3D Cadastre in China - a Case Study in Shenzhen City

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Key words: Land Administration, Land Use, Cadastre, Three Dimensions

SUMMARY

A rapid urban growth in China urges to extend land use to land space use in three dimensions due to limited land resource in cities. 3D cadastre is emerging as an effective means to support such a demands for using urban land in a way of three dimensions. Shenzhen, located in the south-eastern coastal region of China, as one of the most economically developed cities in China, has experienced a sustainably rapid economic growth and demands more urban space and more precise management of rights of land and property in order to meet such a fast development in social and economic reform. The typical land space use in Shenzhen includes underground parking lots and commercial streets and over-ground arching buildings where their surface parcels have a different ownership or are used by other parties. The vertical heterogeneity of land rights challenges the capacity of parcel-based cadastre systems in description of spatial nature of land space and of the rights pertaining to the land space. Management of the three-dimension urban land space adds some complexity to the current convention of land administration, which requires some change in the procedures of land administration such as land planning, cadastre surveying and land registration. The practice of a 3D cadastre in Shenzhen shows a good example of effectively managing limited urban land resource and accumulates a lot of available technology and experience for introducing 3D cadastre in land administrations.

In this paper, a brief introduction about Shenzhen city is given regarding to land use and economic growth, which account for emerging vertical use of urban land. Such a vertical use of land space raised some problems in the current parcel-based management of urban land use, which is shown by a few of examples of use of land space above- or under-ground. Those examples indicate the necessity of applying 3D cadastres in urban land administrations. As a cadastre is associated with social and administrative issues, the current context regarding to legislation and administration for applying 3D cadastre in Shenzhen is outlined. The practice of a 3D cadastre in Shenzhen is briefly described in terms of technology such as basic hypotheses, data model and 3D data generating. A real case of applying the 3D cadastre is introduced and shows the functions of the 3D cadastre system in representation of spatial extent of a 3D property. Our practice shows that there is some gap in the current administrative procedures when installing a 3D cadastre on the one hand, but an effective 3D cadastre technology also provides a good means to bridge the gap on the other hand.

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1. INTRODUCTION

China economy has achieved a world-known success to which rapid urbanizations have made the major contribution. In the process, land resource has played one of the key roles in supporting such a rapid urban development. As a developing country with a big population, China steadily needs a rapid development in economy in order to reduce poverty because there are still about 90 millions people under the poverty-line(annually income under 1500RMB, equivalently about US$234, according to China current living standard) [1]. However, the conflict between urban growth and limited land resource has been emerging increasingly and the pattern of urban development in the form of the current urban sprawl cannot sustainably afford for such an development. Land use patterns and land use changes are considered critical for promoting sustainable development in developing countries,(Foley et al., 2005; Tilman et al., 2001; Turner et al., 2007).

Managing urban growth in continuously rapid urbanizations in China has become the critical issue for land use policy. During the period 1978–2009 China had an average urban growth ratio of 0.93 percent per annum and by the end of 2009 China's overall urban population had reached 622 million(Zhao, 2011). To meet a challenge of the rapid urban growth in China, some developed cities such as Shanghai, Guangzhou and Shenzhen urges to extend urban land use to land space use in three dimensions due to limited land resource in such cities. Although those cities started their practices of using land space vertically, supporting such a change in land use is presently a traditional cadastre technology which has shown its deficiency in management of 3D properties and thus a 3D cadastre is emerging as an effective means to support this kind of managing the use of land space in three dimensions(Agdas and Stubkjær, 2011; Benhamu and Doytsher, 2003; Chong, 2006; Choon et al., 2010; Doner et al., 2010; Hassan et al., 2008; Stoter, 2004; Guo and Ying, 2010). Actually, use of land space becomes possible in a city depending on two prerequisites: urban land being very precious and the city being able to afford such a development of land space. Both would been finally attributed to developing level of the city in economy.

Shenzhen, located in the south-eastern coastal region of China(Figure 1) and adjacent to Hong Kong, as one of the most economically developed cities in China, has experienced a steadily rapid economic growth and urbanization. According to Shenzhen Statistic Yearbook in 2010, Its total population is now about 8.9 millions, and its land area is abut 1, 991 square km covering 6 districts (now 8 districts). The GDP in Shenzhen has increased by 3.75 times that in 2000, reaching 8,200 billions Yuan (RMB, US$1,281 billions) in 2009. The proportion of

[1] http://www.chinanews.com/gn/2011/03-31/2941996.shtml

Primary Industry in GDP decreased as less than 0.1% from 0.7% in 2000 whereas the proportion was 37% of GDP in 1979 when Shenzhen was established. The GDP per capita reaches 92,772 Yuan (US$14,495), the highest level among the all cities in China, and 4.3 times the national average. With such a rapid development, urban area (construction acreage) has sprawled greatly. But the core urban area including 4 districts(Futian, Luohu, Nanshan, Yantian) which compose Shenzhen Special Economic Zone, increased its construction acreage by 64% between 1990-2000 and only about 8% between 2000-2010. The outskirt including 2 districts(Baoan, Longgang) became the major contribution of the increased construction area of the city during 2000-2010. Figure 2 shows the pattern of change of construction area during 1990-2010 and Figure 3 shows the land use in 2010, which indicate very limited urban land resource in the core urban area.

