Systematic Analysis of Functionalities for the Israeli 3D Cadastre

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Key words: 3D Cadastre, Functionalities, Spatial Analysis, 3D Volumetric Parcel

SUMMARY

Following public demand to improve the efficiency and transparency of government administrations, together with the existence of mature technologies and modern urban planning necessities, it is now essential to establish more advanced and comprehensive land management (cadastre) systems. Cadastre systems available today are mostly based on two-dimensional registration procedures only, limited in their ability to manage modern urban and complex areas. This requires the ability to handle various types of data in a uniform way - both spatially (horizontal position and altitude) and temporary, with emphasis on infrastructure development that must be addressed and registered with respect to the third dimension – above-terrain and below-terrain. That is, establishing a series of conditions and functionalities, which will enable utilization of land/space for various complex projects, individually owned, above and below the surface. The Survey Of Israel (SOI) is advocating towards a solution related to 3D cadastre, establishing the idea of a unified spatial 3D volumetric parcel, such that the volume of such new 3D spatial parcel can be a part of (subtracted from) a number of 2D parcels. The required 3D Cadastre system should be capable to combine different types of data that are relevant to cadastre systems, and to constitute a unified model from different government databases: among others, the Survey Of Israel, the Land Registry, and the Israel Land Authority. The system should enable archiving, visualization, queries and analysis of three-dimensional characteristics and structures on different temporal time-stamps. So far, three-dimensional systems are currently having their focus on 3D topography (modelling physical real-world objects), and are limited in supporting the multi-dimensional cadastre implementation needs. This study aims at investigating and presenting a set of spatial functionality requirements from such a system that would enable good governance in accordance with the definitions and guidelines of the SOI, derived mainly from technical specification required to support the third dimension (depth/ height) in existing platforms or systems. A systematic analysis of the processes and functionalities needed by such a system is made, each is a workflow of specific geometric and topologic functionalities integrated in the system (such as: intersection, extraction, merging, deletion – to name a few). This study will give an overview of all required functionalities for this system (and relate this to the information needs as expressed in LADM), with detailed description of three processes, and their contribution to the establishment of the 3D cadastre system.

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1. INTRODUCTION

3D cadastral information system is the framework for defining and understanding the spatial restriction, responsibilities and rights. According to Aien et al (2012), the related information model should allow the understanding of the various parts of the three-dimensional cadastre (classes and attributes), explain how they are arranged, organized and conserved on computerized operating system (instances of classes and constraints), and simplify data understanding required by all parties involved. An efficient cadastral system will provide and organize practical documents and guidelines for surveyors, and other involved parties. The system should support the implementation of the spatial cadastre processes in various ways, such as: promotion of standards/regulations so that they could be universally understood and used by all the involved parties; establishment of three-dimensional databases and facilitating the process of data exchange/transfer with the possibility to combine and share datasets for the purpose of interoperability. Such a system will define management functions for the three-dimensional cadastre data, while ensuring the integrity and legitimacy of geometry, topology and semantics.

Establishing a 3D cadastral information system is a direct response to increasing public demand aimed at improving existing efficiency and transparency of government administrations, mainly related to managing modern urban planning necessities. To date, cadastre systems are based mostly on two-dimensional registration procedures only, limited in their ability to manage complex areas. 3D cadastre, on the other hand, requires the ability to handle various types of data in a uniform way - both spatially and temporary, with emphasis on infrastructure development that must be addressed and registered with respect to the third dimension – above-terrain and below-terrain. That is, establishing a series of conditions and functionalities, which will enable utilization of land/space for various complex projects, individually or publically owned. It is important to define an appropriate topology for spatial parcels and to implement the 3D cadastral process as suggested in the relevant workflows making sure that the data-structure and datasets defined in the system is compatible with existing spatial reality. Table 1 depicts the necessary functions, and their inter-relations, related to 2D and 3D cadastre data (*integrated* refers to cases where 2D and 3D cadastre are analysed simultaneously) that should be addressed when such a system is to be established.

Table 1. 2D and 3D cadastre data necessary functions

		Cadastre Data		
		2D	3D	Integrated
Aspects	Cadastral survey	•	•	•
	Geometric	•	•	•
	Topologic	•	•	•

According to the cadastre principles used in Israel, the landowner's ownership is concurring to the volume of the pyramid created and defined by the 2D land parcel (projection on earth) which origins at the center of the earth to the space above it.

This study presents the systematic analysis of the spatial functionality to be provided by the 3D cadastre system. Each of the identified workflows is based on specific geometric and topologic functionalities integrated in the system. More specifically, the list of basic spatial functionalities the (3D) system is to incorporate is as followed: spatial intersection, spatial overlap and overlay, spatial buffer and extrusion, spatial union and merge, spatial clip and extract, spatial select, spatial split, spatial delete and erase, distance calculation, area and projection calculation, and volume calculation. Section 2 summarizes the status of 3D Cadastre in Israel. The role of the database and information requirements in a 3D Cadastre are elaborated on in Sections 3 and 4. The basic system functionalities and cadastral workflows are described in Section 5. Finally, the main conclusions and indication of future work are given in Section 6.

2. BACKGROUND

For more than a decade, the Survey Of Israel (SOI) is advocating towards a solution related to 3D cadastre. Recommendations so far consisted mainly of two key aspects (Shoshani et al, 2005): 1. Preparation of appropriate legislation and regulation; 2. Placement of a technological base and implementing solutions for 3D cadastre, while establishing the idea of a united 3D volumetric parcel, such that the volume of such 3D spatial parcel can be a part of (subtracted from) a number of 2D parcels. The recommendations suggested also an approach for numbering the 3D spatial parcels. Moreover, it was advised to represent the third dimension of 3D volumetric parcels' coordinates in both ways: analytically, as an absolute orthometric height, and descriptively, i.e., above/below or in mixed position with respect to earth surface.

Already in 2009, an in depth legal analysis made in Israel (Caine, 2009), argued that the use of existing legal tools (especially leases and concessions), with no change made to the nature of existing features, might create a huge gap between the factual reality to the legal one. Documents were drafted, stating four optional legal paths to reach this goal, where the principal one discusses the structuring and implementation of specific legislation of spatial

3D volumetric parcels, which was favoured by the Israeli Ministry of Justice. These issues were reinforced when it was clear that planning, with an emphasis on urban planning, is moving rapidly towards spatial planning, consisting of planning, which is considered as multi-layered: above and under -ground (Sandberg, 2014; Felus et al, 2014). Assessment showed that these will lead to better use of land, protecting the rights and treatment of land, and preventing illegal use or misuse.

