The Applications and Practices of 3D Cadastre in Shenzhen

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Key words: 3D Cadastre; 3D Cadastral Administrative System; 3D Cadastral Database; 2/3 Dimensional Cadastral Integration; Practical Applications

SUMMARY

As the economy and urbanization develop, the expansion of the city not only develops towards the horizontal space, but also towards the vertical space. Facing the development of three-dimensional (3D) space, the traditional two-dimensional (2D) cadastral management mode cannot satisfy the need of current 3D land use and urban plan, so developing a 3D cadastral management mode is very imperative. In 2012, Shenzhen city of China puts forward a 3D cadastral management prototype to meet the requirements of 3D land use. After two years' developments, the focus of 3D cadastre in Shenzhen moves from research and prototypes toward the implementations and the uses of practical systems Shenzhen forms a special model for 3D cadastral administration up to now, based on the needs of businesses for 3D land planning and use.

In this paper, business workflow and legal supports are introduced firstly as they offer the explicit direction for development of 3D cadastral administrative system. Then, 3D cadastral data and modules of 3D cadastral system are discussed. Based on current business requirements and 3D technology, the 3D cadastral administrative system includes three modules: 3D data generation module, 3D query-platform and 3D mapping module, and all these modules are built based on the 3D land and planning database. Besides, the cadastral system integrates 3D land planning and management with a 2D environment. This 3D/2D land administration system is deployed in the office automation system for routine management.

Finally, this paper introduces the practical applications of the cadastral administrative system in Shenzhen. Up to now, the system has been carried into practice for more than one year. Several 3D land cases have been granted in 3D method, particularly the title certificates are attached with 3D certificates. Although the 3D cadastral administrative system has made great progress in practical applications, it still faces many difficulties and challenges, such as 3D data integrity and more elaborate legal supports.

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1. INTRODUCTION

As the economy and urbanization develop, the conflict between limited land resources and huge development demand is very serious (Guo, 2011). As a result, the expansion of the city not only develops towards the outer space, but also towards the vertical space. However, facing the development of three-dimensional (3D) space, the traditional two-dimensional (2D) cadastral management mode cannot satisfy the need of contemporary 3D land use and urban planning, so developing a 3D cadastral management mode is very imperative.

In 2012, Shenzhen city of China puts forward a 3D cadastral management prototype (Ying, et al 2011) to meet the requirements of 3D land use (Van Oosterom, 2013). As a first attempt in China, the 3D cadastral system focuses in academic and technical research, including geometry of 3D property objects, compatible 3D data models, generating 3D model data and 3D topologies (Guo et al, 2013). After two years' developments, the focus of 3D Cadastre in Shenzhen moves from research and prototypes toward the implementations and the uses of practical systems. Shenzhen forms a special model for 3D cadastral administration up to now, based on the needs of businesses for 3D land planning and 3D land use.

2. BUSINESS WORKFLOW AND LEGAL SUPPORT IN 3D CADASTRE

Similar to the traditional 2D cadastral business, the 3D business workflow divides into three steps: project preliminary, project design and project construction. According to "City Planning Law of the People's Republic of China", when applying for the use of land for a construction project in an urban area, the unit or individual undertaking construction must get the approval and license from the department of land administration, in the planning, designing and construction phase. 3D administrative workflow and phases are illustrated in Figure 1.

