Design and Development of a 3D Cadastral System Prototype based on the LADM and 3D Topology

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Key words: 3D Parcel, Topology, Solid

SUMMARY

In this paper the design and development of a prototype 3D Cadastral system will be presented. The key aspects of this system are that the model is based on Land Administration Domain Model (LADM) and that the spatial profile is based on a full 3D topological structure. The prototype development starts with profiling the LADM (selecting relevant model classes and extending the model with attributes and classes where needed). The LADM supports various options for representing spatial units (parcels); e.g. a 2D parcel or a 3D volume. 2D parcel is well-known, however, how to create and maintain 3D valid parcels is still a challenge in practice. The 3D topology structure uses the well-known primitives node (0D), edge (1D), face (2D) to construct body (3D), which represent a spatial occupation of 3D parcel. Geometry is only explicitly stored at the nodes.

A 3D Cadastre topology is realized using the API of Google SkecthUp. Details of geometric and topological aspects of the model are specified in the paper. 3D data (collection of faces) initially created by other tools or software can be loaded in prototype and then valid 3D solids /bodies of cadastral parcel volumes can be constructed and stored into the database. Of course, each 3D cadastral object and its intermediate neighbourhood can be retrieved from the database to be edited. During the editing, certain geometric changes need topological reconstruction before the updated data is loaded back into the database. Also other applications, non 3D-topology-aware, can connect to this database populated with 3D topologically structured parcel data; e.g. a 3D web-viewer, or a 3D analysis application like Skyline and Google Earth.

The developed system is currently limited to represent closed solid/bodies. The purpose of this paper is to illustrate the feasibility a 3D topology based implementation of LADM by developing a prototype (tools), loading real world data and to implement construction of the 3D parcels.

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1. INTRODUCTION

The development of land use has promote the land parcels to be subdivided in three dimensional (3D) space according to certain property rights, especially in metropolis with dense population. This results in 3D parcels above or below the land surface. To manage this 3D space becomes an urgent task for the government, thus the representation and modelling of these 3D parcels with geometrical representation as "solid" in computer environment is to be handled.

A solid (mostly we use the term "body" in the paper) model is a complete representation of polyhedron able to support the various calculations and analysis related to the 3D cadastral objects. The cadastral application requires the manipulation of the solid objects by operations to manage, operate and analyze the 3D parcels.

There have been large amounts of 3D data that show what the 3D objects look like, but they mostly consist of individual faces. Real geometric 3D body is required to describe the true 3D characteristics of the objects. We need the proper boundary faces to define a body as well as an effective method to determine each boundary face with normal vector to limit the closed interior space of 3D polyhedron. At least three aspects should be clearly presented in order to manage the 3D parcels correctly: 1) the precise geometric model that describe the shape and geographic location of various 3D parcels, mainly based on sets of flat faces; 2) solid model that indicates all its boundary faces with orientation to present the corresponding 3D parcel object; 3) the topological relationship that encode all the information about the adjacencies among the solids/parcels shared common faces to keep the consistence of the objects' geometries .

The paper extends the model in LADM to create a prototype and confirm its feasibility in implementation. The paper is organized as follows. Basic land administration model and our model are stated in section 2. The details about 3D body construction based on software SketchUp are presented in section 3 with topological processing to achieve the target model. Implementation of the prototype is described in section 4, including data flowchart, operations and publication. Finally the conclusion and outlook are delivered in section 5.

2. 3D CADASTRAL MODEL IN LADM AND THE PROTOTYPE

It was decided to use a topological model for the 3D cadastre, land planning and management for the following reasons:1) the desire to utilize the surveying boundaries to generate the 3D cadastral objects; 2) the desire to store the 3D body surface of the 3D cadastral objects, and attributes explicitly and separately from the objects; 3) the desire for rapid topological queries to provide for real-time user interaction and management. Comprehensive land administrative model is essential to build the cadastral management system.
The LADM (Land Administration Domain Model) provides a conceptual description for a land administration system, including a 3D topology spatial profile; see Figure 1a. The LADM contains classes for parties, RRR's (rights, restrictions, and responsibilities), spatial units (for example parcels or apartments), and basic administrative units (collections of spatial units with the same RRR's); see Figure 1b. All LADM classes inherit from VersionedObject, providing full temporal support. LADM defines a 3D parcel as the spatial unit against which (one or more) unique and homogeneous rights (e.g. ownership right or land use right), responsibilities or restrictions are associated to the whole entity based on ISO 19152 (Thompson and Van Oosterom. 2011). Spatial units (synonym of parcels) have two specializations: legal spaces buildings and legal spaces networks. Here we only focus on the 3D space of a spatial unit based on a 3D topological spatial representation. Other content or spatial profiles are out of the paper's scope. In case of the 3D topology representation, a 3D boundary face has plus/minus information included in the association to a 3D spatial unit. Each boundary face can be derived from the surveyor with Surveying and Representation Subpackage. How to construct the 3D spatial unit (polyhedron) and establish the topological relationships is the main topic of this paper.

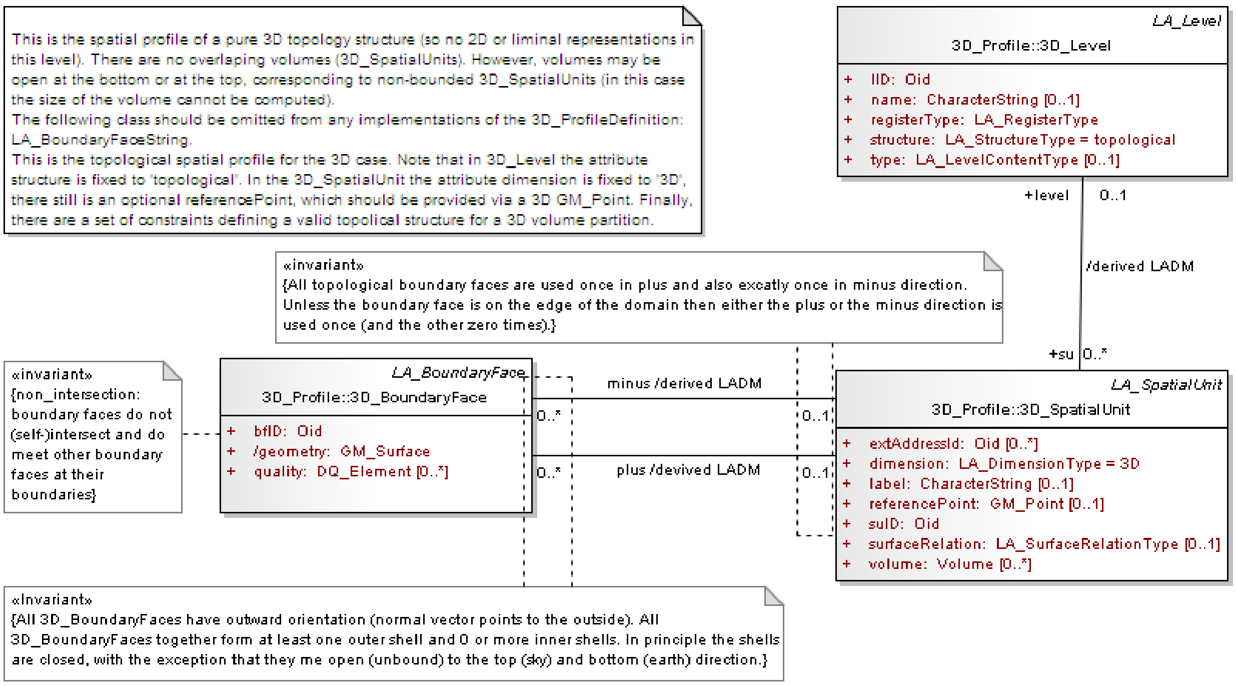


Figure 1a. Data model in LADM. 3D Topology spatial profile, from Annex E (ISO/DIS 19152, 2010)