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 is 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.

Additional 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 detailed analysis of various 3D spatial configurations in an attempt to examine and finally evaluate the ability of providing 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 have 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 in Israel.

3. DATABASES AND FUNCTIONS

3D Cadastral system is expected to enable efficient management of 3D 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 surface and below 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. Visualization and navigation in 3D environment; and, 3. 3D 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.

3.1 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.

3.2 Functions

For providing efficient services, while archiving land rights, restrictions and responsibilities in different zoning plans, 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 3D usage with 3D 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 3D cadastral systems. The implemented 3D queries should answer the user's questions and fulfil 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, RS), identity and relationship of land parcels within an area of interest (ID, name, ownership, history, tax, value,…), 2D and 3D parcels, lots and objects – on- and sub- surface.

In addition to the previously mentioned targets of using functions, they could be implemented for checking the ability of providing 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).

4. PRIMARY REQUIREMENTS OF INFORMATION

Aien et al (2012) discuss data modelling development cycle for 3D cadastre, providing a framework for implementing the 3D cadastre, that starts from mapping the cadastral concepts and their relation to the real world, Data modelling is evolved according to the following procedure: 1. Gathering requirements of the 3D cadastre: before creating a conceptual data model, relevant data and requirements should be collected from proper sources, such as business documents and discussion with technical teams; 2. Developing a conceptual data model; 3. Developing a logical data model; and 4. Developing a physical data model.

Preliminarily to setting the structure of any 3D cadastral system, it is necessary to consider the existing regulations, legislations and the jurisdictional aspect. Various organizations and parties are involved in the procedure of creating appropriate rules. In Israel the key players are: the Survey of Israel, the Land Registry (especially when also considering to register apartments, condominiums in 3D), the Israel Land Authority (93% of the land in Israel is in the public domain, where the Israel Land Authority is responsible for managing this land), and the licensed surveyors. It should be noted that for a nationwide 3D LADM country profile, this model should also include the key concepts of other relevant registrations; e.g. geometries with legal implications resulting from spatial planning).

Several issues concerning building 3D cadastral system have not yet been determined, and different questions were raised regarding the development of 3D cadastral registration model in Israel. Answering these questions properly would make it easier to implement a cadastral system. Felus et al (2014) mention the main scoping questions that were addressed by the FIG Working group 3D Cadastres for developing the Israeli 3D LADM country profile. Among them: 1. Which types of 3D objects needs to be registered as 3D parcels? 2. Is it essential to take into account both airspace and subsurface objects? 3. How to define for each 3D parcel its position related to earth surface? 4. How to define a parcel, which is open on the side of the top and bounded on the other side? These questions, among others, where answered in their paper in a manner that the way the system should be built becomes obvious. For example, it was decided in 3D LADM Israel country profile that a legal space have its own geometry, and is not specified by referencing to existing topographic objects.

The 3D Cadastre information model should describe the plot both legally and financially and provide valid information about official registration of a plot. The supplied information is expected to be based on queries that users often make and to answer frequent needs, such as defining parcel's ownership rights, describing the space and the time interval of an ownership, supporting and enabling transformations between different systems, providing documentations that prove ownership. The information model may suggest fiscal description of properties, and satisfy the needs to perform queries related to: property taxes, land use management, financing public programs.

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, accuracy of data collection and propagation of errors must be appropriate.

In addition, it is vital to determine several different aspects of the information prior to building the system. E.g., how to represent the third dimension (analytical or in a relative manner), which is the best way for 3D spatial parcel numbering (a 3D volumetric parcel sequence associated with block), which land transactions need to be registered (real estate transfer tax notice, registration to support claim to lands, deed descriptions, land values, field books…). Exact definition of the needs and requirements of the cadastral system may highly simplify its implementation. Without answering the related questions, and deciding how the system is expected to be designed, it would not be possible to build it. Still, applying such system is equivocal and depends on the requests, expectations and the jurisdictional vision.

5. SYSTEM FUNCTIONALITIES FOR REALIZING THE CADSATRAL WORKFLOWS

The basic system functionalities were identified and detailed based on a survey of requirements made that should serve all processes and terms of a 3D cadastral information system. The 10 functionalities, which relate to the 2D domain, to the 3D domain, and to the inter-actions of both, are: intersection, overlap and overlay, buffer and extrusion, union and merge, clip and extract and select, split, delete and erase, distance calculation, area and projection calculation, and volume calculation. All 10 functionalities, when implemented into a 3D Geo-database storing 3D features, should give a comprehensive tool. The appendix gives a detailed description of several of these functionalities. Next we will show the use of these functionalities within a detailed 3D cadastre system complete process: main workflows. A useful 3D cadastre management system is required to efficiently process the operations and functionalities for a computerized handling of 3D cadastre responsibilities, restrictions and rights, among them: 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 are presented here in further detail in respect to the basic system functionalities.

5.1 Insertion of a new 3D object (3D volumetric parcel)

In general, when inserting a new 3D volumetric parcel, several geometric and topologic functions and validations should take place, before the new 3D volumetric parcel is authenticated and inserted into the geo-database, e.g., receives a system ID. These are depicted in the workflow in Figure 1 (please note that the indications depicted in the figure, e.g., B.2, B.4 and so forth, are indications classifying the 10 functionalities integrated in the system; see Appendix for details), with an example of such processes depicted in Figure 2.

Stages are as follows, where after a 3D object is inserted, it passes through a detailed checklist, which outputs ‘true’ in the case that the object fulfils all the requirements and integrity rules, or ‘false’ – in case it does not.

1. Format validity

In the first stage, the system checks whether the topology stored for the 3D object is valid to the used GeoDB. In case the topology is not valid an error message will be presented, otherwise the process moves to the next stage.

2. "Safe" distance validity

This spatial validity verifies whether the distances between the new input 3D object and other neighbouring objects (objects exist in its near space) are legal? The output depends on the system's allowed "safe" distance definition, which is the minimal distance that should be preserved between any adjacent physical objects (above or below the ground) to ensure, among others, environment protection, maintain stability of physical structures, and prevent negative mutual influence between objects. Usually, law and regulations determine the range of physical separation distance between objects. Keeping "safe" distances among 3D objects (especially when it comes to handling objects with no planar geometry, such as tunnels with curved facades) is one of the more important recommendations that was made by SOI's 3D cadastre committee (recommendations that will probably be formulated into the 3D cadastre treatment and application).