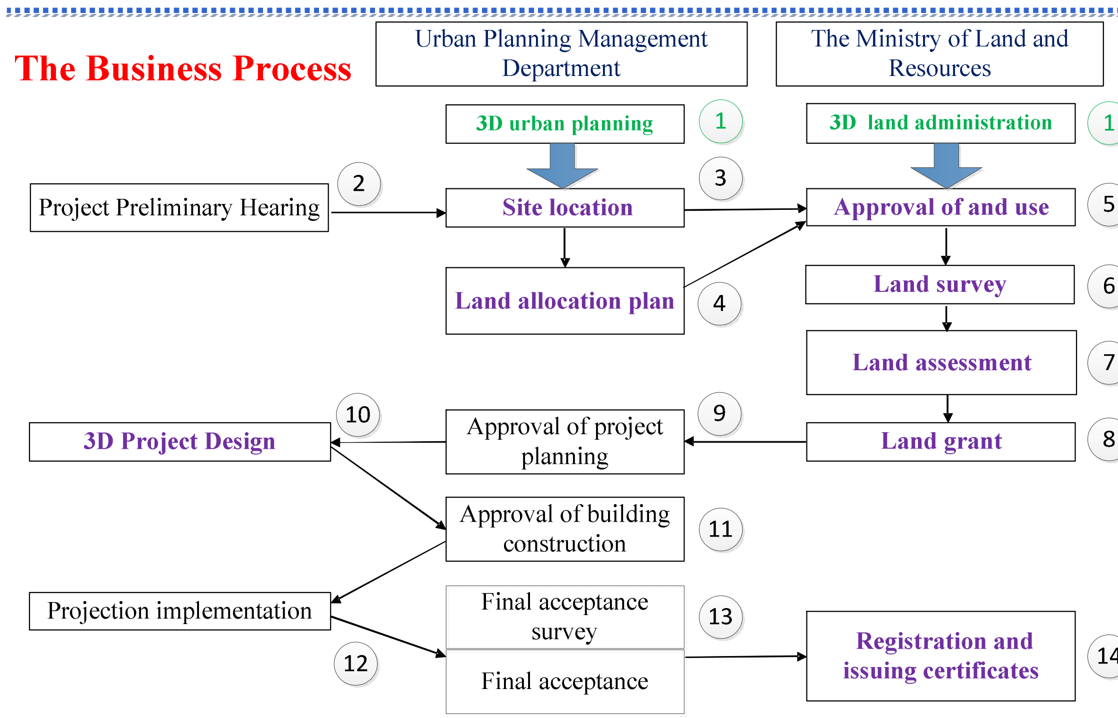

Figure 1. The administrative workflow

In the planning phase, 3D plan scheme and redline are two important modules. 3D plan scheme refers to selecting the rough site from the planning department while 3D redline will further design the spatial shape and other property information. After registered and constructed, the parcel's certification will be issued to the holder.

Besides the progress of technical aspects in practice and the clarity of the business process, the relevant laws and regulations are further amended to support 3D cadastre. Legislation is a foundation of 3D property. Without proper legislation, 3D properties cannot be formed (Jenny et al, 2013). Legislation is a significant issue of 3D cadastre and many researchers stress in this domain (Dimopoulou, 2013 and Gerhard, 2013). A joint registration mechanism for land and house properties has been made available for practice in China. This unified registration mechanism (hereinafter referred to as the joint registration) is proposed all over the country according to the "Registration Regulations Of Real Estates in Shenzhen Special Economic Zone" and "The Law of the People's Republic of China on Urban Real Estate Administration (2007Amendment)". What's more, the workgroup protocols the mapping specification of 3D property rights in Shenzhen and revises the "Contract for State-Owned Construction Land Use Right Assignment".

3. 3D CADASTRAL DATABASE

3D cadastral database is the foundation for 3D cadastral administrative system, which offers an interface for 3D data reading/writing and spatial analysis. It has three parts: spatial database, attribute database and historical database. The spatial database stores the spatial data of topology and geometry; the attribute database is extracted from the 2D cadastral database, which means the attributes data are shared from the 2D attribute database; the historical database stores the historical data in order to improve the robustness of the system.

3.1 Spatial database

In the 3D cadastral prototype, the spatial data are just stored in five topological data tables. This is insufficient in the system of B/S mode. While interacting with the database, the low efficiency will cost much time, such as 3D mapping module, the data read speed causes the server responds slowly. Therefore we adjust the data structure in the spatial database. The new data storage structure is shown in Figure 2.

