Constructive Solid Geometry as the Basis of 3D Future Cadastre

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Key words: developing countries, urban, modelling, visualization, geometric, three-dimensional, spatial, CAD.

SUMMARY

The presentation of 3D spatial parcels and the development of spatial data visualization models play an important role in establishing the future 3D cadastre, which has become one of the salient targets of the government's urban activities in most developed countries.
The method of 3D-spatial parcel registration in the future 3D cadastre dictates the nature, characteristics and constraints of 3D visualization of the cadastral parcels. These could assist in choosing the most suitable visualization model.

This paper presents a number of alternative models for visualization of 3D spatial parcels in the future 3D cadastre. It takes into consideration a number of important practical aspects, including: existing 3D cadastral registration methods, 3D spatial topology in the future 3D GIS, accuracy of cadastral constraints, effectiveness in establishing a 3D database for constructing the 3D spatial parcels, feasibility of the database's application in existing CAD software and its effectiveness in building 3D city models in the future cadastre for city planning purposes.

The paper proposes a method that has been developed by the authors using Constructive Solid Geometry (CSG) for 3D cadastral data visualization. It emphasizes the advantages and disadvantages of the CSG model in relation to other models, such as a boundary-representations model, primitive-instancing models, sweep representations and spatial-partitioning representation models. The comparison is based on the models' potential for visualization of the 3D parcel through a constructive method for founding the 3D future cadastre.

The method proposes a special text data format, called ”3DSRV”, based on the CSG model, for arranging the cadastral mapping data, in order to edit the future 3D cadastral digital map automatically. An important advantage of the ”3DSRV” format is that it can be converted to other computers' graphics model formats. Such model formats might be the future 3D GIS format.

The method is implemented by writing a macro using AutoCAD Visual Basic for Application (VBA) development environment. The macro reads the proposed text data format and establishes the 3D cadastral spatial parcels automatically, as well as assisting in generating the future 3D registration plan maps.

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1. INTRODUCTION

In the last decade we were witness to an obvious worldwide trend to improve the cadastre system, the system responsible for managing countries' real estate. De Soto (1993) explains that the main reason for this trend is the role of the cadastre system in enforcing economical growth.

While countries around the world are busy transforming their cadastre systems from the graphic old system to the modern analytical one, the characteristics of the modern target system has been increasing, depending on the rate of acceleration of technological growth. The characteristics of the modern system are not satisfied by being a 3D digital high accuracy system; it tends to elaborate upon and improve the service standards, which provide for the citizens of the country, particularly the engineering population such as architects.

One of the services that manifest themselves by using the 3D data measured and saved in the 3D cadastral database is the production of 3D-city models. These models ought to be almost compulsory in the 3D digital cadastre system, which became a target for the government of Israel in 2002, when it funded a "3D-Cadastre" R&D (Research and Development) project. One of the R&D projects involved crystallization of a solution for defining and registering titles in strata of 3D spatial parcels.

2. PROBLEM DEFINITION

The 3D cadastre system will manage the 3D spatial data in strata in the same way the 2D-GIS manage the 2D spatial data currently. This task can be separated into two parts; the first part is 3D cadastral data spatial analysis of 3D parcels and 3D objects, and the second part is 3D digital visualization as well as 3D city models.

As a basic hypothesis, this task will be performed in the future by a 3D-GIS system that does not exist yet. The 3D-GIS system is undergoing intensive research and development efforts at this time. The lack of a 3D-GIS system emphasizes the need for an intermediate system consisting of existing software such as 2D-GIS. The intermediate system must fulfill minimal demands and functions that will be required for managing and visualizing the 3D cadastral spatial data.

The main limitations of the 2D-GIS software are weakness in visualization of complex 3D objects and the non-existence of 3D topology. The 3D topology issue is considered the basis of the future 3D-GIS system model. Hence, the intermediate system which must be designed during this decade must not rely on a possible immediate solution for 3D topology, but the system database must be planned in such a way that it can permit transformation of its database format to the 3D topology future solution format.

On the other hand, in order to overcome the 3D visualization limitation of the 2D-GIS, the intermediate system may use CAD software, that specializes in 3D visualization. It is obvious that the "intermediate 3D cadastre system" may consist of 2D-GIS and 3D-CAD, such as the AutoCAD.