Figure 1. Location of Shenzhen in China

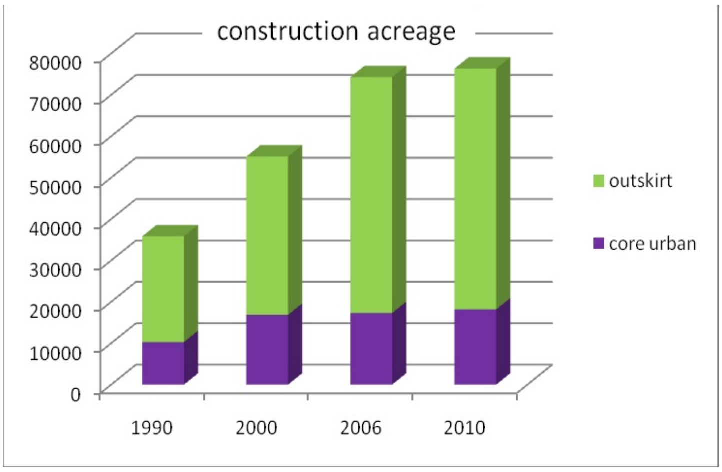


Figure 2. Construction acreage during 1990-2010

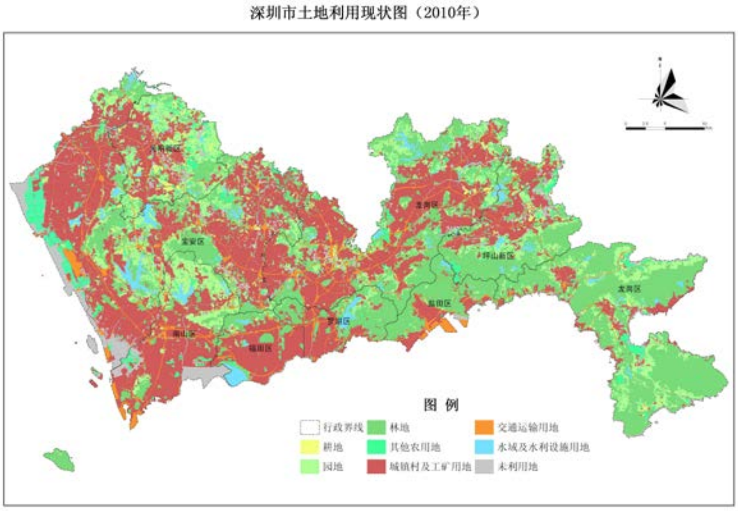


Figure 3. The Land use in 2010

2. DEMAND FOR 3D CADASTRE IN SHENZHEN CITY

2.1 Examples of land space use

When a rapidly economic growth of a city confronts limited land resource, more precise administration of land resource and extending land using form a plane to a space become a necessary and available means to sustain a fast-development pattern during its social and economic evolution. With this logical necessity is a more precise management of rights of land and property. The typical land use in three dimensions or termed 'land space use' here in Shenzhen includes underground parking lots, commercial streets, over-ground arching buildings and so on where their surface parcels have different ownerships or are used by other parties. A management of adjacent properties in three dimensions requires a clear and explicit description of their spatial extent, otherwise conflicts in rights and interests will arise. A few examples show the demand for a 3D cadastre in land administration.

(1) Fengshengding (bazaar)

Fengshengding is a special commercial street (bazaar) under the main avenue-'Shennan Boulevard' in Shenzhen city. There is a need for a bazaar for intensifying retails in this area where no any land on the ground is available to build a bazaar. Instead, this overall bazaar is designed under the main avenue for two layers and its total built area is about 24km^2. Each layer can accommodate a lot of small stores along its pavement within such the construction. Figure 4 shows its land parcels on the 2D cadastre map and Figure 5 shows the use of land space under the ground. A part of profile is pictured in Figure 6. The roof and floor have no explicit height at the phase of planning. The parcels designated for the construction of the bazaar actually also cover a part of underground space used for a subway. That is that there are at least three layers of land space uses within the parcels. A parcel-based description fails to provide a clear description of spatial extent of land space rights pertaining to those constructions.