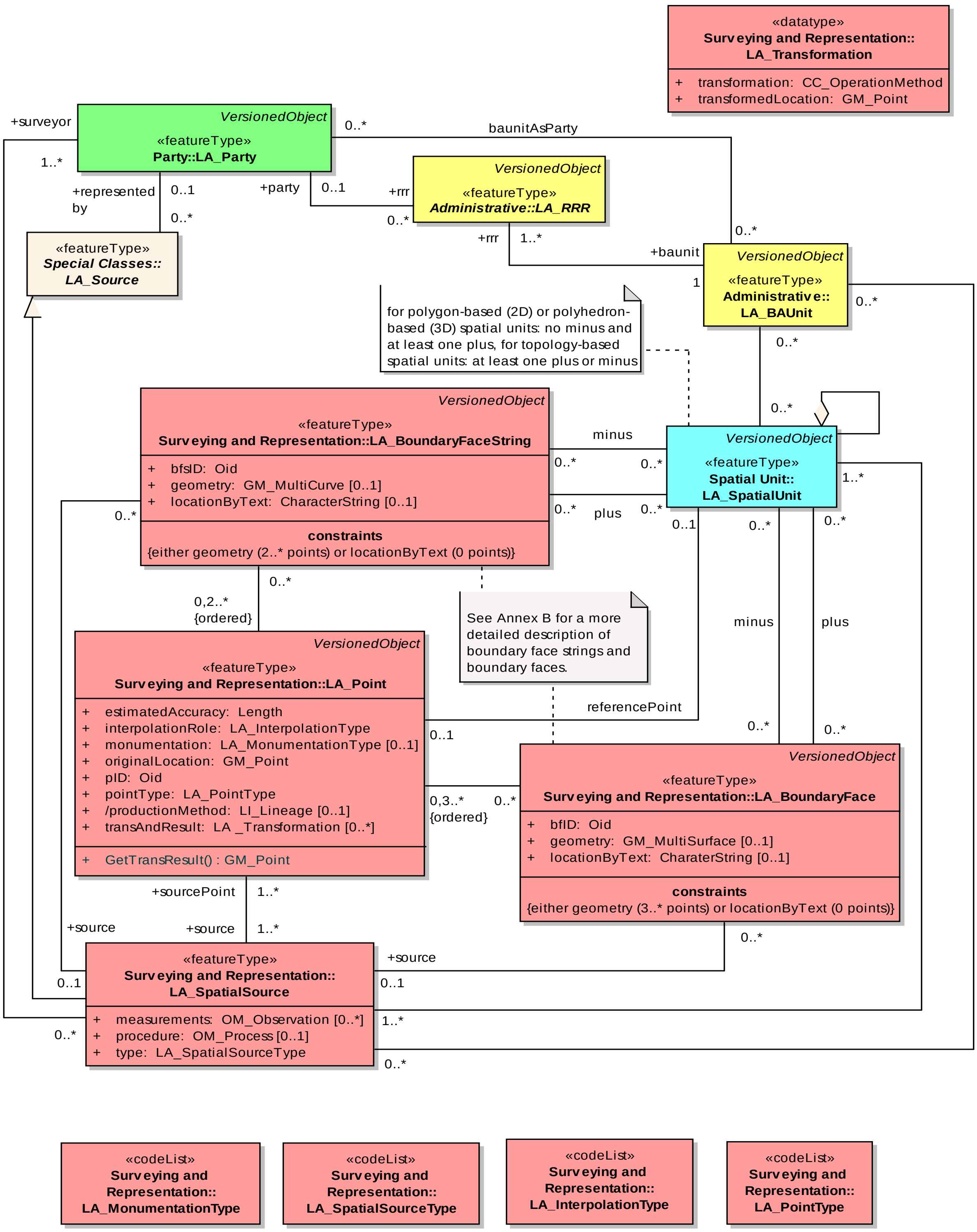


Figure 1b. Data model in LADM, overview spatial representation (ISO/DIS 19152, 2010)

According to the requirements of the LADM, taking into consideration that topological information alone is not sufficient to describe a three-dimensional object, geometrical information must also be associated with each topological primitive. So we design our model of the prototype system to describe and store the topological and geometric relationships of 3D cadastral units, as well as the entities, as Figure 2 shows.

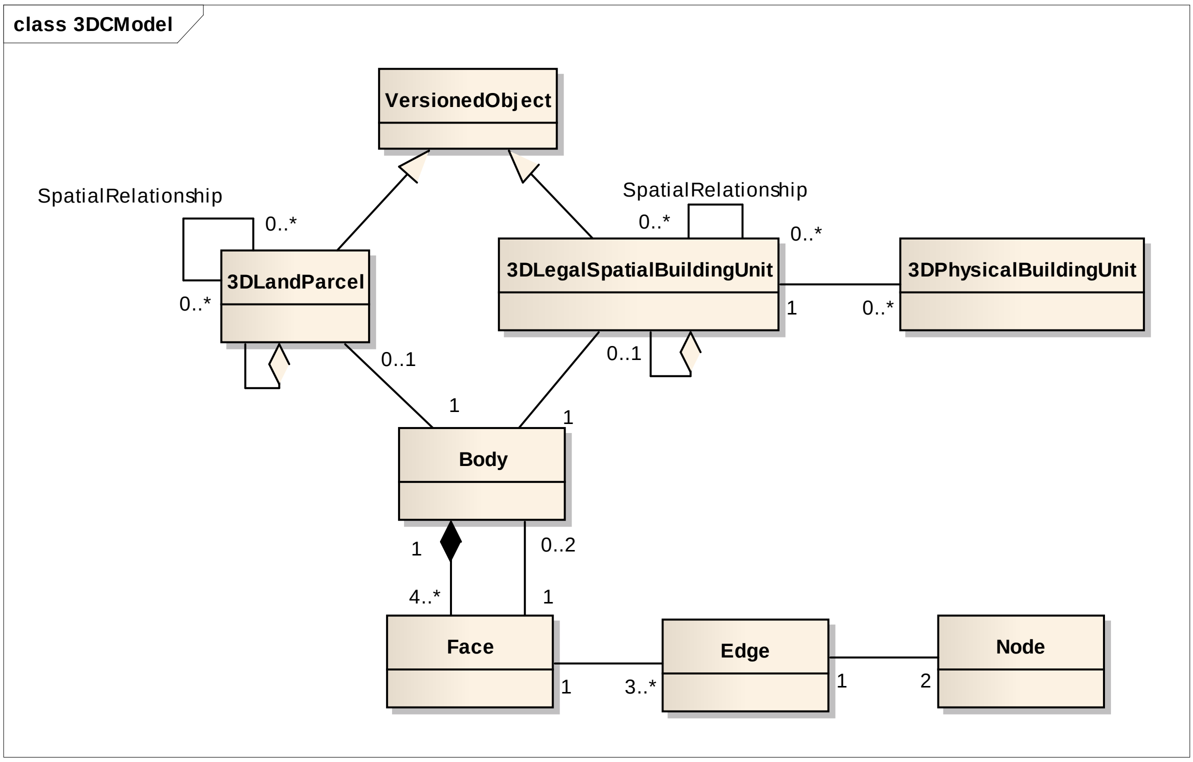


Figure 2. Data model in prototype system

The real geometric geographic coordinates are only recorded in Node, and other topological elements (*Edge*, *Face*, *Body*) will use the references to describe the relationships. Two conceptual or entity classes, 3D land parcel and 3D legal space building unit, are defined to describe the 3D space represented by 3D solid/body. Graphic illustration of the different types of spaces is depicted in Figure 3. A 3D legal space building unit can be associated with a physical construction and the description of the space focus on the homogeneity of the legal attributes (Karki, McDougal and Thompson, 2010). Of course, the physical constructions that the legal units represent may have their own shape, which we will not be covered in this paper. The 3D land parcels still remain as the spatial container of the legal space building units, and should be kept constrained by other rights, responsibility and restrictions, such as condominium and collective right, which is out of this paper's scope. Thus the key technique focus on how to construct the 3D body with the planned or surveyed boundary edges and faces, to assure all the manageable cadastral objects are valid 3D bodies with precise descriptions and consistent topology, which can further be used in computation and analysis.