In Israel, surveyors are requested to submit the 2D spatial cadastral data in special ASCII format named "SRV" (see http://www.armig.org/srv.html). The main aim of this format is to enable transforming the spatial data to a 2D-GIS layer format. Therefore, the main task of authors is to establish an ASCII format for saving the 3D cadastral spatial data, in such a way that permits two assignments:

- Future data transformation for the 3D topology data format.
- Designing an application for an automatic 3D visualization of the cadastral 3D parcels and objects, as well as producing 3D city models.

Saving of the data format depends on the legality of the visualization model. Hence, the role of this paper is to develop a suitable visualization model that permits fulfilling the two aforementioned tasks in a minimal time period, using existing software that is common in the geodetic markets.

3. MODELS FOR VISUALIZATION OF 3D OBJECTS

According to R&D for the "3D Cadastre" project solution, the boundaries of the 3D parcel will be defined by delimited primitive solids, while the standards for choosing the primitive solids underground will be done by architect engineers in accordance with engineering and mechanical criteria.

Spatial sub-parcels will be defined as objects that bind their ownership space (Shushani et al, 2003).Thus, the visualization model that is suitable for the 3D cadastre according to the project solution will be founded on *Solid Models*. In the literature, five different Solid Models can be found: Primitive Instancing, Sweep Presentations, Boundary Representations, Spatial-Partitioning Representations and Constructive Solid Geometry (CSG).

3.1 Primitive Instancing (PI)

Geometric Solids are defined by a number of constant parameters. The modeling system defines a set of primitive 3D solid shapes that are relevant to the application area. For example, one primitive object may be a regular pyramid with a user-defined number of faces meeting at apex.

3.2 Sweep Presentations (SWP)

Sweeping an object along a trajectory through space defines a new object called a sweep. A trajectory may be defined by a mathematic function or by a 3D spatial polyline. The simplest kind of sweep is defined by a 2D area swept along a linear path normal to the plane of the area to create a volume (see figure 1.a and 1.b).

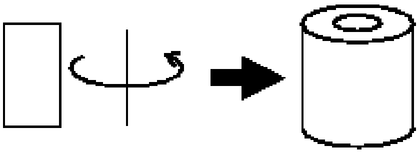

Figure 1.b: Building a cylinder with a hole by sweeping a rectangle.

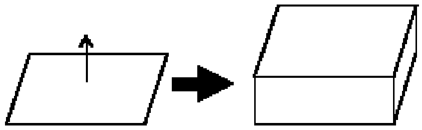

Figure 1.a: Building a cube by sweeping a square

3.3 Boundary Representations (b-reps)

Boundary Representations (also known as b-reps) resemble the naïve representations in which the object is described in terms of its surface boundaries: vertices, edges and faces. Some b-reps are restricted to planar, polygonal boundaries, and may even require faces to be convex polygons or triangles.
This representation of Solid Modeling is very commonplace and is a platform of several known representation solid modeling such, as Mesh Models, NURBS Surfaces and so on.

3.4 Spatial-Partitioning Representations (SPRs)

In this model, a solid is decomposed into a collection of adjoining, nonintersecting solids that are more primitive than, although not necessarily of the same type as, the original solid. The primitive solids may vary in type, size, position, parameterization and orientation, much like the different-shaped blocks in a child’s set of blocks. The principle of SPR is a base for other known solid modeling geometry such as Binary Space-Partitioning, Spatial-Occupancy Enumeration, Cell Decomposition and Octrees.

3.5 Constructive Solid Geometry (CSG)

Simple primitives are combined by means of regularized Boolean set operators that are included directly in the representation. An object is stored as a tree with operators at the internal nodes and simple primitives at the leaves (see figure 2.a and 2.b).