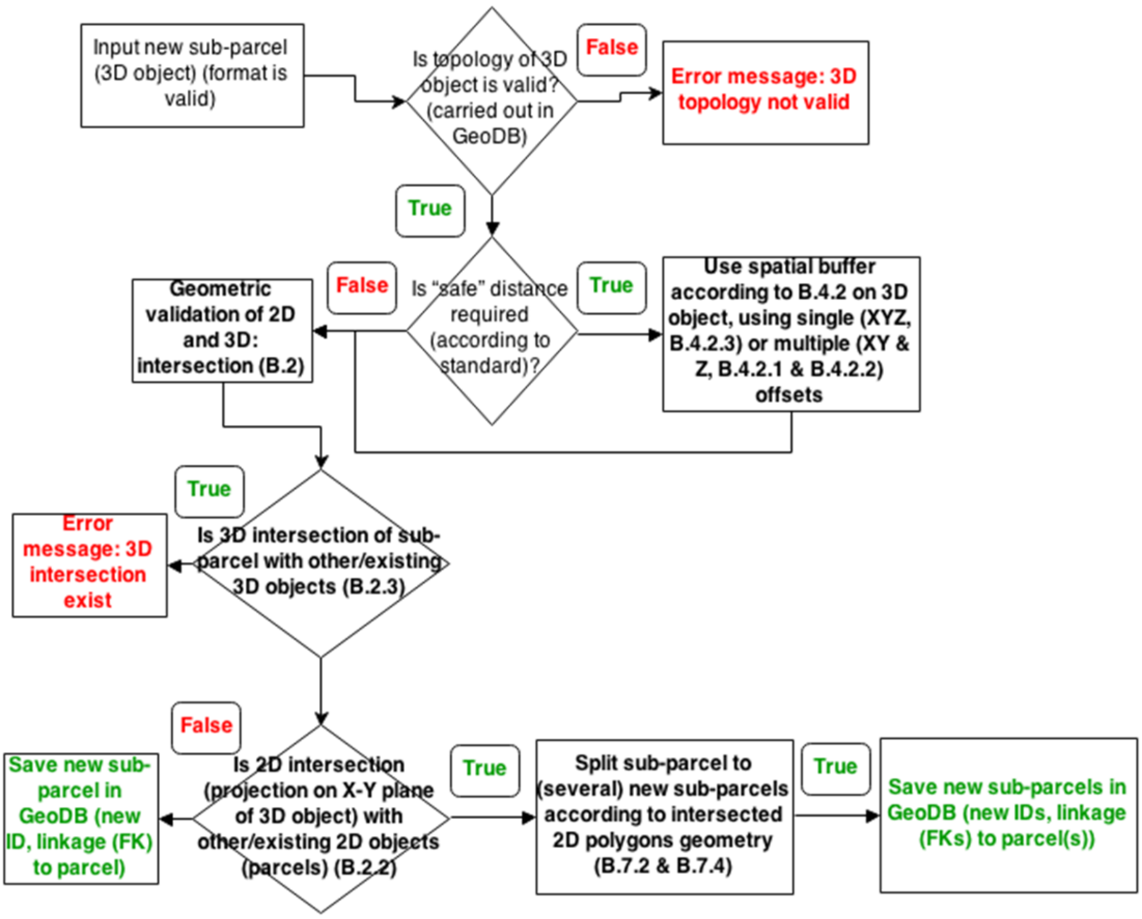

Figure 1. Insertion of a new 3D object (3D volumetric parcel, denoted here as sub-parcel) workflow

For ensuring "safe" distances, and examining the proximity to neighbouring 2D and 3D objects, the use of the functionality Buffer and Extrusion is conducted. According to the recommendations of SOI's 3D cadastre committee, enlargement and reduction of 3D objects is intended for the examination of 3D objects and their correspondence with cadastral conditions on the one hand, together with the possibility to join such neighbouring two 3D bodies into a single object – on the other. Using the Buffer functionality is available here in different implementations:

- Using multiple offsets: one offset in horizontal plane ("sideways"), and another offset in vertical plane ("Height"/Extrude). It enables choosing vertical and horizontal buffers separately and independently. Working in this mode is considered for a 3D object when preserving "safe" distance is requisite in only one plane: either horizontally or vertically, or in case different "safe" distances exist for the different planes.
- Using a single offset (XYZ): this function enlarges a 3D object both vertically and horizontally by the same factor.

If the distances between the new inserted 3D object and the existing neighbouring objects in the system do not deviate from the minimal required "safe" distances (as required by the law and regulations), the object proceed to the next validation stage.

3. Geometric validity

This stage used the Intersection functionality: it checks whether the new inserted object (or its "buffer") intersects an existing object (or its "buffer"). In this case, an insertion of 3D object, intersection of 3D objects is applied first. In case the new inserted 3D volumetric parcel intersects an existing 3D objects (wither partially or fully, as in contain), the system returns an error message, and the new 3D volumetric parcel is not added to the database. In case there exist no intersection among 3D objects, the next validation is concerned with the projection on X-Y plane of the new 3D object and existing 2D objects (parcels). If there exists no intersection with other 2D objects, e.g., it is fully contained, the new 3D volumetric parcel is saved into the geo-database, i.e., receives an ID, and the process of inserting a new 3D parcel ends. Otherwise, the inserted 3D volumetric parcel is split into new 3D volumetric parcels according to the intersection of the 2D polygons geometry.

The split action is done by the Split functionality, which exists of four sub-functions; each is responsible for a slightly different operation. Only two are relevant here: 1. split of 3D objects in relation to existing/neighbouring 2D objects - the input would be the new inserted 3D object and one (or more) 2D objects describing the limits of the 2D parcels and lots existing in the 3D parcel surroundings (above/below the 3D volumetric parcel). The function suggests the split of the 3D object on vertical planes determined by X-Y coordinates of the 2D objects. The output is two - or more - 3D objects (multiple polyhedrons) created by splitting of the original 3D object. 2. Split of 3D objects as function of geometric/cadastral constraints. The input is the new inserted 3D object, the geometric constraints function and/or the cadastral threshold values function. The output of the process will usually be composed of two - or more - 3D objects derived from splitting up of the original 3D object. Examples for applying split of 3D objects as a function of geometric constraints could be splitting a 3D cadastral parcel on a horizontal or vertical plane; parallelism or perpendicularity between faces of the

3D object are maintained. Minimal object volume and minimal area of faces are examples of applying split of 3D objects as a function of cadastral constraints. To summarize, this step enables the split of a 3D parcel in accordance with both the cadastral aspect and topological aspect, as they are manifested in the projection of the 3D parcel on 2D plane.