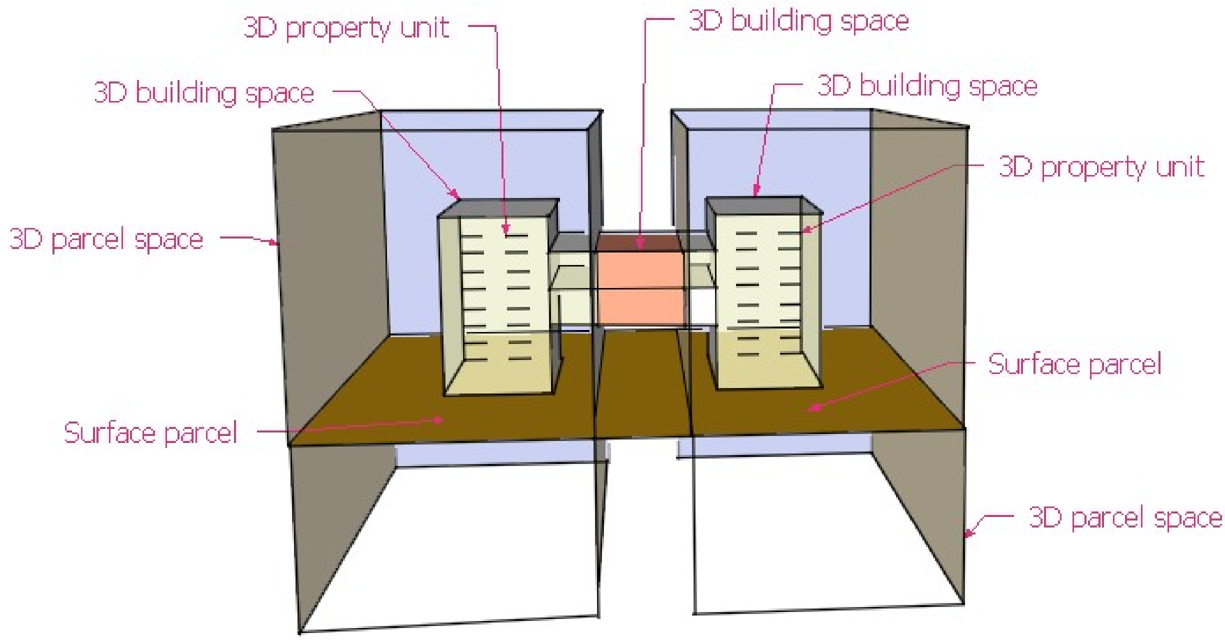


Figure 3. Different 3D spaces in 3D cadastre (modified from (Guo and Ying, 2010))

3. BODY CONSTRUCTION BASED ON SKETCHUP

3.1 Definition of solid model and topology

Each 3D cadastral object is represented by boundary faces based on Boundary Representation. Normally 3D land space is bounded by vertical and default "ceiling and floor" faces, but for other 3D unit that may be an irregular solid, it is not easy to which faces define the close 3D space, especially for the coherent set of 3D units as in an apartment building. In this paper we focus on how to build and represent the 3D cadastral objects represented by the solid model based on SketchUp.

We define the solid model as a seamless 3D space with interior orientation, and commonly its shells, which is closed and is made up of the faces together completely separating the interior and exterior of the solid. Solid object represented by face model is defined by a set of planar faces as spatial boundaries, based on Boundary Representation. In general, the term face is used to denote a simple flat face that is used to define a part of the boundary.

Here we suppose that the precise 3D data must be adequate segmented and tessellated to describe the discrete faces. Otherwise the constructed results may be not reasonable. The model surfaces are subdivided maximally into non-intersecting flat faces that will be used as candidate faces to create the bodies. Unfortunately, many tools are not intelligent enough to recognize and define the closed body with these sets of faces. Some software, such as SketchUp(v8) and Oracle, know to check whether there is a correct solid / body with the precede selected faces, but do not know how detect and find the body from the all faces, let alone the assembled bodies or bodies with holes.

Topology is defined as the incidence or connectivity between various geometric primitives. Under 2D space, an edge is related to not only two vertices nodes but also the left/right two faces which share it, and a face refers both to its boundary edges. In 3D space the topology between the 3D body and other geometric primitives should be built, especially the incidence between body and its boundary faces, and other topological relationships, such as node-body and edge-body relationships, can be derived via face.

3.2 Utilization of the topological model based SketchUp

SketchUp is a 3D modelling software, with which it is easy to create 3D data with geometric tools. In SketchUp every object is made up of edges and faces, and the developing language Roby APIs provide basic topological model between class *Edge* and *Face*. More deeply, class *Loop* and class *EdgeUse* in SketchUp are developed to be the low topology classes to describe the incidence between *Edge* and *Face* according to the orientation of *Edge*, which is similar with half-edge structure (Weiler,1988). But taking the future created bodies into consideration the *EdgeUse* can be used more than twice.

The model represent how the face, edge, and vertex are related to each other. A 3D body is a 3D primitive and is basically incident to faces, the lower dimensional 2D geometric primitive, as Figure 4 shows. So the class *Face* is the focused element to be handled to create the 3D body. An important condition of the Face is its normal direction pointing outward or inward of the body which is essential to the body construction. The face's normal direction determines the interior orientation of the 3D body, and class *Face* is a oriented facet/facets with one outer loop, and zero or more inner loops. Figure 5 describes the main methods of class *Face*.

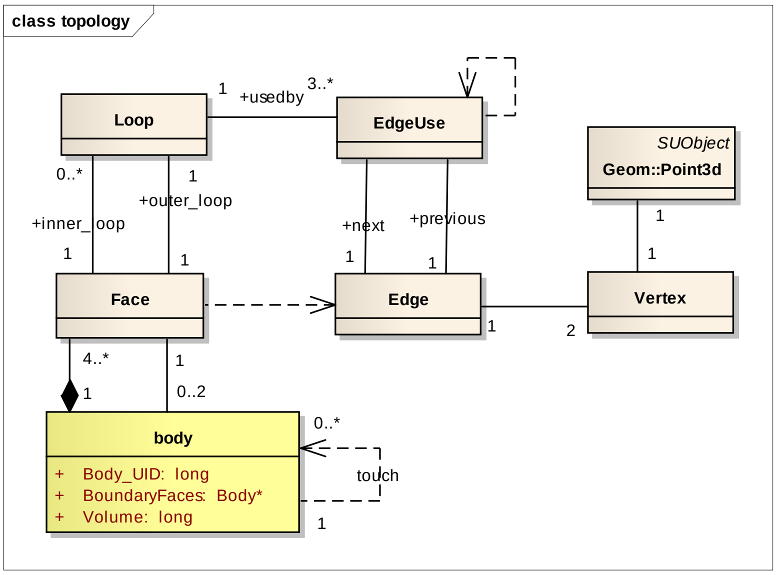


Figure 4. Data model in SketchUp

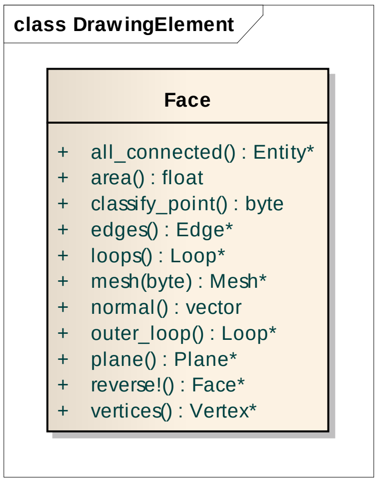


Figure 5. Functions in class Face

Whether the inner loops is a hole or not relies completely on the orientation of the constructed body. For example, there are two incident bodies touching each other at the middle laminar faces as Figure 6a, and the faces that they share or intersect include three faces, *f1*, *f2* and *f3*, see Figure 6b. From the 2D view, there is a face *f1* geometrically with two inner hole faces *f2* and *f3*. But standing from the 3D primitive side, the situation is different. When two 3D bodies are constructed, the system should maintain the consistent topologic relationships between two bodies. In terms of the above primitive body, there should be only one face *f1* delimited by one outer loop oriented upward and two inner loops that indicate the heterogeneous holes, *f2* and *f3, as* Figure 6c shows. While for the below body, there should be the union of three homogeneous faces *f1*, *f2* and *f3*, all with downward face normal direction, whose *EdgeUses* are described in Figure 6d.