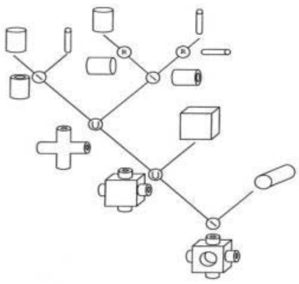

Figure 2.b: Describing a complex CSG tree that define a complex 3D object

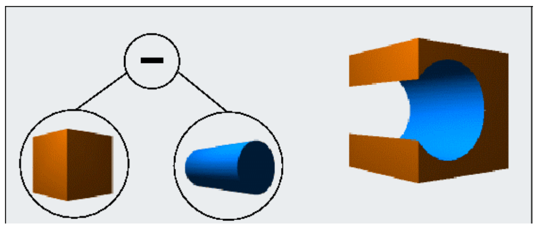

Figure 2.a: Describing 3D complex object representing by Boolean operator of the CSG method

4. DEVELOPMENT OF A SOLID MODEL FOR PRESENTATION Of THE 3D CADASTRAL PARCELS AND 3D-SPATIAL CADASTRAL OBJECTS

4.1 The Important 3D Cadastral Representation Model Characteristics

According to the authors' point of view, there are important characteristics that are ideal for a 3D geometric model that represents the 3D-spatil cadastral objects. The seven most significant characteristics are:

a. *High accuracy level:* The ability to represent the measured 3D spatial object without distortion. The SPR and the polygonal b-rep methods produce only approximations for many objects. Alternatively, the method that supports high-quality graphics is the CSG method, with nonpolyhedral primitives and b-reps that allow curved surfaces. Primitive instancing also can produce high quality pictures, but does not allow simpler objects to be combined with Boolean operators.

b. *Flexibility*: Flexibility in representing the cadastral objects and very complex ones at that. On the one hand, the Primitive Instancing model is limited, since it is impossible to parameterize all objects. Similarly, it is very difficult to reproduce an object with a hole inside by b-reps models. The same limitation is relevant for the Sweep Representation model. On the other hand, the CSG and SPR models are both able to reproduce very complex 3D spatial objects, especially those that are hand made by humans, such like buildings and bridges, and require 3D cadastral mapping.

c. *Validity:* Among all the representations model, b-reps stand out as being the most difficult to validate. Not only may vertex, edge and face data structures be inconsistent, but faces or edges may also intersect. On the other hand, to validate a CSG tree only simple local syntactic checking needs to be done.

d. *Closure*: Primitives created using primitive instancing cannot be combined at all, and simple sweeps are not closed under Boolean operations. Therefore, neither is typically used as an internal representation in modeling system. Furthermore, particular b-reps may suffer from closure problems under Boolean operations. In most of the cases, these problems can be avoided (Foley et al, 1996).

e. *Efficiency for 3D cadastral uses:* Every representation model could be ideal for cadastral representation missions. For example, new cadastral permutations, such as union and partitioning, is ideal for representation by using CSG model, whereas using b-reps is ideal for finding topology relationships.

f. *Calculating 3D topology*: Much research is being conducted in this field, as it is the main key for establishing the 3D GIS system. Most of the 3D topological models rely on the b-reps. However, there is no specific model that has been adopted until this time. Hence, the most important character of the representation model that will be used for the "intermediate 3D cadastral system", mentioned above, is that the model representation must enable the conversion of its data format to other representations' model data formats as easily and accurately as possible. The CSG and the SPR models facilitate an accurate and simple conversion to all the other representations models. While the same operation in the b-reps models is also complex, it is not practicable in most of the cases (Cambray, 1992; Foley et al, 1996).

g. *Implementable by large scale measurements methods.* This means that the representation models have been used by Photogrammetry and Airborne Laser scanning technology for automatic 3D spatial object visualization. Haala et al (1998), Frostner (1999), Wang and Gruen (1998) and Brenner (1999), present various models of databases that are used for constituting 3D City Models by means of Photogrammetry and Airborne Laser scanning techniques. Most of the representation techniques are based on the CSG model, whereas a few are based on the use of the b-reps.

Of the five models presented above, the two prominent solid models are the CSG model and the b-reps model. Although the CSG model does not deal with 3D topology, and this is considered the main disadvantage of the model, it defeats the b-reps in the other areas. However, the CSG data tree format successfully and simply enables conversion for other formats in a simple way, while the same operation, in the b-reps models, is complex and not always practicable.