Following the Split operation, the process of inserting a new 3D volumetric parcel ends by saving the new 3D object (spatial parcel) into the system's geo-database, i.e., it receives an ID. This process can be referred to as the process of "Insertion of a 3D plan" if implemented several times until all 3D volumetric parcels that exist in the 3D plan are validated and inserted into the system.

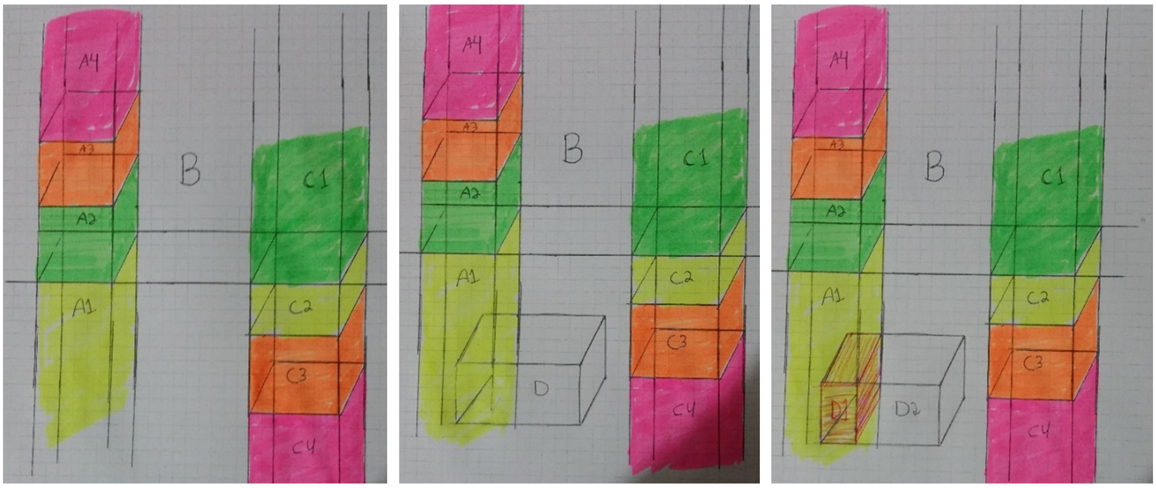

Figure 2. Examples of the 3D cadastre approach made by the SOI. Left - three 2D parcels: A, B and C, where A is divided into four 3D volumetric parcels (A1 and A4 are infinite 3D parcels; A2 and A3 are finite 3D parcels), C is divided into four 3D volumetric parcels (C1 and C4 are infinite 3D parcels; C2 and C3 are finite 3D parcels), and B that is not divided (i.e., unbounded space column). Middle - D is a 3D volumetric parcel that is inserted; D has an illegal 3D parcel validation, since a 3D parcel can not overlap with another 3D parcel. Right – part D1 is split from parcel A1, and part D2 is split from parcel B (unbounded column), together properly forming the new 3D parcel D. Accordingly, the volumes of A1 and B decrease

5.2 Visualization of 3D objects (via search criteria)

This process, depicted in the workflow in Figure 3, is perhaps one of the most implemented in 3D cadastre system. It can be carried out via the "identify" function (e.g., interactive 'touching' of an object), though mostly it will be carried out via a search criteria function, typically by inserting a geometric extent criteria.

Select function can be implemented in both 2D and 3D domain. Selecting objects in geo-databases in general, and in cadastral databases in particular, is a basic step in using these types of data, especially for online use. Search function is implemented for different objectives, such as uniform spatial search for target detection, extracting/clipping objects, avoiding 2D/3D slivers between 2D/3D adjacent objects, and avoiding nodes that are too close to each other. Selecting objects via search criteria having a specific defined extent may rely on a geometric threshold in 2D or 3D. In 2D, the geometric extent is defined by $(X,Y)_{min}$ and $(X,Y)_{max}$ values, where similarly, in 3D, the geometric extent is defined by $(X,Y,Z)_{min}$ and $(X,Y,Z)_{max}$ values (e.g., planar/spatial box, rectangle, and envelope). Also, the use of single point coordinates and radius values can be implemented, resulting with a circle or sphere/ellipsoid search criteria.

Steps are as follows, where after a search criteria is defined, the system activates a search algorithm in the defined extent, with output of the relevant 3D objects that correspond with the geometric requirements; output can be made on screen, also including attribute tables, DTM of the area, and relevant 2D parcels when necessary.