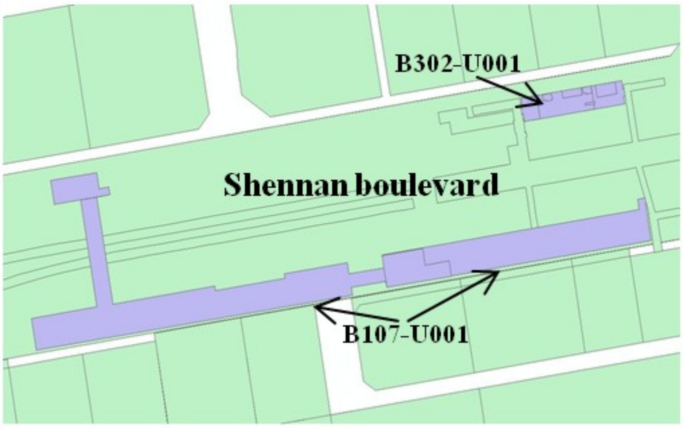


Figure 4. The cadastral map

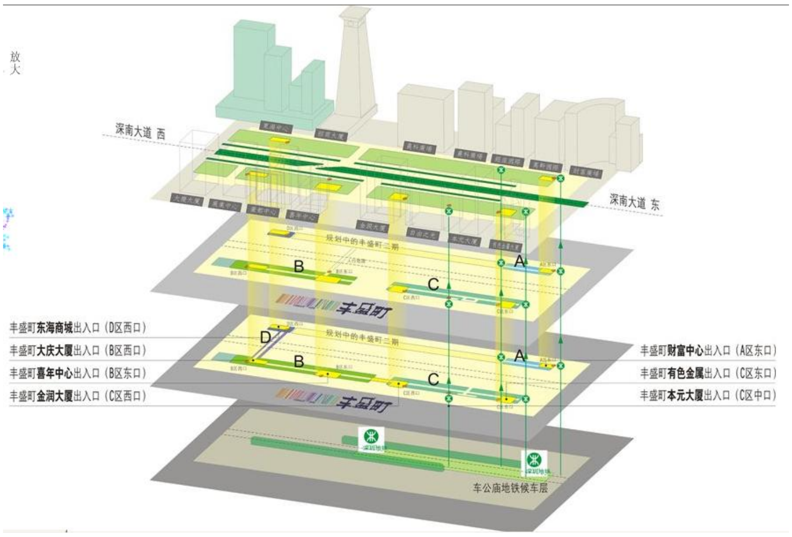


Figure 5. A multi-layer of land space use

Figure 6. An image of the bazaar

It is also worthy noting the vague description of the spatial extent of the construction at the phase of planning and approval. The text 'this construction is mainly built for two layers but some part of it is allowed for three layers ' is filed and 'some part' has no clear spatial extent depending on the developer who uses this chunk of land space. Such a description leaves the developer a great variety of constructing the bazaar/street, which may raise a risk of encroaching others' rights of land use. For example, if an underground pipeline (utility) is under the construction soon, the developer is likely not to know where the pipeline is going. In this case, some spatial conflict may occur and it is not easy to mediate the case because there is no cutting line to justify who use this space rightly. It couldn't find the risk of spatial conflict in the current parcel-based cadastre system.

(2) Tanglangshan

Tanglangshan is an example of multi-using land space above the surface, where the construction on the ground is a subway station and above the subway station is a group of commercial residential mansions (Figure 7). The station is owned by the subway company and mansions consist of many apartments which are owned by different people. This is an example of intensively using land resource on the ground. The construction is integratedly built for different uses: transportation and residence but has a clear separation in vertical direction. The roof of the station is about 16m form the ground in height below which land space is utilized by the subway services and the mansions protrude from the station (Figure 8). This case provides a good model for different land use above the surface (Figure 9). However, managing such vertically different land uses on the same parcel is out of the scope of parcel-based cadastres and may lead to incorrect results when retrieval of land use data from the system.

Figure 7. Overall image of construction of Tanglangshan

Figure 8. A vertical dividing of the construction

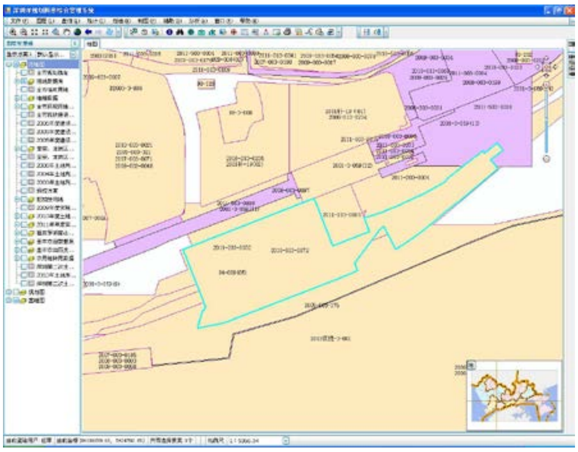


Figure 9. Two developing proposals on the same land

(3) Wanxiangcheng (The MixC)