Therefore, the proposed 3D-cadastral representation model was based on the CSG model. This model is designed especially for establishing the “Intermediate 3D Cadastral System”, which will work during the entire period in which the 3D-GIS system did not exist.

4.2 The Proposed Model

The proposed representation model is based on the CSG model. The primitives that are combined by means of regularized Boolean set operators consist of:

- A Cube, which is defined by two points (X, Y and Z) of the diagonal (see figure 3.a).
- A Cylinder, with two ellipses at its base. The cylinder is defined by two points (X, Y and Z) and the main axes values of the ellipse (see figure 3.b). The paper deals with the circle bases cylinder as a simplification of the general case.
- An Ellipsoid which is defined by a central point and the two axes values. The paper deals with a particular case of the ellipsoid where the two axes are equal which is a sphere (see figure 3.c).
- A Cone which has an ellipse basis. The cone is defined by the central point of the ellipse and its head node point (X, Y and Z) (see figure 3.d).
- A two heads pyramid. The pyramid is defined by six points (see figure 3.e)

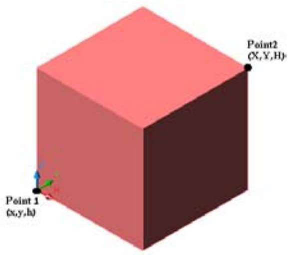

Figure 3.a: Illustrates the cube parameters definition

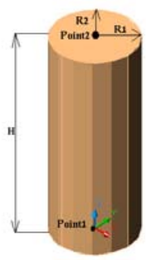

Figure 3.b: Illustrates the cylinder parameters definitions

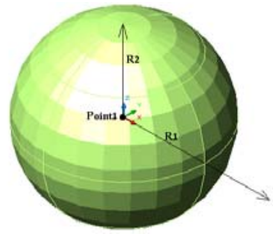

Figure 3.c: Illustrates the ellipsoid parameters definitions

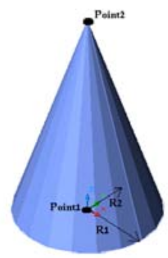

Figure 3.d: Illustrates the cone parameters definitions

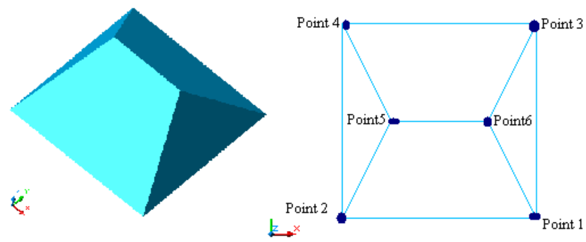

Figure 3.e: Illustrates the two heads pyramid parameters definitions

These solid primitives are represented by the Primitive-Instancing Solid Representation Model. Every complex 3D object may be represented by a combination of the five primitives above. However, tremendous effort could be spent by using the Sweep Representation Model to represent most of the cadastral objects and 3D buildings. For example, a tunnel can be defined by sweeping a normal representative profile, consisting of a 3D polygon, through the central 3D Polyline. Additionally, a 3D cadastre requires the conversion of the 2D parcels to 3D. This issue will be resolved by providing the dimension of volume. The easiest way to give the 2D parcel a volume dimension is by sweeping the 2D parcel polygons vertically.

To sum up, the Sweep Representations Model is a vital model for the 3D Cadastral objects representations and it will be the sixth "primitive" of the proposed CSG model. These six primitives will be combined by means of Boolean and geometrical operators, which are:

- Intersection
- Subtraction
- Union
- Slicing (subtraction of a huge cube from an object)

5. DEVELOPMENT OF ALPHA-NUMERIC DATA FORMAT FOR SAVING THE 3D SPATIAL MEASURED DATA – 3DSRV

The proposed alpha-numeric data format, called 3DSRV, may be one of several of formats that can fulfill the 3D cadastral "intermediate system". The data is saved by number set of files. The "intermediate system" will use the 3DSRV files for:

- Semi-automatic production and automatic representations of the 3D parcel and the 3D sub-parcels of the future 3D cadastre as it is defined by the Israeli R&D "3D-Cadastre" project (Shushani et al, 2003).
- Future conversion to the future 3D GIS format.
- Preparation of the 3D Cadastral data for the 2D GIS system which will manage the 3D Cadastre in cooperation with a 3D CAD software during the intermediate period.
- 3D visualization and 3D City Models executions.
- 3D reparcelation planning map preparing.