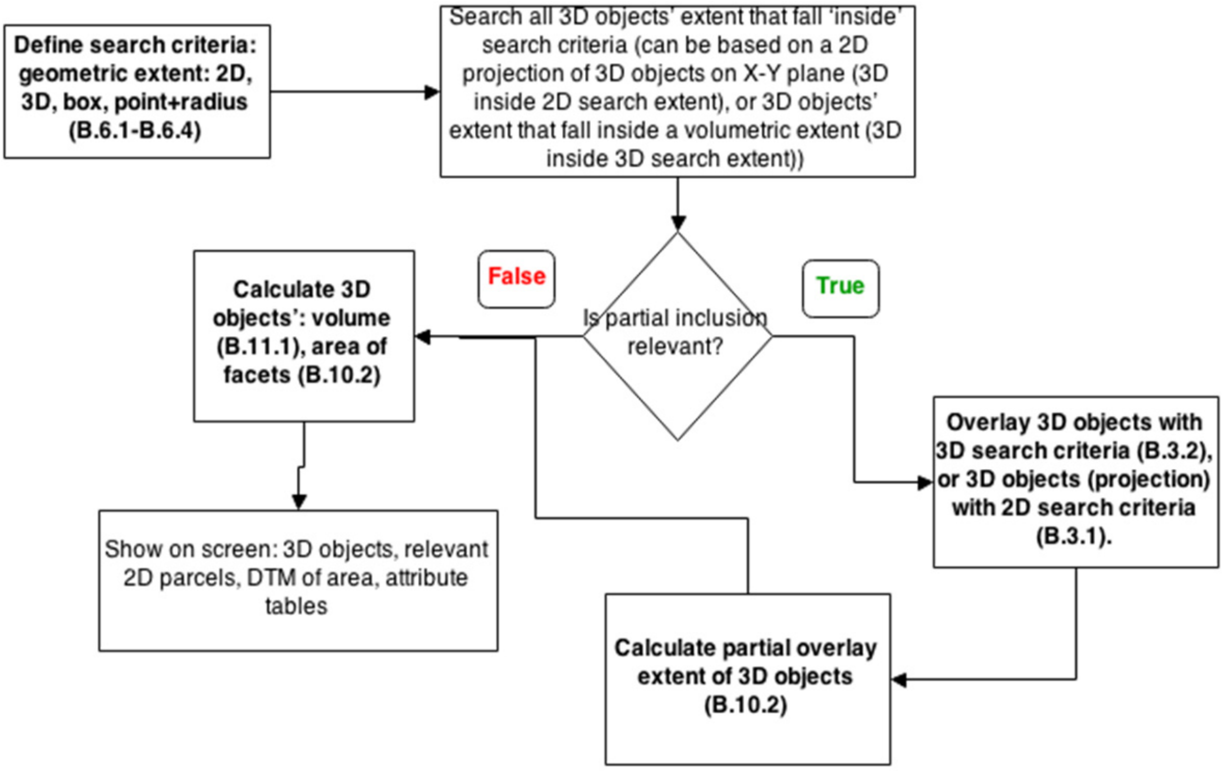

Figure 3. Visualization workflow of a 3D object (3D volumetric parcel) via a search criteria

1. Search operation

Search can be applied in 3D extent, or based on a 2D projection of 3D objects on X-Y plane. In 3D search, the required input depends on the search approach: 1. Geometric box search; 2. Spatial ellipsoid/sphere parameters (with ellipsoid, center coordinates and two search radius values for planimetry and altimetry ranges are required; the search ellipsoid is symmetrical/circular around Z-axis, and is usually a vertical ellipsoid, i.e., the search radius of Z-axis is larger than the search radius on X-Y plane). In both cases, the output is all 3D objects that partially/completely full inside the 3D search extent. Similarly, there are several options for performing search that is based on 2D projection, resulting with: 1. Areal rectangular search; 2. Circular search. System output is all 3D objects that are partially/completely overlaid the 2D search extent.

Search operation can be implemented using the Intersection function (B.2), which outputs three possible results: no-intersection, partial-intersection and fully contained. It is also credible to search objects relying on the Overlay function. When 2D search criteria is applied, it is enough to overlay the 3D objects in horizontal plane to detect whether the overlap (if exists) is partial or full. However, in the case that a 3D search criteria is implemented, it is essential to overlay the 3D objects in both horizontal and vertical planes, since partial/full overlay in one plane does not necessarily means that the 3D object exists inside the 3D search extent, thus a complete Overlay is required.

Next steps depend on the output classification, whereas the output 3D objects are classified into two groups: 1. Partially included 3D objects; 2. Completely included 3D objects. Examples are depicted in Figure 4. 3D objects in group 2 are immediately forwarded for calculating the 3D objects' volume and area of all its facets (step 4), while 3D objects in group 1 undergo two additional steps (steps 2 and 3), before proceeding to the volume and area calculation (step 4).

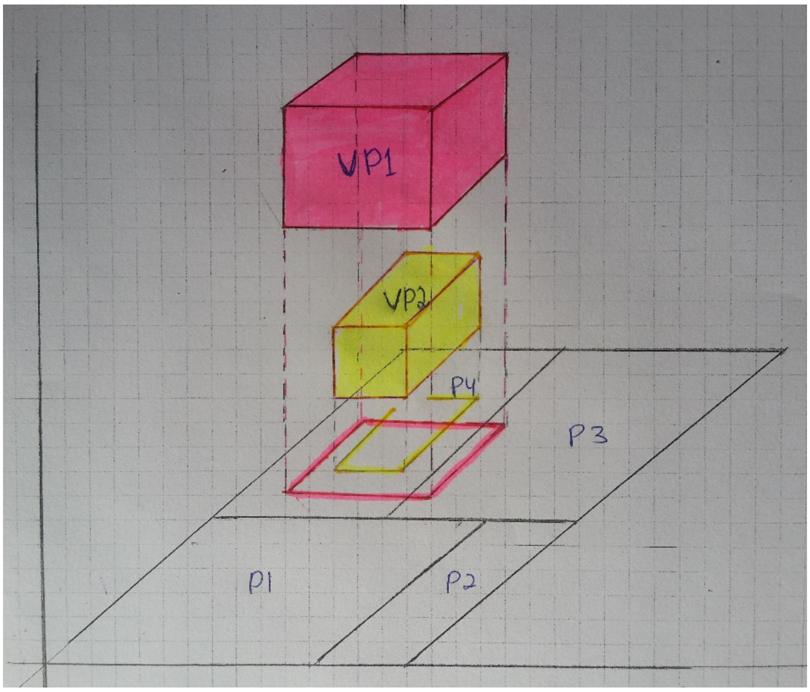

Figure 4. VP1 and VP2 are 3D volumetric parcels overlaid unto the horizontal plane. The output is partial-overlap for VP1, and containment for VP2, where overlapping areas of both projected convex polygons are calculated by the Area function. Here, since VP1 and VP2 facades are planar, both convex polygons are constructed from points defining the X-Y plane

2. *Overlay of 3D objects with 3D or 2D search criteria (according to the type of the search performed in step 1)*

In this context, Overlay function is implemented as an alternative to full intersection in the purpose of detecting whether a 3D object covers in-full or in-part other 3D object/s. Two primary Overlay functions exist: horizontal plane and vertical plane.

- 2.1 In horizontal plane, two 3D objects are projected unto the horizontal plane (X-Y, while Z has a constant value) for the implementation of the Overlay function examination. Since objects are in 3D, a vertical exterior does not implicitly exists (convex polygon), thus a first-stage will entail the calculation of the objects' exterior convex polygons (maximum horizontal extent, projection on X-Y), e.g., a body with planar facades will result with a convex polygon constructed from all points defining the X-Y plane. Required data-blocks input are two 2D convex polygons, and the output is: 1. No-overlap; 2. Maximum-overlap: one polygon is contained - or contains - the other polygon; and, 3. Partial-overlap (it might be required to compute the overlapping area of both polygons).
- 2.2. In vertical plane overlay, both input and output data are the same. Yet, the overlay is computed on X-Z plane (while Y has a constant value), or alternatively on Y-Z plane (while X has a constant value).

Before moving to the subsequent step, it is worth noting that a unique overlay case might exist, where vertical plane orientation is not arranged with the East-West or North-South notion. In this condition, rotation of the coordinate system from X-Y-Z to U-V-Z before calculating convex polygons is required, while U-V is rotated relative to X-Y in an angle of the observed azimuth.