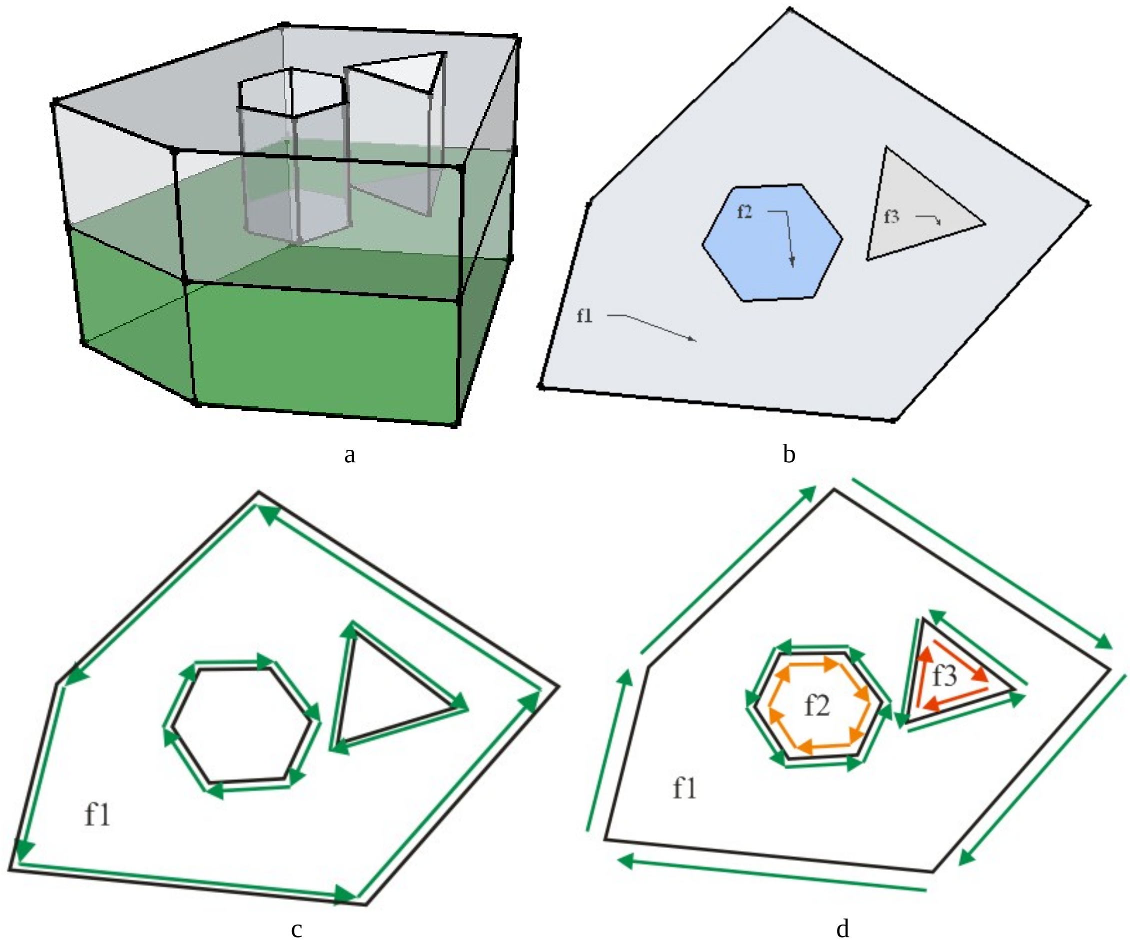


Figure 6. Face with inner holes and its different roles in the different bodies

3.3 Solid construction

We describe in this section how, given a set of surfaces representing one or more solids, we construct the solids. First observe that the ISO19107 solids are not sufficient. The ISO190107 solids are simple solids whose shells are not allowed to touch (they have to be 2-manifold). We follow the definition of a 3D parcel as given in Thompson and Van Oosterom (2011) and Kazar et al. (2008) in which the main rule is that the interior of a solid is connected; that means that a shell can self-touch, as long as the interior of the solid stays connected. Our approach for modelling valid 3D solids satisfies the following requirements when constructing actual 3D cadastral objects:

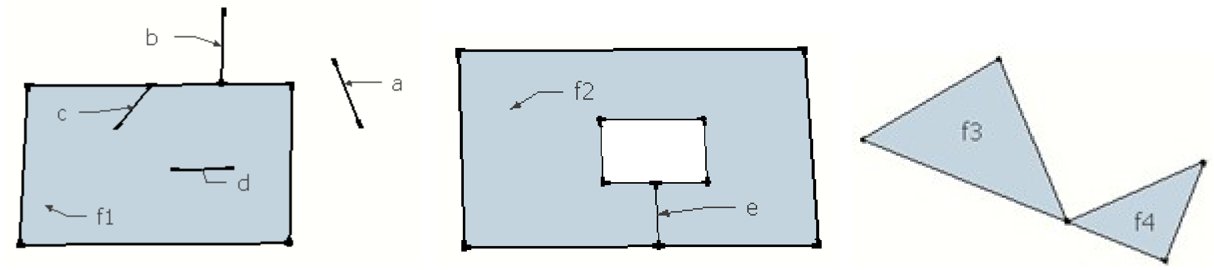
1) The capability to detect hanging and dangling faces or lines. Many initial conditions are the constraints to construct valid solid, and some pre-processing is needed to handle the raw input data (section 3.3.1).
2) Solid coherent set modelling. A solid coherent set is different from single-solid accumulation with duplicated boundary edges or faces through Boolean operations. Multiple solids, without overlaps and voids, should be constructed simultaneously and maintain consistent topologic relationships (section 4).
3) High automation and consistency. Many software tools are dedicated to create 3D data for simulation and visualization, but seldom a model is suitable for actual applications of 3D solids. Furthermore, without any topological structure, constructing a valid 3D object to support spatial relationships and analysis cannot be done automatically. Basic geometric data are maintained unitary with consistent topologic relationships between faces and solid, especially for solid coherent set.
4) The flexibility to support the complexity of polyhedral solid. Many 3D solids are not (only) composed of just vertical or horizontal faces, in addition they may have various singularities, needed for our primary modelling purpose.

We construct solids in three different steps:
1) Input surfaces incident to a given edge are sorted around that edge.
2) The result is stored in the topological data structure provided by Google SketchUp.
3) Navigation in the data structure to extract solids that are deemed valid according to our definition.

3.3.1 Initial conditions and constraints

Observe that for the algorithm to properly terminate and construct solids, the input surfaces must respect certain criteria. Basic geometric and numeric pre-processing is thus first required to deal with the raw data. For example, certain tolerance and threshold are set to snap the points, and pre-processing is carried out to assure no self-intersection and no dangling vertex and edge before solid construction. Furthermore, the initial discrete sets of faces in 3D space should be divided and segmented maximally. The basic constraints and conditions in the input step before constructing the valid solid as follows:
1) Each polygon is closed (same start and end point);
2) Each face is a flat polygon and the curve face should be divided into several flat faces;
3) No self-intersection with lines and no overlay between polygons;
4) No isolate, hanging or dangling point and edge.

The initial conditions are aiming to keep the incoming faces 'clean'. Figure 7 depicts the isolate edge interior (d in Figure 7a) or exterior (a in Figure 7a) of the polygon, and the hanging /dangling edge or line-edge in boundary of the polygon edge (b and c in Figure 7a) and the redundant edge (e in Figure 7b) should be deleted. There should be two edges incident to two faces (f3 and f4 in Figure 7c) respectively. In other words, each edge should be related to the boundary of a certain polygon, but its orientation is not vital because of the recalculation of face's normal direction in 3D space. Moreover, since the concept of hole will be reconstructed in 3D space, the interior holes should be represented correctly in geometrics.