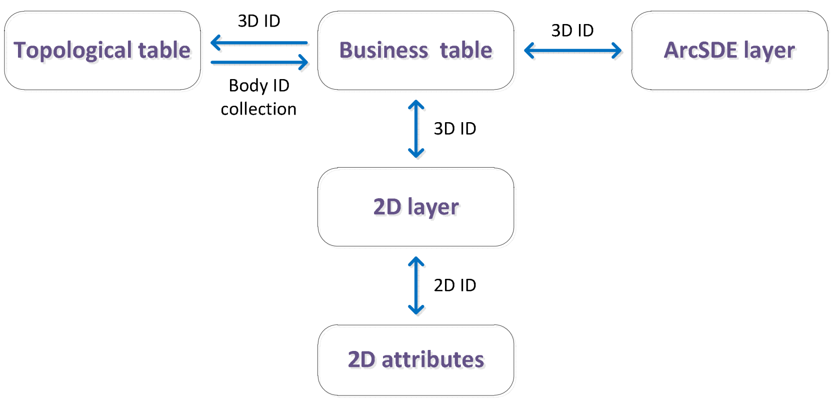

Figure 2. Relations between tables in 3D and 2D database

The business type includes: parcel, plan scheme and redline. Every business type corresponds to three kinds of data table. The data tables are linked with each other by primary key (3D identifier). Topological tables store 3D topological data, supporting for 3D topological query and spatial analysis. Business tables store 3D spatial data and specific 3D attribute data. ArcSDE layers store the "2.5" dimensional (2.5D) data and true 3D data, supporting for visualization in 3D platform. As the figure 2 shows, the tables in 3D database are linked by primary key "3D ID". Besides, when a parcel generated, its 2D project polygon will be saved in the 2D layer so that in the geometric level the 3D database and 2D database are interrelated.

Topological tables: store not only topological relations between 3D parcels but also store the geometric information. It consists of five tables, two of which describe topological relations and the others describe geometric information. 3D cadastral topological model (Guo et.al., 2012) is a hierarchical topologic organization model. That is, body consists of faces, surface consists of edges and edge consists of two nodes. The higher dimensional primitive is bounded by lower dimensional primitives.

Business tables: store the geometric and specific 3D attributes (such as volume and surface area). In order to improve the efficiency of data exchanging with the server, the business table saves the geometric information in a CLOB type. Different from the geometric information in topological tables, the geometric information of the parcel is saved in a field while in topological tables is saved separately in three tables (node table, face table and body table).
ArcSDE layers: polygon layer stores 2.5D data and multipatch layer stores 3D data. 2.5D data means the parcels generated by extrusion so that their geometric shapes are regular. They can be represented by a horizontal polygon and the altitude of the lowest face and highest face. In the irregular cases, particularly the solid with concaves or holes, the parcels are represented by a set of 3D polygons in multipatch layer.

3.2 Attribute database

The 3D database and 2D database share the common attribute data as it can reduce data redundancy. Before the 3D cadastral system developed, the 3D parcels were managed as 2D parcels so the attribute data were stored in the 2D database. According to the business workflow and regulations in 3D Cadastre, when newly creating a 3D parcel, the general attributes are saved in 2D database and the specific 3D attributes saved in 3D business tables. When the server needs to visit the usual attributes, the service will request the 2D database through the 3D identifier.

3.3 Historical database

In the parcel's life cycle, it often occurs that two parcels or more are merged into a new parcel or one parcel is divided into several parcels. In these cases, the record of the original parcel will be kept in the historical database. The advantage of maintaining the relationship between older parcels and the new ones is we can understand the change information during the parcel's life cycle and improve the robustness of the system.

4. 3D CADASTRAL MODULES

Based on current business requirements and 3D technology, the 3D cadastral administrative system includes three modules: 3D data generation module, 3D query-platform and 3D mapping module, and all these modules are built based on the 3D land and planning database. Figure 3 describes the relations between the modules and 3D database.

4.1 Generating 3D data

In the 3D cadastral system, data generating module is a significant module as it is the basis of all 3D cadastral data. This module creates 3D spatial data with the manner of manual input, data input and interactive configuration via editing or operations with visualization. It is noted that there are two types of generating 3D data: one is generating regular 3D solids with the B/S mode and the other is generating irregular 3D solids with B/S+C/S mixed mode.