3. *Calculate partial overlay extent of 3D objects*

This stage is performed by implementing the Area/Projection function (B.10) for geometric area calculation. The function calculates the geometric area of 3D objects' facets or projection, in accordance with the selection. The input is the 3D object, and indication of the type of area required for calculation. The output is: 1. Area of one of the 3D object's facets; 2. The area of the 3D object's horizontal projection (on X-Y plane).

4. *Calculating 3D objects' volume*

At this point, the Volume function (B.11) is activated for calculating geometric 3D objects' volume. The input is the 3D objects for which it is necessary to calculate volume, and the output is the volume calculated for each 3D object, including the accumulated volume of all 3D objects. In this step, the area of all 3D objects' facets is also calculated (step 3).

5. *Final output*

The selected 3D objects, which fall inside the search extent, are represented on the screen, together with the relevant (parent) 2D parcels, DTM of the area, and attribute tables.

5.3 Area analysis for plan and design

This process is required for a preliminary assessment of a certain area, in which plan and design are planned to take place, e.g., use of space, existing objects, etc. Normally, this will be according to a specific 2D parcel - or a collection of several. The implementation of the previous process (5.2) is part here, since it enables the implementation of the necessary workflow for calculating areas before displaying them on the screen. Area analysis steps, depicted in the workflow in Figure 5, are as follows:

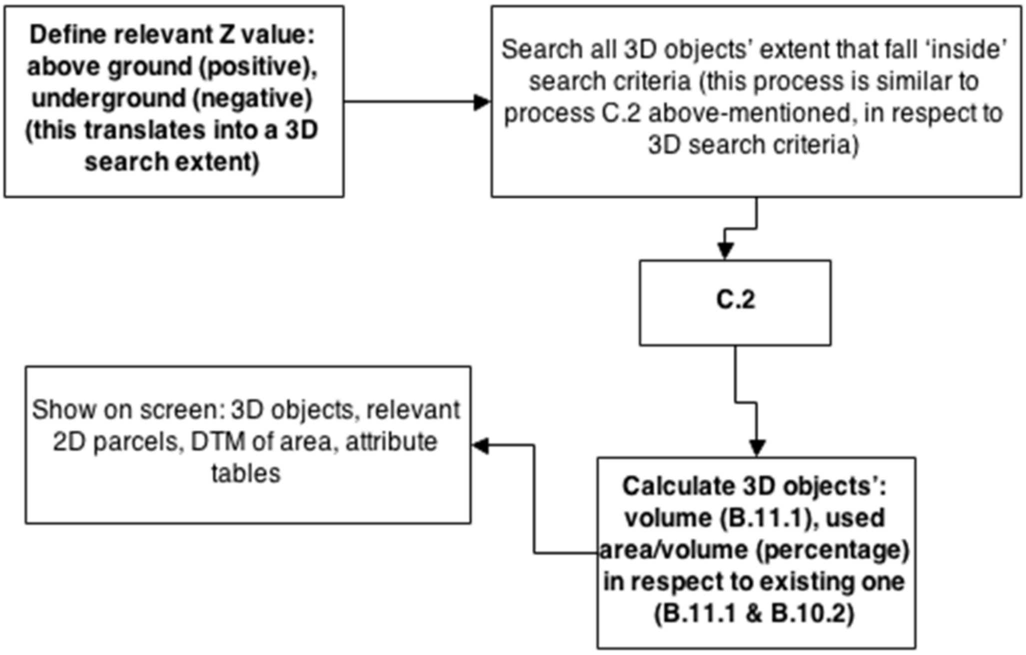

Figure 5. Area analysis for plan and design workflow

1. Define relevant Z value

Since the analyzed area is an integral part of the space, preliminary definition of the height level is essential, as plans, designs and projects will exist inside limited zones, both vertically and horizontally. Z value can be positive, as in the case of a plan that is above ground, or negative, as in the case that it is underground (e.g., tunnels, subterranean infrastructure). In this context, it is vital to determine whether the height sign of a 3D object depends on its position relatively to the ground level, or whether it is defined as an absolute value in terms of the 3D coordinates system.

2. Search

This step is designed to retrieve all 3D objects' extent that fall inside the search criteria, and calculate the 3D objects' volume and area, as outlined in section 5.2 (visualization of 3D objects via search criteria).

3. Display
This step is designed to show on the screen all the analyzed 3D volumetric parcels, together with the relevant 2D parcels, DTM of the area, and attribute tables.

6. CONCLUSIONS

The objective of this research paper is to produce a complete and computerized set of functionalities required for the 3D management and handling of 3D cadastral objects in a 3D cadastre system from physical and jurisdictional points of view in respect to the configuration and guidelines made by the Survey Of Israel. Constructing proper and comprehensive functionalities is an indispensable part of building a good and reliable system. This paper outlined several of these functionalities, outlying their input, output and the way they perform. Following the establishment of functionalities, the assembling of processes that make use of the functionalities is required, whereas for an effective cadastre system these can be numerous. In this paper, we have presented three primary processes, outlying all the steps required and functions handled.

So far, research has mainly concentrated on the topology of 3D cadastral objects, focusing on 3D spatial relationship models, with almost no concentration on the functions needed for correct operations to be handled. It is believe that implementing these functionalities is vital for establishing these systems. Our next step is to construct a 3D geo-database and data-structure required for handling 2D and 3D objects, and integrate these functionalities, while implementing the different processes into a cadastral system in a manner that enables good governance, in accordance with the definitions and guidelines made by the SOI. Further research will also include requisite to validate the functionalities, and to examine their workflow in various conditions and different situations within a system.

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APPENDIX. BASIC SYSTEM FUNCTIONALITY

In this appendix a number of the basic system functions are described in more detail (please note that indexes, e.g., B.2, B.4 and so forth, are indexes related to the complete system's functionality list).

B.2 Intersection

The intersection functionality emphasizes the importance of the calculation of the relative spatial condition and status among spatial objects, and states the requirement of distinguishing between 2D and 3D geo-objects. Accordingly, three types of intersection are stated.

B.2.1 <u>Intersection of 2D objects</u>

Number of situations and conditions require the implementation of 2D intersection in a cadastre system:

- Adding a 2D mutation plan patch (one or many) into the database/system, and the examination of existing geometric contradictions in respect to (adjacent) cadastral parcels.
- Adding land parcel (one or many) existing in a detailed outline map/plan, and the examination of its spatial (2D) condition/position in respect to existing (adjacent) cadastral parcels (e.g., detection of parcels on which lots are situated, and the identification and detection of ownerships/ownerships types required for the examination or use possibilities/building potential).
- Examination of possible discrepancies existing between adjacent cadastral map blocks (although this is the responsibility of SOI, there still exists situations of 'overlays' and 'gaps' between adjacent approved cadastral blocks and mutation plans).