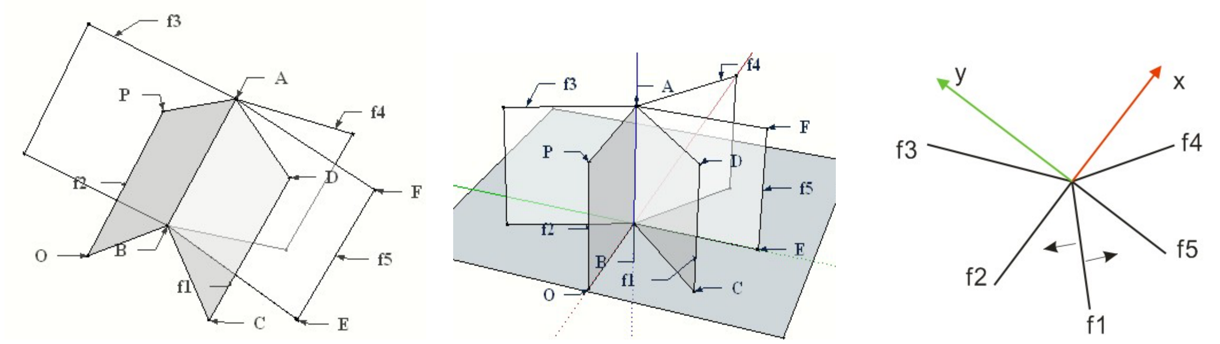
(a) (b) (c)

Figure 7. Hanging and dangling edges (a) and redundant edge (b)

3.3.2 Sorting faces around edges

The topological relationship among faces can be built based on the shared incident edge. The degree of the edge is defined to deliver the number of the faces incident to this edge, which potentially expresses the degree of the faces along one edge side. The edge of degree 1 indicates that the related face is hanging or dangling in 3D space; and the edge of degree 2 means the two related faces may connect with each other at the "corner" of this shared edge. So the problem is how to deal with the faces radiated together with edge degree larger than 2. Face-sorting based on the shared edge is an effective method to handle this situation. Face-sorting around the shared edge is the foundation of the automatic construction of solid because it provides the ordering information about the faces how to select and connect the successive face.

In fact, each face incident to an edge exists in the half-plane delimited by the shared edge as Figure 8a shows. If we use a supposed plane perpendicular to the shared edge to cut the sheaf of faces (Figure 8b), the faces radiated with this shared edge in 3D space becomes the radial-line beam in 2D plane shared on vertex (Figure 8c). So we can sort the radial-lines according to the angles among them in a clockwise (or counter-clockwise) direction. The sequence in Figure 8c is {*f1, f2, f3, f4, f5*} in a clockwise direction. Actually, the angles and the location relationships of the radial edges can be calculated by the dihedral angle of in the sheaf of faces. With the dihedral angels and the sorted sequence, for each face there exist only two candidate faces that may be used during the construction of valid solid. For *f1* in Figure 8c, its left successive face is *f2* and the right one is *f5*. Also the face *f5* is the farthest left face. This left or side view is based on the transformed radial-line beam, for the faces in 3D space this idea can be further realized and confirmed by incident and topological relationship among the face sheaf. The sorting result is stored in Google SketchUp (as shown in Figures 4 and 5).

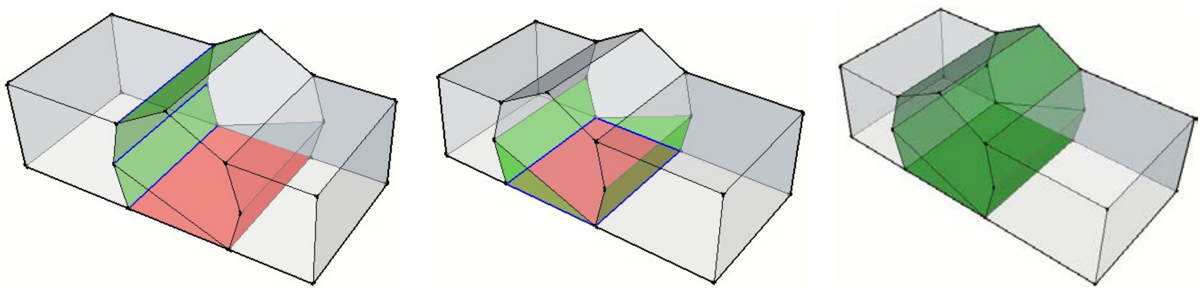


(a) (b) (c)

Figure 8. Face-sorting based on shared edge

3.3.3 Reconstruction of the solids

In this paper we focus on the minimal solid based on the above face-sorting sequence and the connectivity with nearest neighbour face. Although the initial face with certain normal direction and connective criterion is specified, there are still different ways to construct the valid solids that are unique. Every face has several boundary edges and each edge may connect with other potential faces. So there are two ways to search and connect the successive faces: depth-first search (DFS) and breadth-first search (BFS), which will create the same unique solid. Both methods make it possible to march from face to neighbour face to get the topological relationship. The difference between them is that, during the constructing process, DFS search will form a strip zone while BFS search will form a surrounding shape. Figure 9a illustrates the shapes of strip zone based on DFS from starting red face, and only one edges is chose at one iteration as the around edge (blue colour) to connect the next face, the green faces may be one possible trip zone during construction based on DFS after three iterations. As for BFS, each edge (blue colour) of starting red face will be searched at the first iteration, and face sequence form the surround of the start red face circularly (Figure 9b). But neither the DFS nor BFS method can affect the unicity of the result with the same start face, the constructed solid is the same one (Figure 9c).



(a) (b) (c)

Figure 9. Different shape during the process: a) the strip zone based on DSF; b) the surrounding shape based on BSF; c) resulting solid

Taking all the given faces in 3D space into consideration, we should detect and cull the faces that will be not involved during the solid construction and flag them. Thus, before the solid constructing, the pre-computing steps that treat the faces include:

1) Calculating the degree of each edge;
2) Culling and flagging the faces with 1-degree edges, and updating the degree of each edge;
3) if there is no 1-degree edge, go to step 3; otherwise go to step 2;
4) Face-sorting for remaining faces whose edge degree value is 2 or more based on their shared edges.

Because of the culling of the faces with 1-degree edges, the hanging and dangling face can be culled, and in case such a situation occurs, the tool developed with this algorithm can highlight them and warn the user to correct the spatial data in 3D space, and exclude them during the solid construction.

So with all the sorted faces around shared edges, the workflow of constructing valid solids based on BSF can be described as follows and showed in Figure 10.

1) For the assigned face f_i and certain direction n_{i1}, create a new solid object s_i to store the face's ID and direction;
2) Traverse each edge of the face f_i , and check whether it is handled, if not go to step 3, otherwise go to step 5;
3) Flag this edge and check the edge degree to determine the nearest neighbour face according to the given face f_i and its direction n_{i1}. In addition, we can store the edge ID if we want to record the relationship between edge and solid explicitly.
4) Check the nearest neighbour face, if it has been flagged go to step 5, else go to step 2;
5) End of one solid construction, and traverse the same face with another normal direction or other faces in the set.

