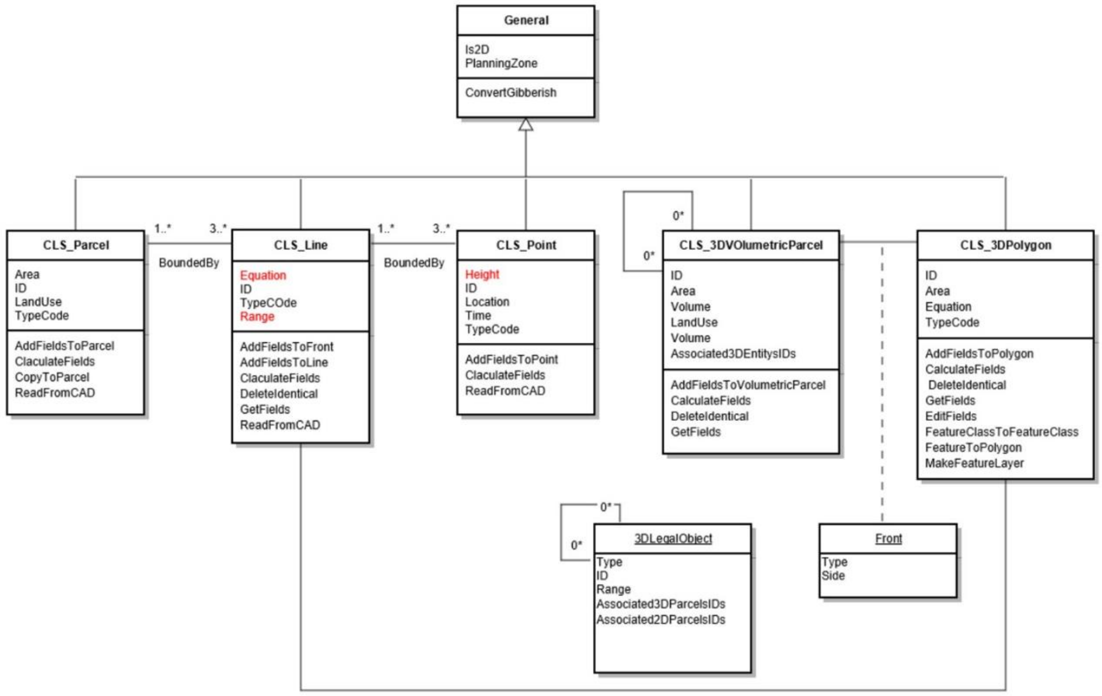

Figure 5. Main classes in SOI's operative cadastral system; integrated with new classes that should be added to the cadastral system to serve the 3D reality. Fields in red are relevant only for 3D representation.

Since mutation plans are submitted in CAD format, additional classes are used for reading the input data from the CAD files and writing them into the geo-databases and tables via the defined processes and for converting the layers' codes that appear in the CAD files to a comprehensible language suitable for storing in the geo-databases. The previous review emphasizes the importance of different data formats for efficient usage, which makes these classes (Figure 6) of big importance both in 2D and 5D systems.

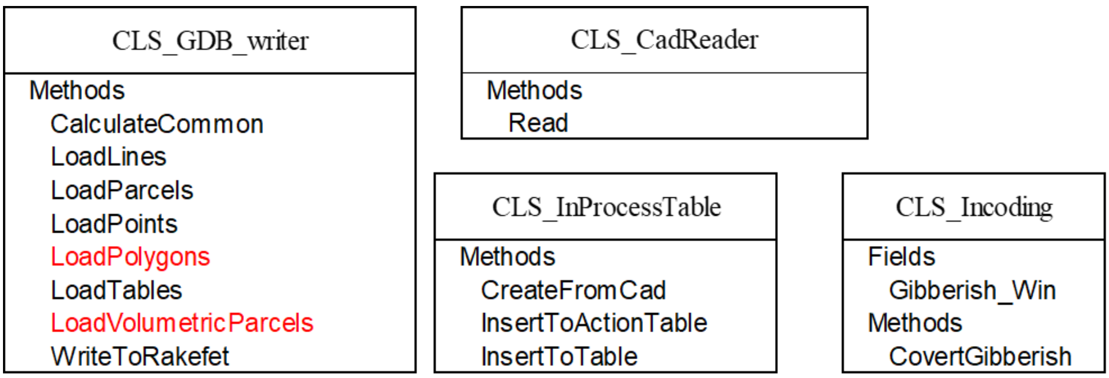

Figure 6. Classes used for reading the input data from CAD files and writing them into the geo-database and tables.