The input of this function are two - or more - closed polygon. The output can be one of three options: (1) no-intersection; (2) full correspondence (full overlay); and, (3) (partial) intersection, producing an areal polygon(s) (e.g., multi-polygon) corresponding to the overlapping area(s) between the two (or more) original polygons.

B.2.2 <u>Intersection of 2D and 3D objects</u>

Number of situations and conditions require the implementation of 2D and 3D intersection in a cadastre system:

- Examination of the spatial condition/position of a 3D object (an existing 3D cadastral volumetric parcel – or a 3D body/feature in potential to form a 3D cadastral parcel) and a 2D cadastral parcel.
- Similar examination to the above, in this case of a 2D lot in a detailed outline map/plan.

The input of this function are a 2D closed polygon and a 3D object, depicted in Figure 6. The output can be one of the three options: (1) no-intersection – the 3D body/feature falls outside of the vertical limits (projection) of the closed 2D polygon; (2) fully-contained - the 3D body/feature is contained completely (falls inside) in the vertical limits (projection) of the closed 2D polygon; and, (3) partial-intersection, with the possible results: a) 2D polygon enclosing part of the 3D body/feature that falls inside the original 2D polygon, or, b) 3D body/feature(s) (e.g., multi-part) defining the portion of the 3D body/feature positioned under/above the 2D polygon area.

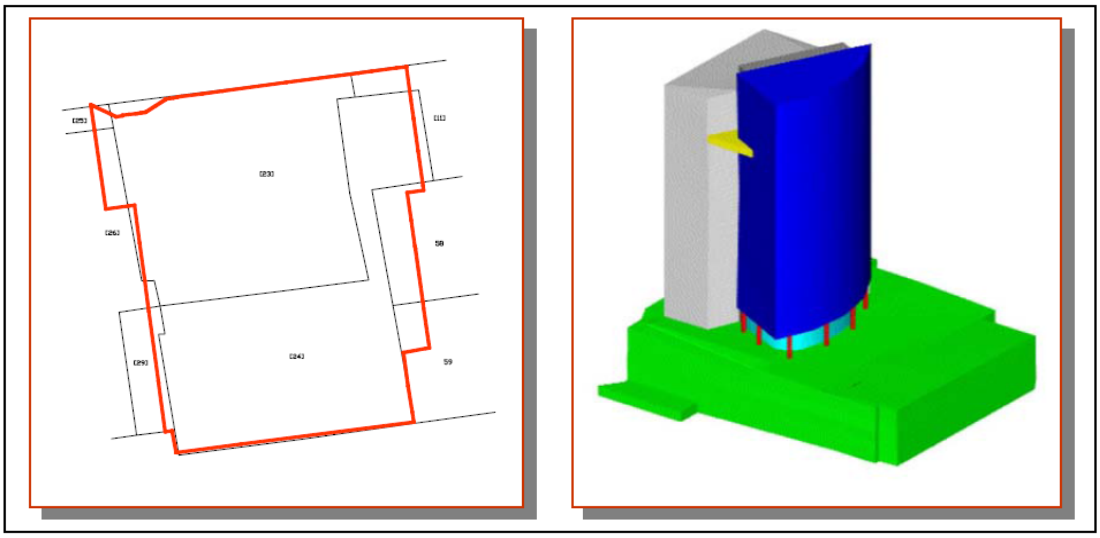

Figure 6. Examination of spatial conditions of an underground parking (depicted in green in the right picture), and 2D parcels (depicted in black in the left picture). Intersection output will produce partial intersection (source: The SOI)

B.2.3 Intersection of 3D objects
The requirement for this function is when seeking to examine the corresponding condition/state between two 3D objects, typically when examining the state of a new entity added to the database/system in relation to previous version/existing objects in the database/system.

The input of this function are two 3D objects, and the output is: (1) no-intersection; (2) fully-contained – one 3D object is contained – or contains - completely the other 3D object; and, (3) partial-intersection of the two 3D objects, producing a volumetric (multi-)polyhedron defining the overlapping/mutual volume between the two original 3D objects.

B.4 Buffer

The use of spatial buffer is designed to solve two main purposes. First, the "expansion" of 2D or 3D objects for the examination of their proximity to other (neighboring) objects, depicted in Figure 7. Second, "expanding" adjacent objects for the examination of the possibility to join them into a single object. Another buffer use can be for the simplification (generalization) of objects having complex shapes/geometry ("stair-case shape"); still, this purpose can be considered as less relevant since cadastral data and detailed plans are received form external sources (SOI, local authorities, etc). According to the recommendations made by SOI's 3D cadastre committee, a 3D cadastral parcel will always be in (contained by) a 2D cadastral parcel – and will not exceed its limits. Further recommendation, made by this committee, was to keep "safe" distances among 3D objects (especially when it comes to handling of objects with no planar geometry, such as tunnels with curved facades). According to these recommendations, enlargement and reduction of 3D objects is intended for the examination of 3D objects and their correspondence with cadastral conditions on the one hand, together with the possibility to join such neighbouring two 3D bodies into a single object – on the other.

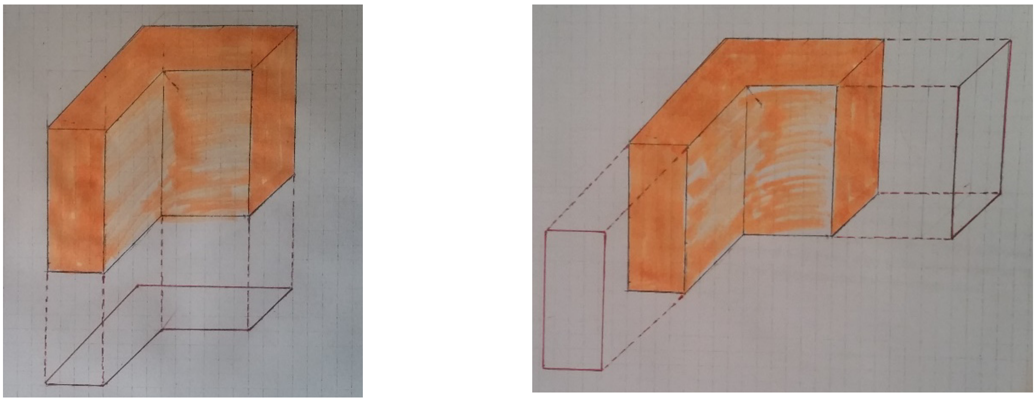

Figure 7. Vertical buffer (left) and horizontal buffer (right) of cadastral 3D volumetric parcel

It should be noted that this functionality does not change the Z-values of the original object in respect to the new object. In cases where the original 3D object's contains a planar bottom, and/or planar top, and/or intermediate planes that are horizontal (including cases where the original object is more complex) - even after enlargement/reduction of the original object these surfaces will remain horizontal planes in the new object. In cases where these surfaces are slopes (e.g., tile roof), the slope of these surfaces in the new objects will differ to some extent from the original slope, which it is assumed that this issue has a minor significance, having no actual practical need.