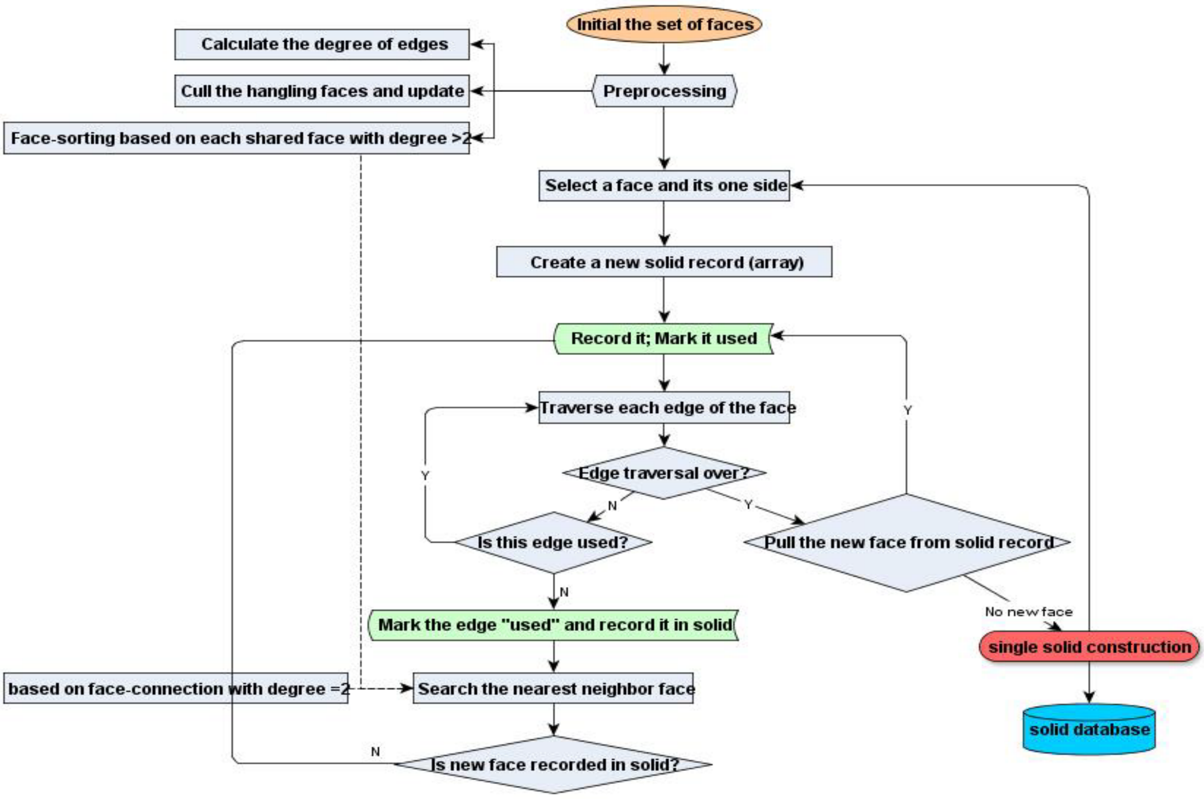


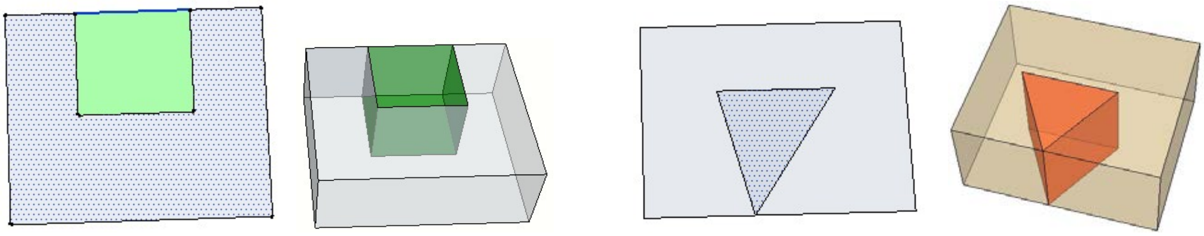
Figure 10. Workflow of the automatic construction of the valid solid based on shared edge

It can be inferred that the stop condition of the constructing workflow is that all the faces are tested and participated directly in the solid construction. Because of the detecting and removing of the hanging and dangling faces, the approach can identify the separate isolated solid and solid coherent set with the edge's degree about face in step 3. The edge with degree 3 or more indicates that there are solid coherent set and the solids are adjacent shared this edge or face, and face connection under this context is based on the face-sorting.

It should be noted that, during the constructing of valid solid, the approach dominantly records the direction of the faces and the interior of the solid. And the topologic relationships between solid and face are stored, as well as the shared edge. It is easy to get the neighbour solids with the shared face/edge and build the topologic relationships among solids. So the relationships of data model in section 3.2 is implemented and filled in, which can keep the consistence of 3D solids and reduce the redundancy of spatial data effectively.

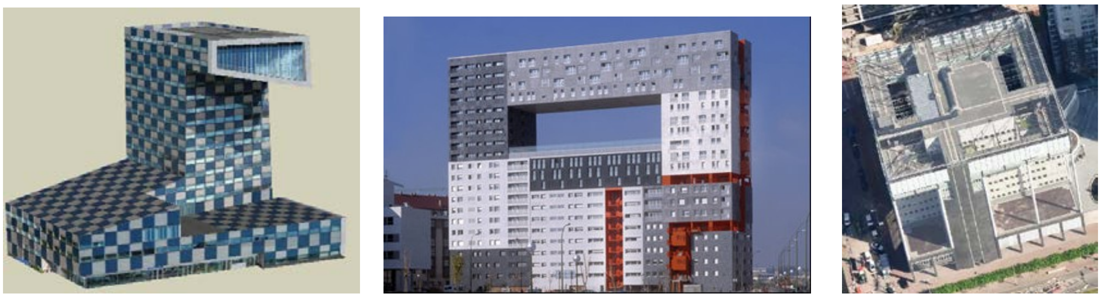
3.4 Handling complex configurations

Situations in 2D and 3D are quite different about the complicated face, for example, touching ring as Figure 11 shows. Not all configuraions of 2D rings can be represented correctly in the datastructures of software packages such as JTS, GEOS, Oracle (Ken Arroyo Ohori,2010). The two faces in case (Figure 11a) are incident to three edges, and the boundary edges of the larger face don't contain the blue one, otherwise there would be a linear face which is not allowed in topological organization of face according to existing data structures. If the blue edge degenerates to a point as case (Figure 11b), the situation is a little strange because of the self-intersection of the outer face. However, case of outer face in Figure 11b is a good face because its interior region is connected. Although there are no enough correction data structure to describe the face with self-intersection ring as Figure 11b, the bodies construction and representation by this face are completely correct and valid as figure 11 shows.



(a) (b)

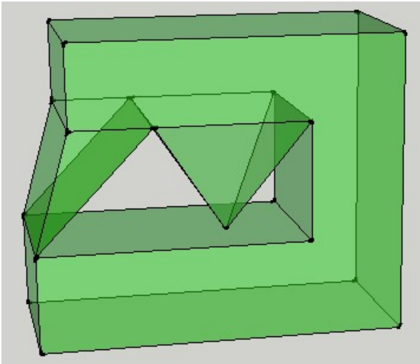
Figure 11. Special cases in 2D and 3D



a b c

Figure 12. Correct solids based on shape with through-hole or irregular polyhedron

Based on the above topological model in section 3.2 and method in section 3.3, various valid solids or bodies can be created completely with the given faces, whether 2-manifold or non-manifold. There are many box-shaped 3D parcels or irregular shape building (Figure 12a), but sometimes the structure of even a single 3D parcel can be quite complex: caves in the interior, through-holes, singularities (node toughing face) as illustrated in Figure 12b and Figure 12c. Under certain conditions also non-manifold can be valid. For example a solid touched itself by edge or vertex may still keep a connected 3D closed interior space, like the shape in Figure 12b and Figure 12c, which is a valid solid. The feature in this non-manifold is that certain edge may be used more than twice in the same solid, but the frequency will keep even (4, 6 and more), see Figure 13a.




(a) (b)

Figure 13. Non-manifold conditions: a) non-manifold valid solid; b) body collection

Things get even more complicated for sets of 3D parcels sharing topology primitives (together forming a space partition) and the various singularities that may be the result. Typically, multiple distinct apartments forming a complicated condominium are always tangent along the shared face/edge (Figure 13b). The focuses will shift to the topological relationship among these aggregated bodies. Each valid body should be recognized and built up from the assembled faces and then correspond to 3D parcels.