Wanxiangcheng (The MixC) is a kind of plaza buildings where international brands gather. This construction consists of several buildings among which two buildings are separated by a municipal road. The two are connected by an arch structure over the road (Figure 10). The cadastre of the buildings is shown on the parcel-based cadastral map (Figure 11). Parcel H102-0037(B) is the projected-on-plane extent of the land space use which includes an underground parking lot, commercial shops and an over-ground arch, and is adjacent to parcel H102-0037 and parcel H102-0038 which are placed by the main buildings. Since the arch is constructed over the road, the parcel overlaps a part of the road parcel and H102-0037(B) means differently from other two in description of relevant rights with the property. This arch and the underground lot are owned by the same owner as the other main buildings on the parcels H102-0037 and H102-0038, but the land space used for the arch actually belongs to the municipality. There are distinct rights of land space use in the vertical direction within the parcel (Figure 12). Figure 13 shows an image of text description of usage of the land. This example breaks the homogeneity of spatial extent within a parcel in parcel-based cadastres. The spatial extent of the land space use under and over ground has no precise and explicit description but associated with its architecture plan.

Figure 10. The arch over the municipal road

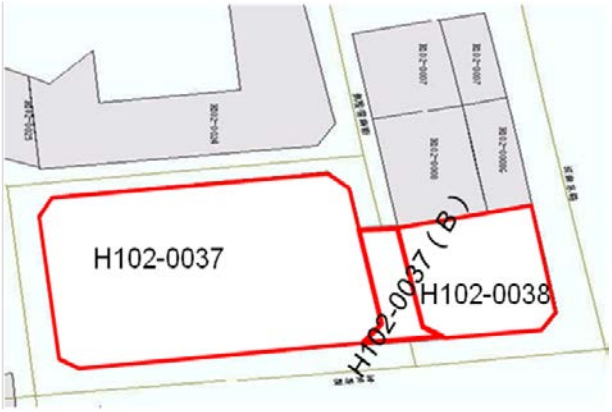


Figure 11. The cadastral map

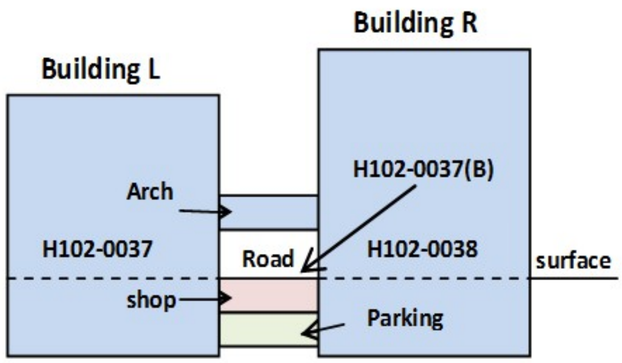
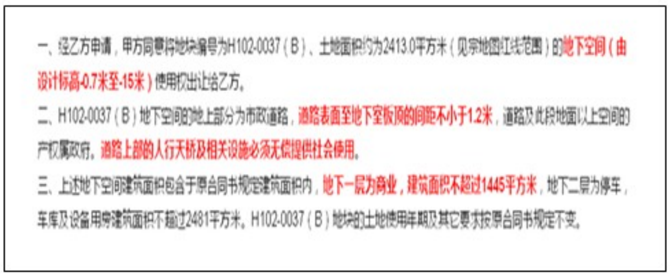


Figure 12. A profile of the buildings



一、经乙方申请，甲方同意将地块编号为H102-0037（B）、土地面积约为2413.0平方米（见宗地图红线范围）的地下空间（由设计标高-0.7米至-15米）使用权出让给乙方。

二、H102-0037（B）地下空间的地上部分为市政道路，道路表面至地下室板顶的间距不小于1.2米，道路及此段地面以上空间的产权属政府。道路上部的人行天桥及相关设施必须无偿提供社会使用。

三、上述地下空间建筑面积包含于原合同书规定建筑面积内，地下一层为商业，建筑面积不超过1445平方米，地下二层为停车，车库及设备用房建筑面积不超过2481平方米。H102-0037（B）地块的土地使用年期及其它要求按原合同书规定不变。

Figure 13. An image of the text description

2.2 Administration of land development

The above examples of land space use has clearly shown that vertical heterogeneity of land rights challenges the capacity of the conventional parcel-based or 2-dimensional cadastre systems in description of spatial nature of land space and of the rights pertaining to the land space. Lack of clarifying spatial extent may lead to potential conflicts of the rights of land space use or property rights. However, vague description of spatial extent of land use has intrinsically its institutional and organizational rationality.

Institutionally,'Land in the urban areas of cities is owned by the State' according to *Land Administration Law of PRC*, and any urban land cannot be transferred to other party through buying, selling or other means. However， the right to the use of land may be transferred in accordance with law such as buying, selling or other means. The use of a piece of urban land by other party means development of the land for construction. Those buildings constructed within the land are owned by the party and as legal objects are registered by law. The right to the use of a piece of land is only delimited by its planar boundary of the parcel in a 2D cadastre system and there is no clear and explicit statement on its vertical extent by law. Spatial extent of the right is tightly associated with the constructions built within the land. Administration of land is a process during which amending height of the buildings or architecture is permitted according to administrative procedures but any change for the parcel in a cadastre system is prohibited. In addition, temporal use of some land or space beyond the delimited parcel is allowed for construction. In order to ease the process, a flexible provision on vertical extent of land use is plausibly justified.