4.1.1 <u>Generating regular 3D data with B/S mode</u>

Regular 3D data are the ones which can be generated by extrusion. Therefore, all the faces bounding the solid are either horizontal or vertical. So the solid can be represented by a horizontal polygon, altitude of the bottom face and the altitude of the top face. In other words, we adopt the method of reducing dimensions in the regular 3D data cases.

One advantage of this method is that it is easy to operate, no matter the parcel is constituted of a single solid or multicomponents. Users just need to upload the data source (txt, dwg et.at). The parcel will be produced automatically and displayed in the 3D scene. Regardless of the fact that it is quite efficient, the parcel can't be edited after generated.

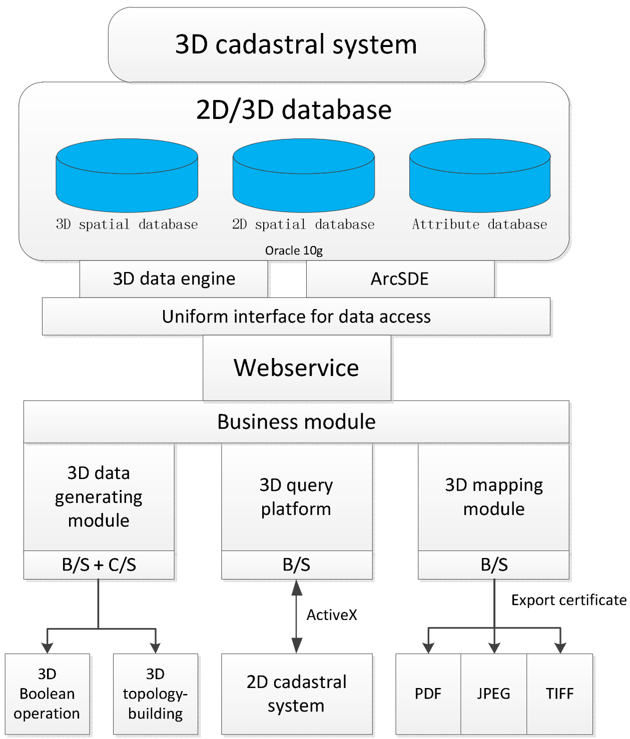

Figure 3. 3D cadastral system framework

4.1.2 Generating irregular 3D data with B/S+C/S mixed mode

Irregular data are more complex than the regular data. In the practical cadastral data, solids usually have concaves or holes, such as an air outlet and a subway entrance in underground space. In those cases, the extrusion method can't handle the irregular cases. As a consequence, we adopt the B/S+C/S mixed mode. B/S mode offers an interface for interacting with database and visualization toolkit while C/S mode offers Boolean operation module to generate irregular solid and detection module to do conflicts detection.

The B/S module is implemented similarly to the regular data generation module. The differences that the 3D parcel is not generated directly in the web but in the SketchUp desktop client. The web client is embedded in SketchUp and interacts with SketchUp through Ruby scripts and web services. The workflow in SketchUp is illustrated in Figure 4.