The required data-blocks input for implementing a vertical buffer offset are mainly 3D objects, requiring the vertical offset-value (which can be with a minus sign, i.e., lowering the object's height, or a plus sign, as in heightening it), and the reference point/plane in the object (bottom or top) to which the function will be activated on. The output is a 3D object having the same X-Y extent as in the original object (i.e., vertical facades remain the same as in the original object), but with a new height-value (Z), which is derived from the chosen parameters.

Here also it is advisable to keep the resulting buffer-width flexible, thus avoiding creating curved shapes (circular domes) around the vertices of the resulting object. In this way, the facades of the new object will stay parallel to the original object facades with a distance that equals to the buffer width, while the new vertices created (in the new objects) will be in a distance that is larger than the actual buffer width used. For example, a vertex that is the corner of a right-hand angle of the original object will be located at a distance of 1.732 times the buffer-width used from the original vertex.

In the examples mentioned above, distances are mostly measured from one object to the other. However, in geo-spatial databases, distances can be measured also as: 1. between two points; 2. between two objects; and, 3. between a point and an object (if required). Distance between points can be unequivocally identified as the Euclidean distance, interrupted as the horizontal distance on the X-Y plane if at least one point is given as 2D point. In the case that both points are given as 3D points, Euclidean distance could be referred as: 1. The horizontal distance between the points (distance on X-Y plane); 2. The vertical distance between the points (the difference of their Z coordinates); and, 3. The diagonal distance (according to the differences of X, Y and Z coordinates). Meaning that it is necessary to receive the two points, their type (2D or 3D point), and the required output from the user to implement the required function for calculating the needed distance.

B.8 Erase and delete

Erasing objects in a geo-spatial database constitutes a basic functionality in processing and editing these type of data. Since it concerns 3D cadastre, functionalities must ensure capabilities for erasing 2D and 3D objects, while maintaining the topological meanings between the 2D and 3D data.

B.8.2 Erasing of 2D objects

Importance should be given to this functionality, since it has an impact on resulting 3D objects. Handling the erasing of one - or more - 2D objects, before the actual erasing, an examination is required on the impact of erasing these 2D objects on relational 3D objects. In case of 3D cadastral parcel, the SOI recommendations for managing a 3D cadastre should be taken into account – inert alia: 1. Not to leave a cadastral 3D parcel without a 2D cadastral parent parcel that contains the 3D objects; 2. It is not possible to erase a 2D parcel and replace it with a number of 2D parcels created from splitting the original 2D parcel – if, as a result of this process, 3D cadastral parcels are being in a state of extending beyond the boundaries of a 2D cadastral parcel. The input for this process is one - or more - 2D objects, and the output can be: 1. Erasing the 2D object (or objects), in case the examination shows that the erasing does not impact any relational 3D objects in the database; 2. In case the investigation shows that 3D object(s) are impacted by erasing the 2D (parent) object – further actions should be advised to maintain topological integrity and legitimacy.

B.8.3 Topological/cadastral validation

While topological integrity must be validated geometrically following each action within a geo-database, when dealing with cadastral data there is an additional required validation after erasing 2D or 3D object (or objects) – of topological integrity, from a cadastral point of view. The two main validations in this context are on the 2D aspect – where according to the cadastral regulations there must be cadastral topological continuity in the content of the single block, the content of a single mutation plan and the content of a town plan, as well as in the transition between adjacent blocks. In the 3D aspect, the validation is mainly to avoid topological contradictions between 3D cadastral parcels and 2D cadastral parcels.

B.10 Area and projection

Calculating areas is a basic cadastral requirement in processing and editing 2D and 3D objects. There must be a distinction between areas in the cadastral sense, and areas in the geometric sense.

B.10.1 <u>"Cadastral" area</u>

Cadastral area refer to the projection of an object on the horizontal plane. This refers to 2D objects, where the area function calculates the horizontal area (on the X-Y plane, while Z has a constant value). The input is the 2D object, and the output is the area of the polygon (parcel, lot etc.).

B.10.2 <u>Geometric area</u>

For 3D objects, this function calculates "geometric" areas. The input is the 3D object and indication of the type of area required. The output is one of the followings: 1. The area of one of the object's faces; or, 2. The area of the 3D object's horizontal projection (on the X-Y plane – i.e. the polygon composed of the vertices of all the points defining it on X-Y plane).

B.11 Volume

In the reality of 3D cadastre, cadastral 3D volumetric parcels are defined as objects above or below the surface. These objects (buildings, apartments, underground parking, tunnels etc.) have volume, and thus the functionality for calculating objects' volume is required.

B.11.1 <u>Geometric bodies/objects</u>

The input is the simplified straight-line polygonal 3D object (one object or a list of objects if there is more than one) for which it is necessary to calculate volume. The output is: the volume of each of the selected objects (one or more), and the accumulated volume of all the objects on the list.

B.11.2 <u>Curved bodies/objects</u>

Cases exist where the 3D objects are geometrically complex, e.g., mesh (TIN, gridded network,…). Thus, as well as calculating the volume of geometric bodies, there is a need for a functionality to calculating curved bodies – especially for the purpose of cutting/filling earthworks for smoothing terrain surfaces. To operate this function, it is, of course, necessary that the terrain model (e.g., DTM/DEM) be stored in the database.

The input is a 2D polygon, which delineates the area for which it is necessary to calculate the volume of earthworks; in addition, the data of the smoothed terrain surface – the planned height and slopes. The output is: the volume of the curved body, calculated from the terrain surface (DTM/DEM) - defined as a regular grid or TIN (according to the DTM/DEM structure) - up to the smoothed surface located underground (in case of cutting) or aboveground (in case of filling).

BIOGRAPHICAL NOTES

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