Organizationally, development of a piece of land crosses through a department of land administration and a department of architecture design and construction who is involved in the process of land administration. The two departments use their own jargon in documentation. A department of land administration is responsible for land planning and development, focusing on whether the piece of land is properly exploited and buildings on the land extend its delimited boundary or not. Description of spatial extent is termed by means of surveying, usually using an absolute coordinate system. The department of architecture design and construction is responsible for providing architecture plan available for construction based on land planning and proposal of land development. It often uses relative and local measurement notions to describe the spatial extent in order to reduce inconsistency between architecture design and its accomplished buildings.

2.3 Context of applying 3D cadastre

Management of 3D urban land space adds some complexity to the current convention of land administration because legal objects in Shenzhen city are by definition 2D and all related rights on real estate are based on these premises. This requires some changes in the procedures of land administration such as land planning, cadastre surveying and land registration.

Legislation

Before 2007 when *Real Right Law of PRC* was issued and entered into force on October 1, 2007, there is no law to state whether the right to use construction land could be separately from the land surface (parcel) or not. The right to use land space under or above the land must be dependent on the construction on the parcel. In most cases, the right to use land space underground is assigned to be a kind of other land rights in the light of *Land Administration Law* and *Construction Law*. *Real Right Law* is the first time to state clearly and explicitly that the right to use land space under or above the land can be independent from its surface construction. Article 136 says ‘the right to use construction land may be created separately on the surface of or above or under the land. The newly-established one may not injure the usufructuary right that has already been established.’ Article 138 further says that space to be covered by buildings, fixtures and affiliated facilities thereof shall be contained in a contract when transfer of right.

Administration
Although *Real Right Law* prescribes that the right to use construction land could be created separately, there is no new procedure and regulation in the current administration for management of such separated rights. Does it need to establish some new divisions or reshape organization for dealing with the new issues on 3D land rights? Is it necessary to build a new system for 3D cadastre or how to integrate with the current 2D cadastre system? How to define spatial (3-dimensions) extent of the rights? Those issues need to be explored technically in advance and find some proposals for agencies of land administration.

3D Technique
3D techniques have been applied extensively and brought up many impressive products. 3D GIS and CAD have provided a lot of available and enabled techniques to support various applications. Regarding to 3D cadastre, both GIS and CAD provide usefully implementing platforms and tools such as 3D modeling, data capturing, spatial data management, visualization and so on. Most of required techniques by 3D cadastre systems are presented in different applications other than the field of land administration. But how to integrate and to adopt those techniques into an operational computer-based system best for 3D cadastres seems not an easy work, especially in 3D geometric computation, visualization and customization, in addition to some administrative and conventional barriers to implementing a true 3D cadastre.

3. PRACTICE OF IMPLEMENTING 3D CADASTRE

3.1 Basic hypotheses

Currently, spatial nature of land space is focused and other attributes relevant with cadastres are hypothesized almost the same as 2D cadastre such as ownership, tenure, location and so on. A 3D object in the 3D cadastre is defined as such a geometry which it has vertical faces enclosing a 3D space with roofs and floors. A 2D object (such as a parcel in the current cadastral system) is a special case of a 3D object which has the coincident roof and floor, and collapses into a polygon. A 3D object termed ‘3D property’ refers a spatial envelope containing the construction built with the land space, rather than a space of land rights because the current laws and regulations can not give a clear and explicit statement about the spatial extent of the rights and it is impossible to describe the spatial extent of those rights. Thus, geometry of 3D property is determined by its physical construction.

3.2 Data model

There are many data models for 3D objects such as simplexes (point, line, triangle, tetrahedron) (Carlson, 1987), 3D Formal Data Structure (FDS) (Molenaar, 1990), tetrahedronized irregular network (Penninga et al., 2006), polyhedrons (Arens et al., 2005; Stoter, 2004; Wenninger, 1974; Zlatanova, 2000), polyhedral regular polytopes (Thompson, 2007) as well as Constructive Solid Geometry (CSG) and B-rep approach in computer graphics. In applying a 3D cadastre, the most important aspect to adopt 3D data model is the capacity of integrating with the existed 2D cadastre. In addition, the 3D data model should support a complete 3D topological structure which is regarded as the most advanced implementation for 3D cadastres (Doner et al., 2010).

The data model for 2D cadastre in our practice includes topological features: faces, edges and nodes and consequently 3D data model (Figure 14) is designed by adding a 3D topological feature volumes to the 2D data model. A volume consists of a set of faces which enclose a 3D space. In order to fulfill geometrical computations efficiently, the data model is structured operationally by 3D piecewise linear complex (PLC)(Cohen-Steiner et al., 2004; Miller et al., 1996; Si and G rtner, 2005; Guo and Ying, 2010).