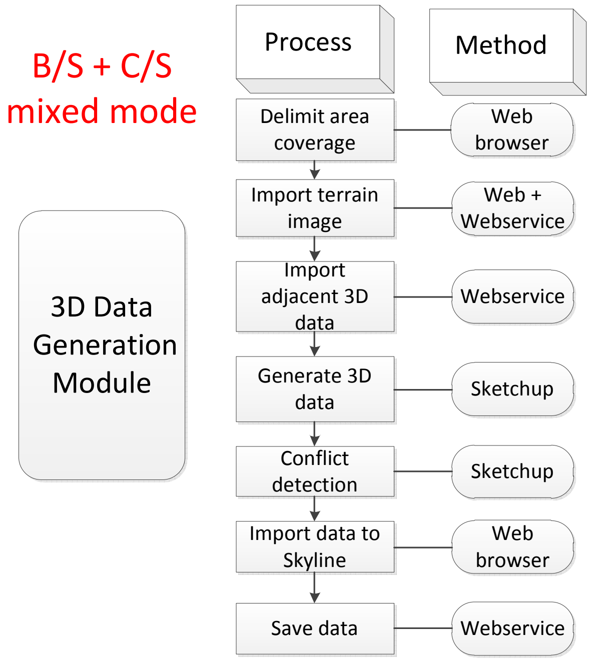

Figure 4. Irregular 3D data generation process

Boolean operation is the core function of this module, which includes intersect, union, subtract, trim and split. All the irregular 3D data can be generated through a Boolean operation. The concaves and holes can be implemented through the subtract operation and the union operation merge multicomponents into the integral 3D parcel. Besides, intersect operation helps checking whether the 3D parcel has conflicts with the adjacent parcels. The Boolean operation in SketchUp is illustrated in Figure 5.

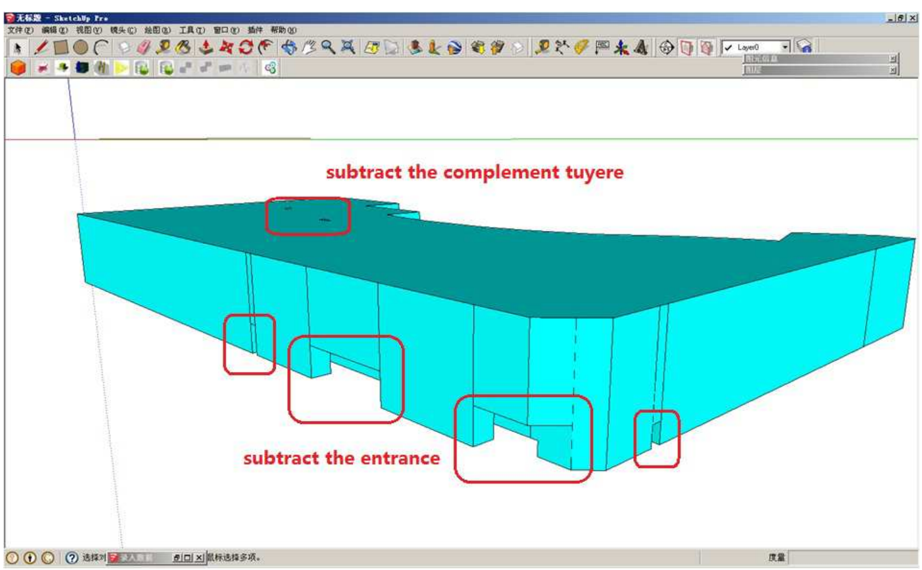

Figure 5. Boolean operation cases in SketchUp

After the 3D parcel generated, no matter it is regular data or irregular data, the data need to be built on topological relations before stored into the database. Building topology divides into two steps: building the parcel own topological relations and building topological relations with adjacent parcels. The process (He, 2011 and Li, 2012) can be summarized in the following steps:

(1) merge points in the set tolerance to ensure the data correct and consistent;
(2) remove the redundant geometric primitives(node, edge and face), making the same primitives unique;
(3) make use of the algorithms of computational geometry to do edge intersection and face intersection, then exploding the common primitive and recording the relations of the new elements and the old ones;
(4) update the topological relations using the new elements.

4.2 3D query platform

Along with the integration of 2D and 3D cadastral system in the B/S mode, the 3D query platform and 2D platform are in a unified framework. The two platforms are linked as they interact with each other via ActiveX technique. As a result, one could respond automatically when the user operates in another one. The integral interface is illustrated in Figure 6.