The 3DSRV files are designed with the same principle of the 2DSRV files format which served the SOI (Survey of Israel) till now. The 2DSRV files are three files that are required from the licensed surveyor in Israel when he/she submits reparcelation maps for the SOI. These 2DSRV three files are used for converting the data to the 2D GIS software as a SHAPE files.

The 3DSRV includes the three 2DSRV files which are:

- *Points.srv*, which contains all the point definitions in the project, including their coordinates X, Y, H, name and codes.
- *Lines.srv*, which contains all the fronts and the poly-lines definition, as a combination of point names and radius values.
- *Parcels.srv*, which contains all the 2D parcel definitions, as a combination of line names, calculated area and registered area.

With an association of the above three 2DSRV files, the suggested 3DSRV files may include:
- *3DSweepObjPolygons.srv*: Its target is to save all the 3D polygons in the space of the 3D Cadastral project which are used to define the 3D objects by using the Sweeping Representations Model (all objects that are by Sweep called “SweepBody”):

<OBJPOLYGON> <Polygon name begin with OBP> <Point name1, R1> <Point name2, R2>… <Points nameN, RN>;

Tangent line is defined by zero radius value. The last point is combined with first one. All the points will be defined in the Points.srv file.

- *3DSweepPaths.srv*: Its target is to define and save all the 3D paths that are used for building objects by means of Sweep Representations model. The last point is not combined with the first:

<3DSWEEPPATH> <Sweep path name begin with SWP and Number> <Point name1, R1> <Point name2, R2>…<Point nameN>;

The last point does not include radius after it.

- *3DPrimitives.srv:* Its target is to define and save all the primitives that will establish the future 3D cadastral objects:
  - *Cube:*
    Object *Cube (String Point_Name_1,
    String Point_Name_2);
  - *Cylinder:* it has two circle bases.
    Object *Cylinder (String Point_Name_1,
    String Point_Name_2,
    Double R);
  - *Cone:*
    Object *Cone (String Point_Name_1,
    String Point_Name_2,
    Double R);
  - *Sphere:*
    Object *Sphere (String Point_Name_1,
    Double R);
  - *SweepBody:*
    Object *SweepBody (String Polygon_Name_1

String Sweep Path_Name_1); And
Object *SweepBodyH(String Polygon_Name_1,
<+ or -> Height);

– *Two heads Pyramid:*
Object *Pyramid (String Point Name1,
String Point Name 2,
String Point Name 3,
String Point Name 4,
String Point Name 5,
String Point Name 6);

The record line format is:

<3DPRIMITIVE> <Object Class Name as String> <Object Name as string begin by the two first character of its name>\t <Object Definition Order separated by ‘,<space>>;

- *3DObjects.srv*: Its target is to save and define all the Cadastral objects that the surveyor had measured during the cadastral mapping. The objects are defined by describing the Boolean operators between them. Additionally, it contains the volume for every object. The Boolean operators formulas are:

1. A_solid Union B_solid → A_solid **+** B_solid
2. A_solid Intersection B_solid → A_solid ***** B_solid
3. A_solid Subtract B_solid → A **–** B
4. AA_plane Slice A_solid → A_plane **/** A_solid. AA_plane is defined by three points coordinates, y, z in two inverted commas like "x1,y1,z1, x2,y2,z2, x3,y3,z3".

And the file record line is:

<OBJECT> <Object Name as string begin with Ob > <{Set of the Boolean operations using ( ) to specify the order of the operations}> <VOL=><volume in m^3 as double> <CODE1=><Integer 0-255> <CODE2=><Integer 0-255> <Date in xx/yy/zzzz format>;

The codes will be used for defining the building types. These set of Boolean formulas, actually, defined the CSG Boolean tree.