CHANIT specifications list relevant objects that need to be registered into the cadastral system. Accordingly, every type of object, whether it is a Line, Parcel, Point, 3DVolumetricParcel, and 3DPolygon, should have a code for effective description of the system, such that the relevant classes should be added a new field declares the objects' type/characteristics (depicted as "TypeCode" in Figure 5), such as tunnel, foundations, construction shaft, sub-ground building, parking lot – to name a few.

Mapping gaps in CHANIT specification relate to the planning zones as the valid range of the vertical mapping, which should be stated in the regulations in accordance with planning zones. This implies that it is necessary to add a field that determines in which planning zone the object is included. This new field should appear in all classes as "PlanningZone", also declared in the "General" table, which includes some of the common fields and methods that will be part of all participating classes. "Is2D" field holds the Boolean value "true" in case the object is spatial having a constant height value, or "false" in case the object is not planar (see Figure 5).

Previous research results recommend allowing the allocation of several land uses for any 2D parcel in accordance with height, inferring adding the fields "Height" and "LandUse", which holds big importance. Array is a possible structure for the "LandUse" field, the same as a building could have several land uses associated with the horizontal and vertical location. The field "Height" is practically the fundamental field required for establishing a 3D management system since it extends the third dimension and the related important information. Determining the legal vertical range depends on the spatial objects that are considered for registration in deeds, such that it also adds a value to the "Height" field.

The routines of editing and submission should be announced in the regulations. For practically editing the spatial objects, the methods "EditFields" and "GetFields" should be inserted and added to all classes in the data structure, so that the user can edit fields in a case that a real change is made. The numbering and naming the 3D spatial parcels should be declared. Numbering is represented by the "ID" field in the data structure. Since the system aims at 3D mutation plans, "ID" field should be uniformly set in accordance with the planning zone and the data type of each object.

“LoadPolygons” method in the “CLS_GDB_writer” class is intended for loading facades, roofs, and floors, while “LoadVolumetricParcels” aims at loading 3D volumetric parcels. These methods enable writing the relevant 3D objects into the geo-database and tables. The field “AssociatedVolimetricParcels” refers to the 3D volumetric parcels that exist into the 3D column containing the volume above and below the 2D “CLS_parcel”, which is necessary for effective processing in the system (e.g. search), as it associates between a 2D parcel and the 3D objects that are above or below it.

As depicted in Figure 7 left, it should be defined to which volumetric parcel the roof, floor and facades belong to, as well as stating to which 2D parcels a volumetric parcel is related to. Façade can be either vertical or diagonal, as depicted in Figure 7 right.

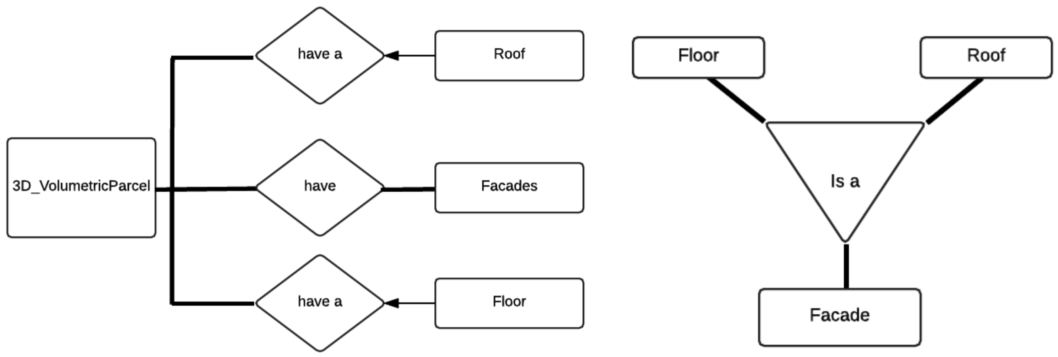

Figure 7. Left: A 3D_VolumetricParcel must have a Roof, Facades, and Floor. Every Floor and Roof belongs to a 3D volumetric parcel. Right: Floor and Roof are Facades in a different orientation.

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