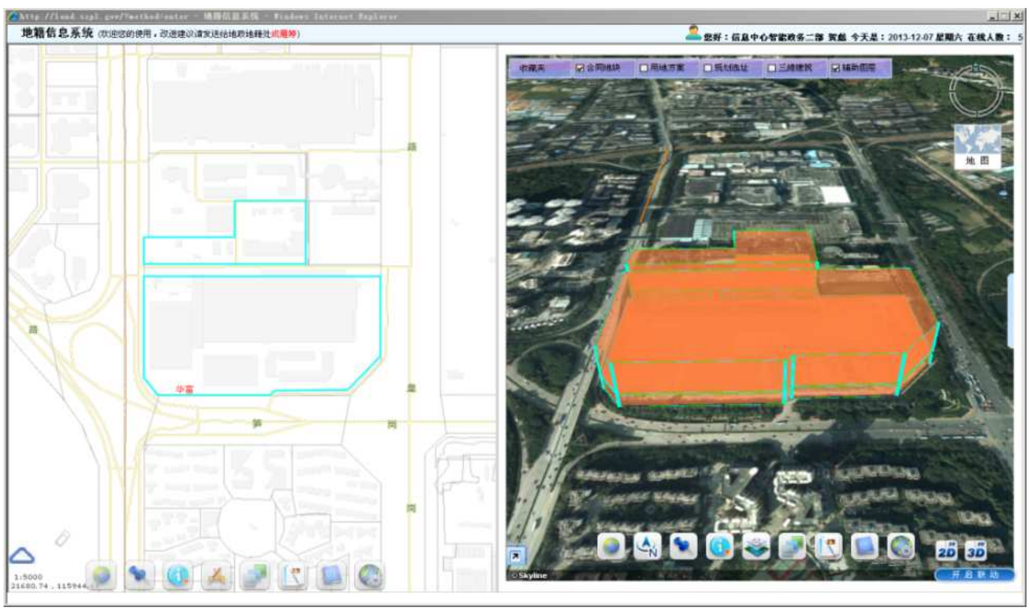

Figure 6. The integral interface of 3D and 2D platform

Skyline TerraExplorer is the 3D visual tool of this platform that visualizes the 3D scene. The 3D scene includes 3D cadastral data (regular and irregular cases), 3D buildings and city environment auxiliary elements. Particularly, urban simulation models improve the stereoscopic impression. The functions in the platform are tightly combined with the cadastral business, including loading various cadastral data, information query, topological query and verification analysis (Figure 7). Taking the cadastral verification function as an example, it helps checking the relations between the target parcel and the adjacent elements.

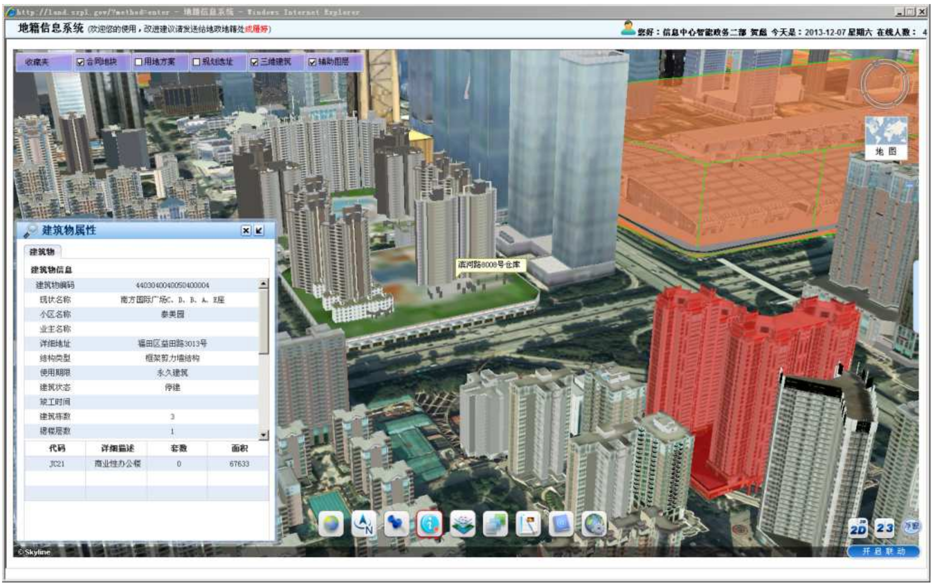

Figure 7. Query in 3D scene

4.3 3D certificate

Yu (2011) indicates that 3D certificate is similar to 2D certificate, used to safeguard the legal rights of the holder and issued by the related land administrative department. Further, it can describe the spatial shape and related information about property rights. Since 2010, more and more construction lands are granted as 3D cases, and some of their land-grant contracts are attached with a 3D certificate.