– *3DParcels.srv*: Its main target is to save and define the cadastral 3D parcels and 3D sub-parcels by describing the Boolean formula that builds it. The sub-parcel is called SPARCEL and the parcel is called PARCEL. In this file, the 2D regular parcel will have a volume by sweeping its polygon vertically up to 12000 meter and down to -1000 meter. The name of the 3D Parcel or the 3D Sub-Parcel must match its legal name at the same way described by the R&D “3D Cadastre” project in Israel. The file record line format is:

<3DSPARCEL or 3DPARCEL> <3D Parcel or Sparcel true name> <{Set of the Boolean operations using ( ) to specify the order of the operations}> <VOL=><volume in m^3 as double> <PAREA= projected area on the plane as double> <Hmax=The maximum height> <Hmin= The minimum height><CODE1=><Integer 0-255> <CODE2=><Integer 0-255> <Date in xx/yy/zzzz format>;

By these 3DSRV proposed format, every Geometrical and Cadastral object can be defined successfully including objects with holes beside them.

Regarding to the "intermediate 3D cadastral system", it must have as automatic application for converting the 3DSRV format to 2D GIS format, by producing the projection of all the 3D data to the plane.

6. AN ALGORITHM FOR PRODUCING THE 3D SUB-PARCEL

One of the main tasks of the "intermediate system" is to produce the 3D sub-parcels and 3D parcel. The proposed algorithm relies on the 3DSRV that exists in the SOI by the Parcels.srv file. The output of the algorithm is the 3DParcels.srv (see figure 4).

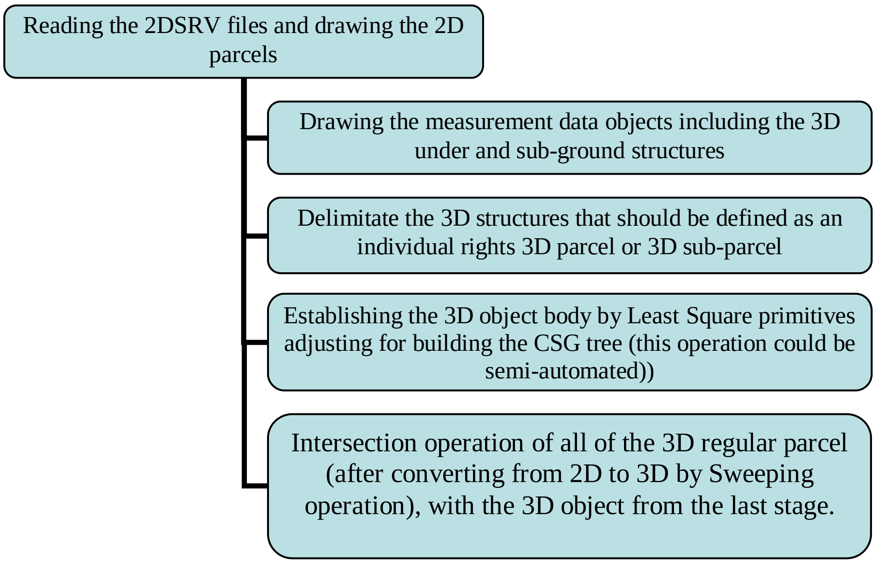

Figure 4: Algorithm description for producing the 3D Sub-Parcels

7. AN EXPERIMENT OF SYNTHETIC DATA

To demonstrate the 3DSRV files, a tunnel has been designed for sub-way train with a underground station. The tunnel was designed under existed buildings in a part of Block Num 16535, in Israel. Figure 5 illustrates the tunnel design under a cadastre map of the specific part of the block.