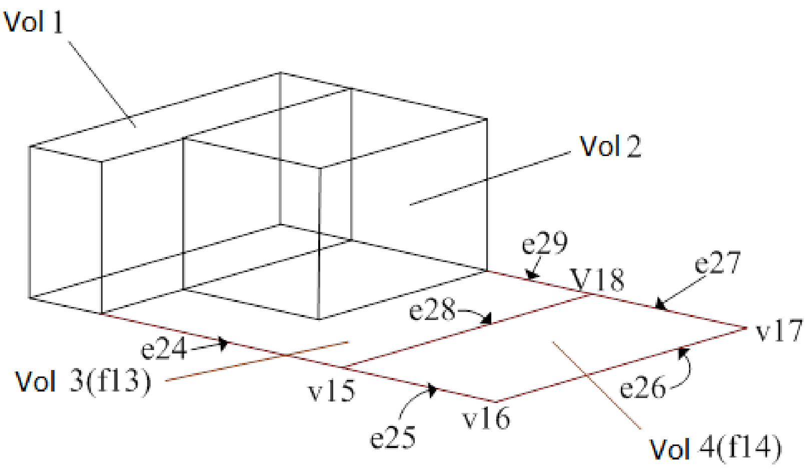


Figure 14. 3D data model with topology (From Guo and Ying, 2010)

3.3 Generating 3D data from 2D plans

It is an effective approach to derive spatial extent of 3D properties from their 2D plans or drawings which are available in the process of management of land use and development. There are a lot of work relating to generate 3D building models from 2D architectural drawings(Lewis and Sequin, 1998; Lu et al., 2005; Mendez et al., 2008; Tanaka et al., 2004; Yin et al., 2009; Ying et al., 2011). In general, a building can be automatically modeled by extruding its footprint plan if the building has a plane roof or simple shape of the roof. However, for a building with a complicated roof, interactive editing would be inserted in the process of modeling the building by extruding each edge according to the profile of the architecture(Kelly and Wonka, 2011). Currently, 2D plans or drawings for construction are formatted in AutoCAD and some interactive processing is needed before automatic extruding. However, since the 3D cadastre does not need exactly the 3D model of constructions and shall focus on the spatial extent not on details of 3D models, no much work need to be done.

After generating 3D data, a topology-building process is designed to build topological relations among volumes, faces. Edges and nodes so that each volume is enclosed by a set of faces, each face is enclosed by a set of 3D edges and incident with exact two volumes, each edge has two nodes and is shared by a set of faces. An example is shown in Figure 15.

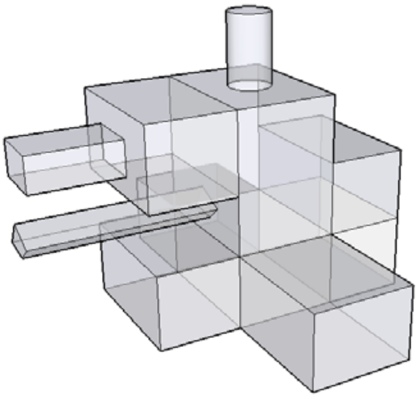


Figure 15. Topological building for 3D constructions

3.4 System development

Functions for the 3D cadastre system are implemented by combination of ArcGIS Server, Skyline TerraGate and Sketchup. 3D data are stored in Oracle with the data of 2D cadastre. Both 3D data and 2D cadastral data can be accessed by the 3D cadastre system which includes functions such as 3D model building and editing, topology building, data management and retrieval, visualization and output of drawings of 3D property. Figure 16 shows one of interfaces of the system.