In the prototype, the 3D certificate function is an independent module and it can only export parcel map in JPEG format. On the basis of business need, we redesign the certificate module in the B/S mode. Firstly, the certificate module is incorporated into the query-platform. As 3D platform and 2D platform are in the unified framework, users can operate fluently no matter exporting 3D certificate or 2D certificate. Secondly, the module supports exporting 3D certificates of various formats (such as PDF, JPEG and TIFF), depending on relevant laws and regulations. After generated, the server offers a package of corresponding map and a list of boundary points (Excel file) to be downloaded. Thirdly, the module needs to be able to export more than just the parcel map. Exporting map for planning scheme and redline is also contained in the module, although the templates are not finally determined. At last, we adjust the parcel map and auxiliary map based on the feedback from the users.

In the 3D parcel certificate, we design two templates for 3D cases. One is the primary certificate which shows the parcel from the 3D perspective view and the boundary points' information. The other one is the auxiliary certificate consists of three projecting maps and one 2D location map. Additionally, we design one template for planning scheme and one for redline. Following are the certificates in Figure 8.

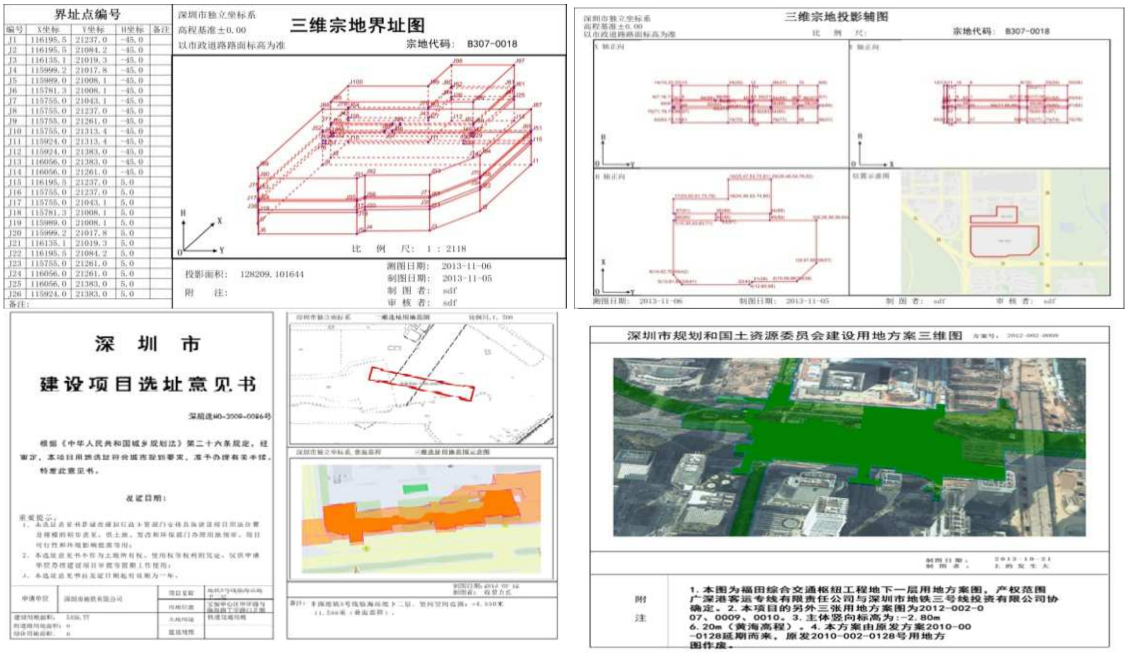

Figure 8. 3D certificates: the upper two are parcel maps and the under two are site location and land allocation plan

5. PRATICAL APPLICATION COMBINED WITH CADASTRAL BUSINESS

Since 2012, the workgroup has worked on the 3D cadastral data, either restored from the 2D database or the newly added ones. So far we create 318 cases in site location, 419 cases in land allocation plan and 91 cases in parcel. Because of nonstandard administration in 3D cadastral data in the past, there is a lot of information lost whose real property space cannot be restored, including 320 cases in site location, 174 cases in land allocation plan and 106 cases in the parcel. Besides, as a result of the disjunction of business, many underground cases have developed the business in site location or land allocation plan, but the parcel business doesn't have a corresponding record. Table 1 indicates the state of the current 3D cadastral data.