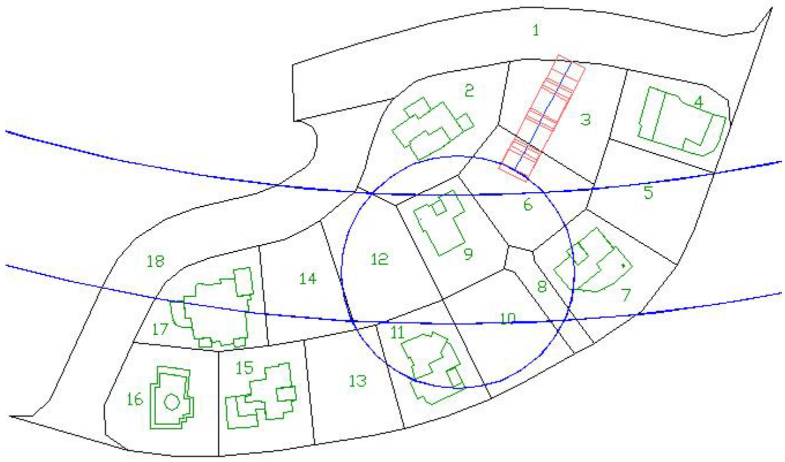

Figure 5: A cadastral map that illustrates the tunnel design under the cadastral 2D parcel in Block Number 16353 in Israel

Some sections of the 3DSRV format files are:

Points.srv

POINT P1	225080.573	736211.121	C=99	S=99	M=99	H=79.50;
POINT P2	225247.552	736155.541	C=99	S=99	M=99	H=79.50;
POINT P3	225421.842	736179.907	C=99	S=99	M=99	H=79.50;
POINT P4	225279.306	736154.832	C=98	S=98	M=98	H=100.00;
POINT P5	225276.243	736160.759	C=98	S=98	M=98	H=100.00;
POINT P6	225275.737	736160.531	C=98	S=98	M=98	H=100.00;

…

3DSweepPaths.srv

3DSWEEPPATH SWP1 P1,385.793 P2,385.793 P3;

Spatial path SWP1 is describing the central axis of the tunnel.

3DObjPolygons.srv

OBJPOLYGON OBP1 P4,0.00 P5,00 P6,0.00 P7.0.00 P8,0.00 P9,0.00 P10,0.00 P11,0.00 P12,0.00 P13,0.00 P14,0.00 P15,0.00 P16,0.00 P17,0.00 P18,0.00;
OBJPOLYGON OBP2 P10,0.00 P11,00 P12,0.00 P13,0.00;
OBJPOLYGON OBP3 P21,0.00 P22,00 P23,0.00 P24,0.00;
…

For example, OBP3 is a 3D polygon that describes the adjusted profile of the tunnel delimited object. OBP1 and OBP2 are two 3D polygons that are used for establishing the house located on parcel 9.

3DPrimitives.srv

3DPRIMITIVE CYLINDER Cy1 P19, P20, 27.08;
3DPRIMITIVE SWEEPBODYH Sw1 OBP1,+4.5;
3DPRIMITIVE SWEEPBODYH Sw2 OBP2,+6.5;
3DPRIMITIVE SWEEPBODY Sw3 OBP3,SWP1;
...

For example, Sw1 and Sw2 are the two Sweeped object bodies that build the house located on parcel number 9 (see figure 5 and 6).

3DObjects.srv

3DOBJECT	Ob1	{Cy1+Sw3}	VOL=89956.473	CODE1=25	CODE2=0	12/10/2003;
3DOBJECT	Ob2	{Sw1+Sw2}	VOL=468.950	CODE1=12	CODE2=0	12/10/2003;

...

Comments :CODE1=25 Public Train Tunnel CODE1=12 Private Building

Object named Ob1 describes the tunnel and the station together. Ob2 desribes the house located on parcel number 9.

3DParcels.srv

...

3DSPARCEL	16533/12/-/1/12	{(T12 * Ob1)}	VOL=6545.928	PAREA= 495.740	Hmax=92.00
		Hmin=79.00	CODE1=15	CODE2=11	23/10/2003;
3DSPARCEL	16533/13/-/1/13	{(T13 * Ob1)}	VOL=210.661	PAREA= 22.372	Hmax=92.00
		Hmin=84.00	CODE1=15	CODE2=11	23/10/2003;

...

The 3D model of the part of Block 16535 is demonstrated by Figure 6.