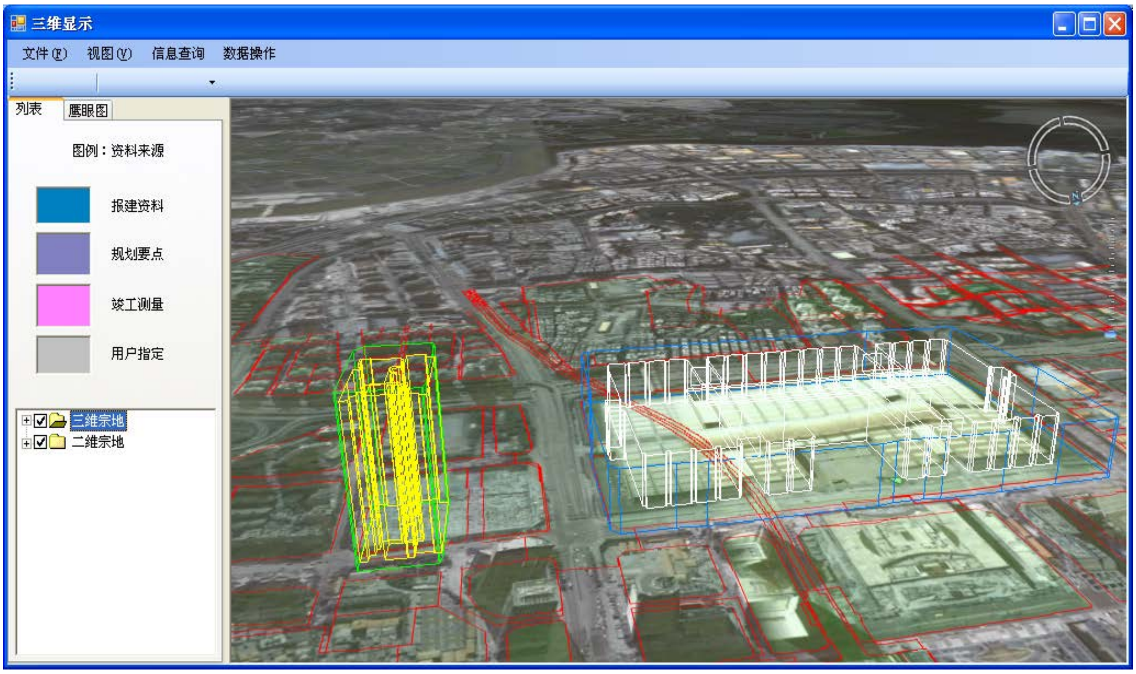


Figure 16. Visualization of 3D spatial extent of constructions

4. AN EXAMPLE OF APPLICATION

According to the current administrative procedures, auction listing of land is the initial phase during which some attributes about the listed land should be stated in the published documents. Those provisioned attributes which would affect spatial extent of using the construction land, in *the bidding auction listing transferring state-owned land use rights provisions*, are 'land use', 'construction area' and 'requirements of planning and design'. However, spatial extent of 3D property shall be described in this phase in order to adapt the 3D cadastre to vertical and multi-layered use of land space.

In May, 2011, Shenzhen auctioned a chunk of land under the ground for building a underground parking lot at the central Houhai in Nanshan district. The surface land is for public use--green land. According to the requirements of planning and design, it will be 2-stories (layers) and have about 16,000 m^2 construction area. No height for the construction, nor elevation for the roof and floor was included in the prepared documents. In this case, the developer could not be sure whether his architecture design is approved or not in terms of the spatial extent at the phase of examining-approval, because there might be spatial conflict with other land use under the ground. He/She has to repeatedly consult with the division of architecture design in the government. With the 3D cadastre system, its spatial extent can be easily described in the published documents together with other geographic information. Figure 17 shows the documents on the official web site.

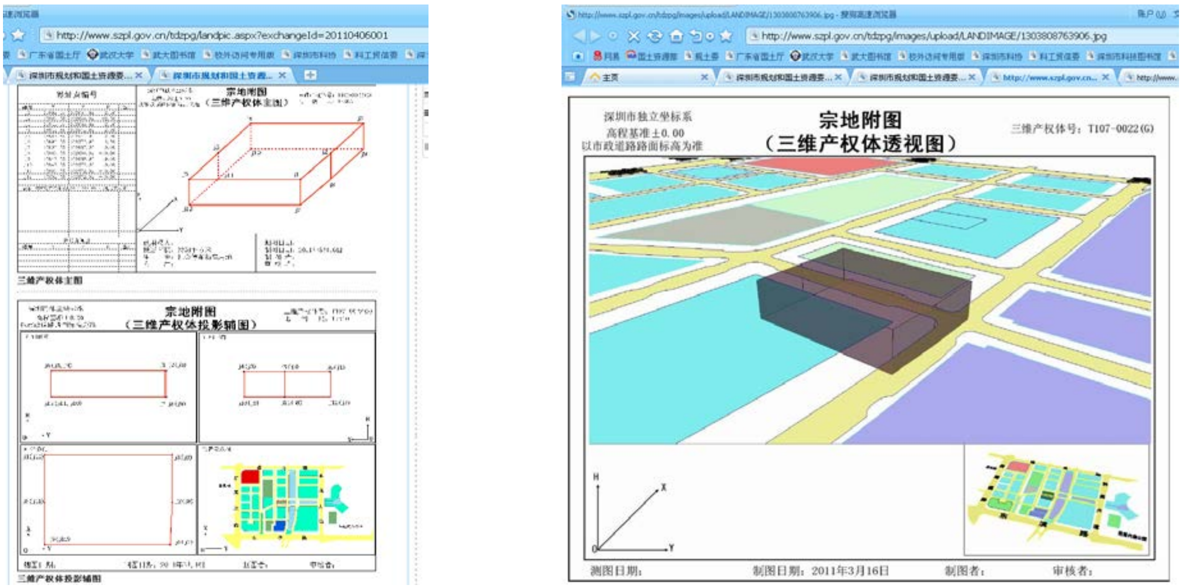


Figure 17. Location and extent of the underground parking lot

After finishing a construction, its 3D model (3D surface model) will be built and stored in the system and visualized with the vertical extent of its parcel when the construction is built above the ground so that spatial relation between construction and land parcel can be viewed (Figure 18). When issuing a certificate of a registered property, its 3D representation will be also included in the registration file (Figure 19).