Table 1 current 3D cadastral data

Business Type	number	Number of increased cases from 2012
Parcel	197	91
Land allocation plan	650	419
Site location	805	318

In the generating data business, there were few 3D cases in the past, so the special cases were generated by the traditional 2D method. The 2D method describes 3D cases using planar project polygon and remark in the texts, as Figure 9 shows. And there isn't a standard to describe the spatial information so that usually the spatial description is very curt. As a result, some 3D cases cannot be restored. What's more, it would lead to difficulties in other business, such as verification and mapping.

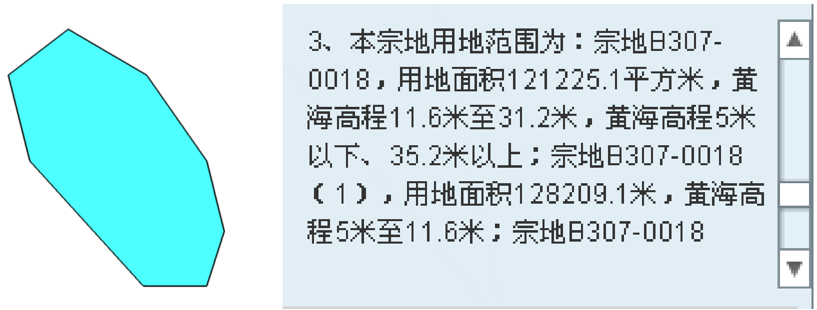

Figure 9. Project polygon and remark describing elevation

As the underground rail transits and other facilities attached to them develop, the 2D method cannot handle the growing 3D cases. According to the statistic 3D cadastral data in the preceding paragraph, we generate all 3D data in 3D method, as section 4.1 indicates.

Verification business is the core business of the land administrative department. The accuracy and clarity of verification can ensure that the granting land is complete and unique. Further, its elaboration guarantees scientific and reasonable development and construction of land space. Current 2D verification is mature and practical in cadastral administration, both in the aspects of technique and data integrity. While 3D verification still faces many difficulties and challenges, the biggest one is the 3D data integrity, as there is a lack of various kinds of data, such as underground pipeline data, microwave channel, limit height of airport and high-voltage power lines. Therefore, current 3D verification mainly concentrates on the verification between land and land. In the future, we will hope more data can be incorporated into the verification business.

As section2 indicates, in the planning phase and after the construction phase, the unit or individual will be issued a permit. In 3D cases, the permit is attached with a 3D certificate according to its type. Taking the parcel as an example, after registered and constructed, the certificate of title issued by the land administrative department contains the main picture, auxiliary picture and a list of boundary points. In 2014, the new parcel “T201-0078” is generated directly in 3D method and issued the contract of granting land with a 3D title certificate.

6. CONCLUSIONS

This paper elaborately introduces the development of 3D Cadastre in Shenzhen. On the basis of a prototype in 2012, the workgroup has been working on practical applications of 3D cadastre combining with the business. Database and function models described above are in close combination with the cadastral business workflow. And the 3D cadastral administration system is seamlessly integrated with 2D cadastral system.

Up to now, the 3D cadastral system has been carried into practice for a year. The land administrative department has already granted land in 3D method directly. Particularly, there are some new cases issued 3D title certificates when granted. The practical application pushes the system to develop and help handling difficult 3D cases. Although there are some advances, the 3D cadastral administrative still faces many difficulties and challenges, such as the supported laws and regulations, the complete 3D data organization.

In future, how to improve the practicability and convenience is the strategic research direction of 3D cadastre. It is hoped that what have been discussed in this paper could provide some references for the design and practical application of 3D Cadastre in other cases.

ACKNOWLEDGMENT

The work was supported by the National Natural Science Foundation of China under grant number 41371369.

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BIOGRAPHICAL NOTES

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