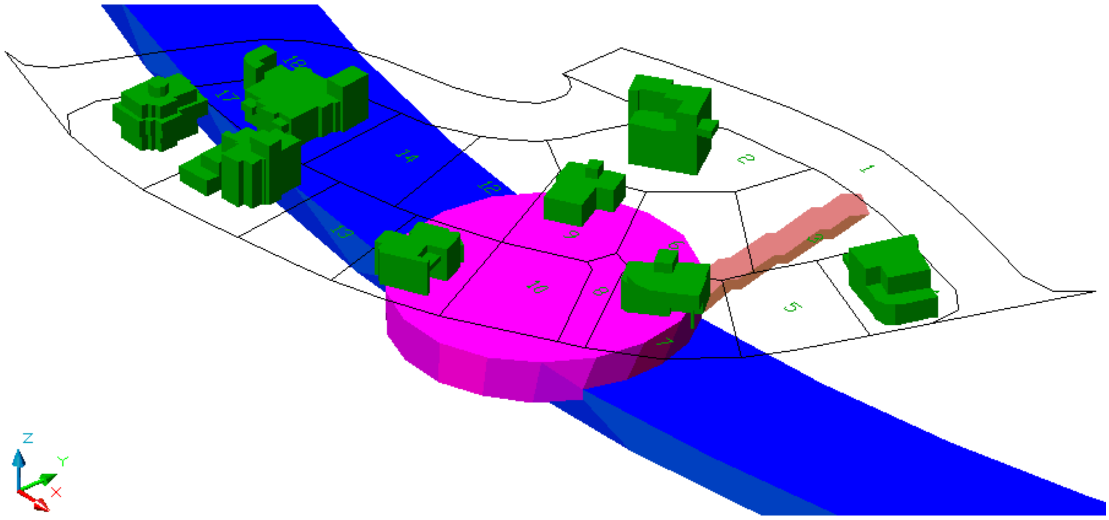

Figure 6: The 3D model of the part of Block 16535

In the file 3Dparcels.src the two 3D sub-parcels are parcel number 12 and 13 (see figures 6 and 5). By using the AutoCAD2002 software which enables Boolean operators, the two 3D sub-parcels could be separated and represented alone (see figure 7). All the sub-parcels that have been produced by intersecting the 3D regular parcel with the tunnel and the station objects may be united together in order to produce the main 3D parcel of the tunnel. The names of the 3D sub-parcels have been taken from the R&D "3D Cadastre" project solution.

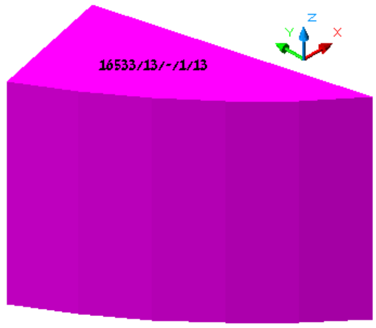

Figure 7.b: 3D sub-parcel of 2D parcel 13

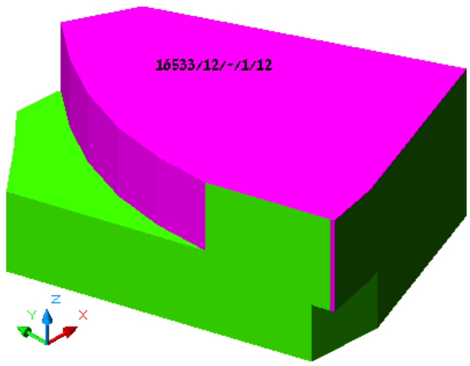

Figure 7.b: 3D sub-parcel of 2D parcel 12

8. CONCLUSION

It could be noticed from the synthetic experimentation that the proposed 3DSRV file format fulfills the requirements of the R7D "3D Cadastre" solution. The proposed 3D visualization model's main advantage is its simplicity. Every surveyor can read and produce them easily. The ability to convert the proposed format to any b-reps model indeed exists,, enabling future conversion to the 3D GIS format.
Figure 6 is an obvious example for producing 3D City Models, which is one of the tasks required from the "Intermediate 3d Cadastral System".
Using the AutoCAD for building Figures 5 and 6 proves its easy implementation. This importance characteristic comes from the fact that every surveyor has CAD software.
In addition, today an AutoCAD 2002 macro is being developed by using Visual Basic for Application (VBA), to imitate the way the "Intermediate 3D Cadastral System" works.

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BIOGRAPHICAL NOTES

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