4. PROTOTYPE SYSTEM

4.1 Framework of the prototype system

The framework of the prototype system is illustrated in Figure 14. The initial input data are 3D data (collection of faces) created by other tools or software, such as extrusion (Ying, Li and Guo, 2011; Ledoux and Meijers. 2011), and they can be organized based on the topological model in SketchUp. With the help of interactive editor to detect the data correction, automatic construction of the valid 3D body about cadastral parcel volumes can be realized and stored into the database. Of course, each 3D cadastral object (valid solid) and its intermediate neighbourhood can be retrieved again from the database to be edited due to transactional changes. During the editing, certain geometric changes may need topological reconstruction before the updated data is stored back into the database in order to always keep the consistency of topology and geometry in the database. Also other applications, non 3D-topology-aware, can connect to this database populated with 3D topologically structured parcel data; e.g. a 3D web-viewer, or a 3D analysis application like Skyline and Google Earth. However, there is some 'middleware' needed to make these applications support and recognize the 3D topological structure (including the volumes) from database. Probably the most effective approach for this is a SQL VIEW and function in the database to compute the well-known geometry counterpart of the topology primitives (van Oosterom et al, 2002).

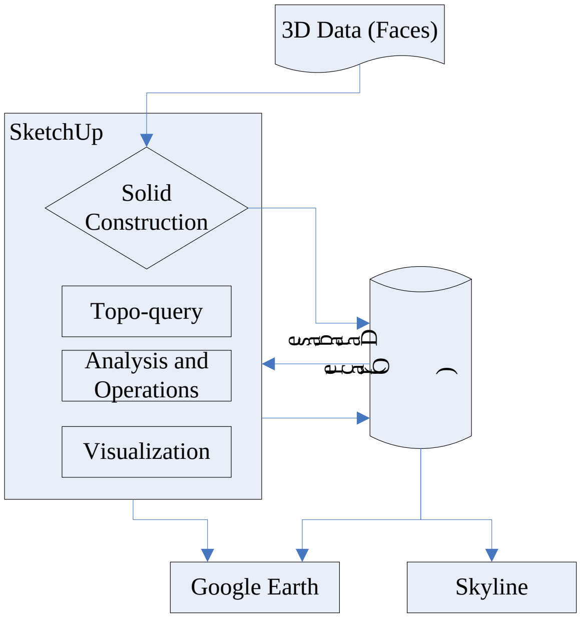
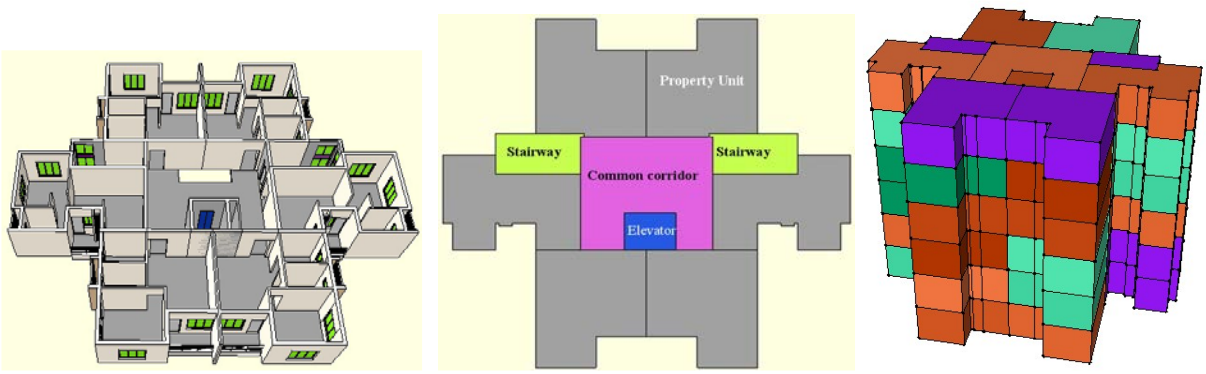


Figure 14. Framework of the prototype

The prototype system is built up based on SketchUp (v7.0), Ruby API (v 1.8.0) and Oracle 9i. Collection of neighbouring solids showed in Figure 13b is selected as test data, and its footprint with cadastral surveying boundaries and the assembled 3D property units with random colours are illustrated in Figure 15.



(a) (b) (c)

Figure 15. Test data: a) Physical shape of the properties; b) Legal boundary of the property units; c) Collection of the 3D property units

4.2 Topological query and operations

If we call the solid / body construction based on face-connecting the initial mass conversion operation, the interactive editing level operators refer to the operations of body mergence and splitting, developed in the prototype system. Some edit operations such as split parcel and merge parcels, are performed. These edit operations should bring the data(base) from one consistent state (old situation) to the next consistent state (new situation). Generally, local geometric and topological relations are updated immediately when the new bodies are created,

also the relationship among the created new bodies and their neighbours should be rebuilt before storing the result in the database in order to keep the global consistency.
Four 3D property units in Figure 16 can be merged together to become one unit as a result of the parcel transaction. To manipulate the splitting a certain plane should be given, also this operator can provide the section view often needed in the engineering field (Figure 17). In the geometric process, when we want to split a body as Figure 18a, each new lines that created by the intersection of the original body and with the splitting plane (Figure 18b) will be computed, and they should be organized correctly to form face (Figure 18c) and sew the incident faces to construct new bodies (Figure 18d). Theoretically it is more complicated for complex body to be split because it relates to how to construct the new face with the new lines related to a solid or a cavity, which is really various and difficult for irregular shapes. Observe that the results of the operators must also be bodies themselves, and the operators can be repeatedly applicable to these results. These operators are more used as modelling tools than visualization for 3D cadastre. It's an important aspect that 3D land parcel may be subdivided or merged during the planning and transactions. And the data model in prototype defines the entities of the land parcel or building units generalized from versioned object supported by LADM, therefore the historical records of all the land parcels should be stored to keep the back-trace and make the related spatial-temporal analysis, such as trading volume and its distribution.