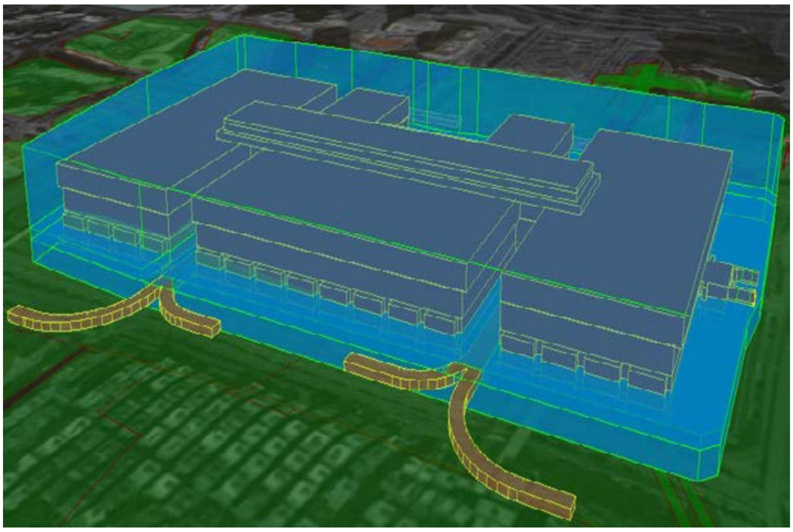


Figure 18. Spatial relation between construction and land parcel

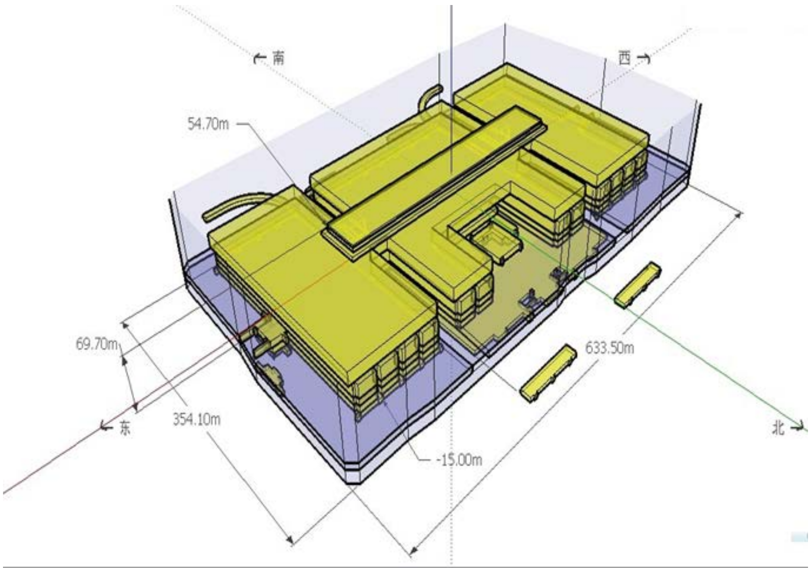


Figure 19. 3D representation in the registration file

5. CONCLUSIONS

Although *Real Right Law* has given developments of a 3D cadastre system a legal guarantee and also legally supported applications of a 3D cadastre system, administration of land shall be amended or adjusted with the emerging requirement of managing land space use in urban development. Our practice shows that there is some gap in the current administrative procedures when applying a 3D cadastre in the administrative process of land use and development. Some divisions (sections) could not see advantages of 3D cadastres from the point of their own divisions and find that preparing descriptions of 3D extent is their additional work. This may lead to redesign of the institution and organization which is a top-bottom process. However, available 3D cadastral techniques can help those divisions to understand this issue better and smoothly to bridge the gap. In the above example of Houhai, when we first asked for an approximately spatial extent from the division of architecture plan and design, they were not willing to do so because it would be a complex work for them without a 3D cadastre system. After we convinced and showed them that it was a simple work to prepare 3D representation with the 3D cadastre system, they changed their attitude and cooperated with us to complete the 3D representation of the underground parking lot.

Technically, our practice shows that a single commercial 3D software system seems not able to fulfill a complete functionality of a 3D cadastre. Integrating several existing 3D software as well as tailoring their some functions is presently an available approach for implementation of 3D cadastres, although it may not provide the best performance of 3D cadastres. Some interfaces among the functions from different software do not match well such as data structures and capacity of 3D geometric computation. It needs to explore further enabling techniques to implement those tools seamlessly for more efficiently fulfilling functionality of a 3D cadastre.

Nevertheless, precise management of property and land resource is a trend pushed by urban economic development and social progress. The proliferation of new property rights, restrictions and responsibilities will force a shift in focus from land parcels to property objects which are embedded in 3D space in reality. Therefore, a cadastre characterized 3D/4D technology would be the future of land administration (Bennett et al., 2010).

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