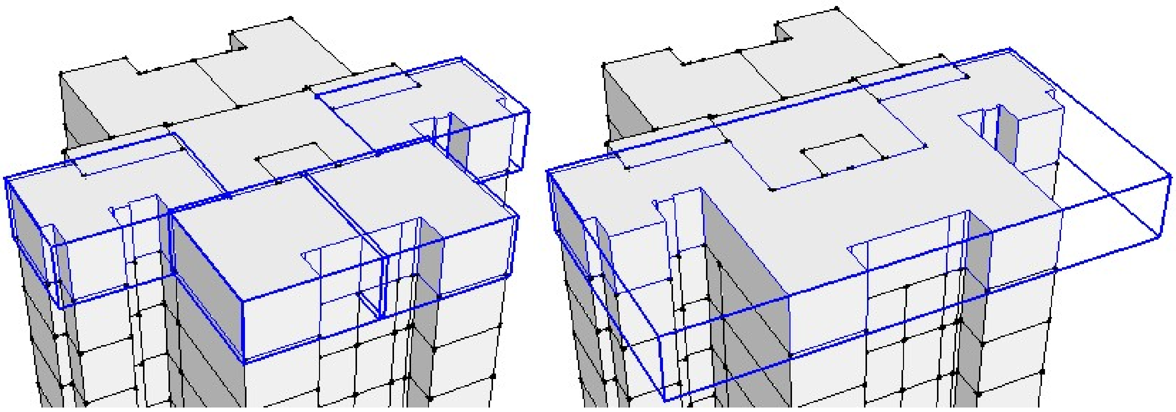


Figure 16. Mergence operator of four bodies

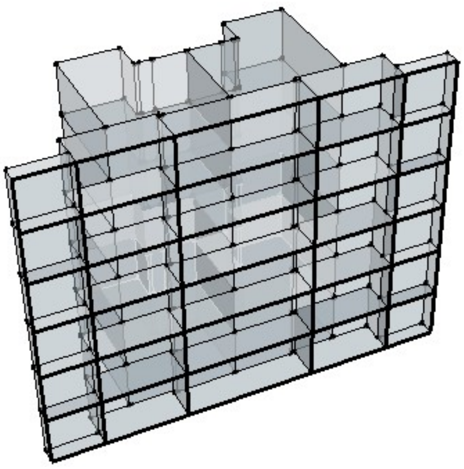


Figure 17. Splitting section view

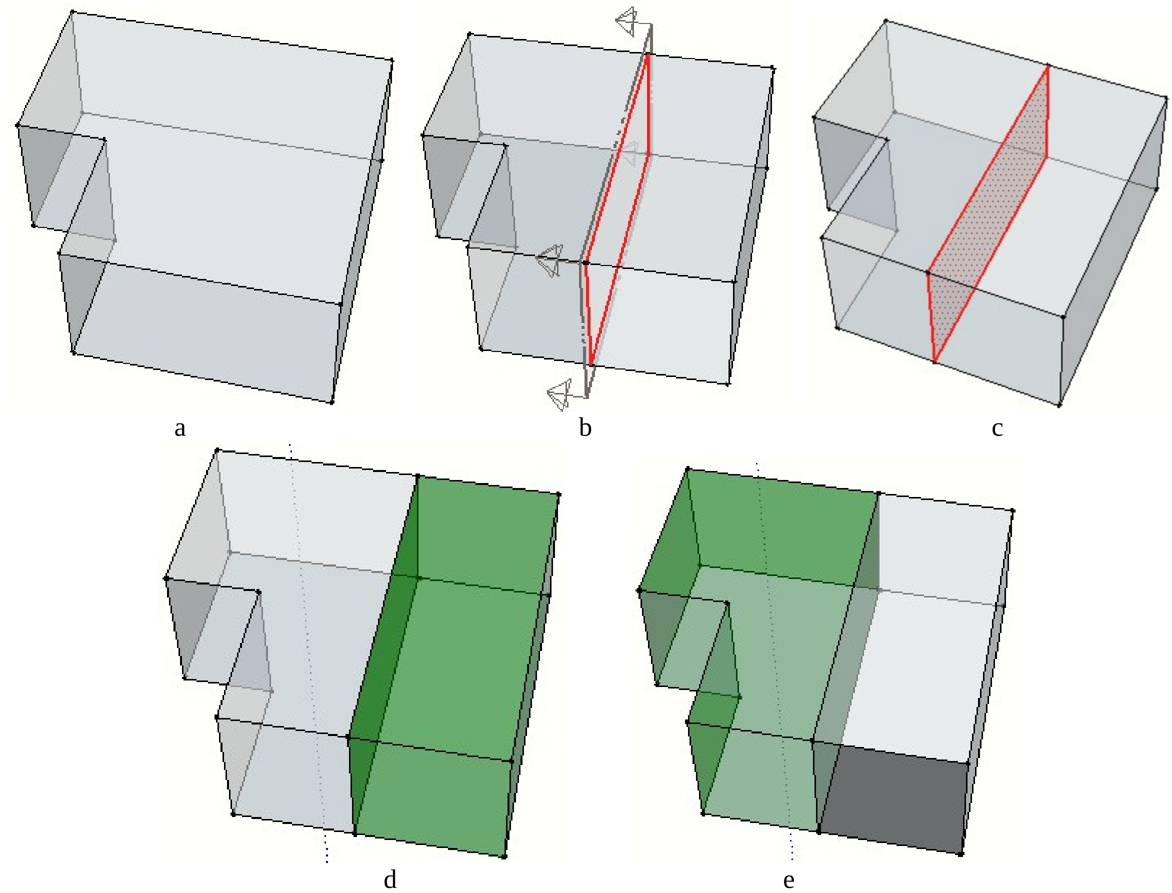


Figure 18. Process of splitting one unit into two bodies

But at the same time, maintaining the topology and solid/body validity are very difficult after the solids are constructed. Thus the developing tools about body modelling is vital to gain the adjacent solids, and to analyze and rebuild the solids after certain operators.

From the application point of view, sometimes we need to query the corresponding objects according to a certain 3D parcel to understand his neighbours and handle some disputations or quarrels between properties. From the implementation point of view, the interior topological relationships must be built among the bodies where they are constructing as section 3 states, to support topological query. The red 3D property unit in Figure 19 is the selected one to query its neighbours through share faces showed in green colour.

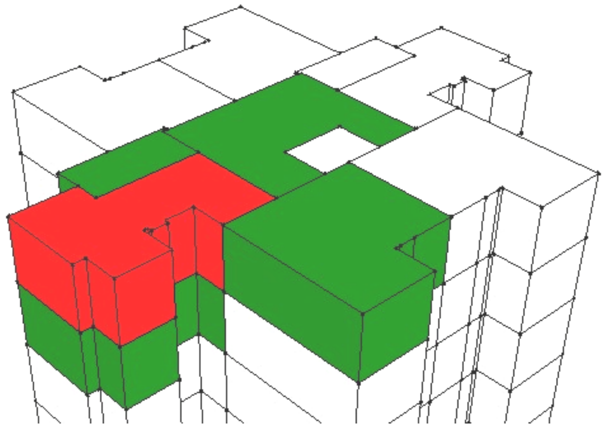


Figure 19. Topological query

5. CONCLUSION AND PROSPECTIVE OUTLOOK

A 3D topology based prototype of LADM is delivered in this article. A mapping can be made between the LADM (3D topology spatial profile) classes and the actual classes used in the prototype implementation. Real 3D (solid/volumetric) bodies should be constructed first with the input faces based on the cadastral model and storing the references in the 3D topological model. In the future, the faces that bound the body can be extended to be surfaces that would support the curve surface and maintain the topology with other geometric elements (solid, edge).

From the 3D cadastral perspective, the LADM provides an abstract framework to model the relevant components in land administration domain, and the main idea of the prototype is implemented based LADM. The attention in the context of 3D cadastre at present is concentrating on the specifications/instances of LADM, and geometries of the 3D cadastral to model the representation of topological relationships, and the operations and manipulations on the cadastral objects. Only when all these issues are resolved, then the complete 3D cadastre can be implemented and realized.

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BIOGRAPHICAL NOTES

Shen Ying is a visiting scholar at OTB, Delft University of Technology , and he stays in the section of GIS-t until December 2011. He received a BSc (1999) in Cartography from Wuhan Technique University of Surveying and Mapping (WTUSM), and MSc and PhD degree in Cartography and GIS from Wuhan University in 2002 and 2005, respectively. Before occupying his present position he was an associate professor in School of Resource and Environmental Science, Wuhan University. His research interests are in change detection, incremental updating and generalization in multiscale geo-database; 3D GIS and cadastre; terrain modelling and visibility analysis; and vehicle navigation system.

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Peter van Oosterom obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, The Netherlands. In 1990 he received a PhD from Leiden University for this thesis 'Reactive Data Structures for GIS'. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague, The Netherlands as a computer scientist. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, were he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology and head of the section 'GIS Technology'. He is the current chair of the FIG joint commission 3 and 7 working group on '3D-Cadastres' (2010-2014).

Hugo Ledoux is an assistant professor in GIS at the Delft University of Technology in the Netherlands. He holds a PhD in computer science/GIS from the University of Glamorgan (UK); the topic of his PhD was the use of the three-dimensional Voronoi diagram for modelling geoscientific datasets. His research focuses on topological data structures, the development of algorithms for three-dimensional modeling, and the use of Voronoi diagram for environmental modeling. He is particularly interested in combining the fields of computational geometry and GIS.

Jantien Stoter defended her PhD thesis on 3D Cadastre in 2004, for which she received the prof. J.M. Tienstra research-award. From 2004 till 2009 she worked at the International Institute for Geo-Information Science and Earth Observation, ITC, Enschede, the Netherlands (www.itc.nl). As associate professor at ITC she led the research group in the field of automatic generalization. She was project leader of an EuroSDR project on generalization from 2005 till 2009. Since October 2009, she fulfils a dual position: one as Associate Professor at Section GIS technology at OTB and one as Consultant Product and Process Innovation at the Kadaster. From both employers she is posted to Geonovum. The topics that she works on are 3D, information modelling and multi-scale data integration. Since January 2010 she leads the 3D pilot that aims at establishing a 3D reference model in The Netherlands in a collaboration of 65 partners. In November 2010 she received a VIDI grant, which is a prestigious award given by the Netherlands Organisation for Scientific Research (NWO) for excellent senior researchers.

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