THE INFLUENCE OF PATH DEPENDENCE ON 3D CADASTRE: A CASE STUDY OF SHENZHEN, CHINA

路径依赖对三维地籍的影响——以中国深圳市为例

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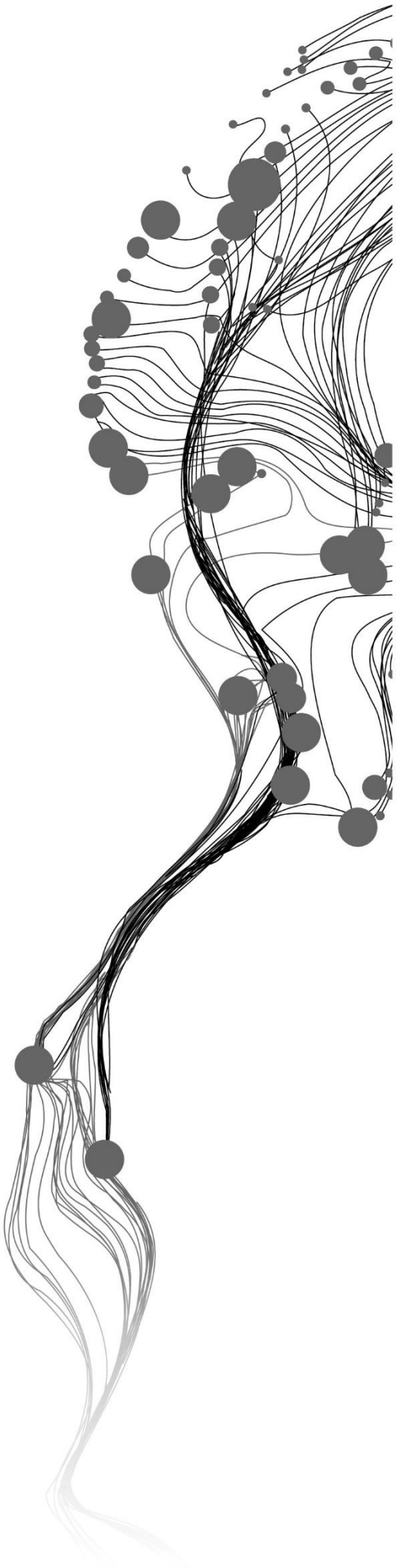

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ABSTRACT

With the emergence of complex infrastructures and multi-use of land above and under land surface in urban areas, the traditional 2D cadastre shows its limitations to represent land and property rights, 3D cadastre is proposed to cope with this problem.

Currently, there is no true 3D cadastre in the world. Partly because improvements are still needed in the technical perspective. Previous research also reveals that developments in the organizational structure and in the legal framework are also crucial for 3D cadastre adoption. However, more attention is given to the technical perspective in 3D cadastral research, and there are few studies combining the technical developments, the organizational structure, and the legal framework.

This research applied path dependence as an analytical lens to investigate the influence of path dependence on 3D cadastre development in China, resulting from the legal framework and the organizational structure. Three dimensions of path dependence are discussed: increasing return path dependence, evolutionary path dependence, sequencing path dependence. The research uses a case study approach, in Shenzhen, China, mainly based on semi-structured interview and focus group discussion with eleven 3D cadastre stakeholders from land administration and urban planning governmental organizations, 3D cadastre supportive and research public institutions, and special zone committee. Sufficient primary data of the 3D cadastral technology, the 3D cadastral organizational structure, and the 3D cadastral legal framework in Shenzhen were obtained for analysing the path dependence of Chinese 3D cadastre.

The current Chinese 3D cadastre shows path dependence in its organizational structure coupled with other hinders deriving from its legal framework. Increasing return path dependence is evident in the lack of complete 3D cadastral law and 3D organizations. Evolutionary path dependence is conspicuous in the barriers of *Civil Air Defence Law* in the legal framework, it is also obvious because of the influence of housing and urban planning institutions on the 3D cadastral organizational structure. Sequencing path dependence is apparent in the barriers due to long period separation of housing and urban planning within the land administration system in China, both in the legal framework and in the organizational structure.

This research contributes to existing discussions regarding what is needed to switch from traditional 2D cadastre to 3D cadastre. Issues linked with path dependence are discussed along with additional hinders beyond the scope of organizational and the legal frameworks, and that influence the Chinese cadastre. Speaking from practical significance, the priority of developing 3D cadastre was discussed due to the incomplete of systematic Chinese 2D cadastre.

摘要

随着复杂建筑结构的涌现以及地上地下空间的多维利用，传统的二位地籍表现土地和权属关系时显示出了它的局限性。建立三位地籍成为了这一问题的解决办法。

目前世界上还没有真正的三维地籍。其技术的不足固然是实施三维地籍的一大障碍，另一方面，研究者们还发现组织结构以及法律框架对三维地籍的实施也十分重要。然而，研究者们大都在关注三维地籍技术上的突破，鲜有学者在探求因为技术与组织结构以及法律框架之间的不匹配给三维地籍发展带来的影响。

本文采用了路径依赖作为规范性研究方法，探究其在法律框架及制度体系两方面对中国三维地籍发展的影。通过阅读不同学科的文献，路径依赖被总结归纳为在三个方面：价值递增路径依赖、进化路径依赖，以及序贯路径依赖。 笔者运用了范例式研究方法在中国深圳市进行了半结构式访谈、焦点小组讨论等实证研究方法，相继走访了深圳土地管理和城市规划部门、为三维地籍提供技术与研究支持的事业单位、以及特区管理委员会，十一位三维地籍的利益相关者，为本文收集了充分的一手访谈资料和数据。

当前的中国三维地籍在组织结构和法律框架两方面展示出了路径依赖。不健全的地籍法律以及地籍组织结构主要证实了价值递增路径依赖；进化路径依赖在《人防工程法》对三维地籍法律的影响上得以证实, 它在中国住房和城市规划部门对三维地籍组织框架的影响上也十分明显。序贯路径依赖则体现在由于住房和城市规划部门于土地管理部门长期分离而带来的影响，这在组织结构和法律框架两方面均得以体现。

从理论意义上来讲，本研究揭露了在传统二维地籍转向三维地籍的过程中，在组织结构和法律框架方面的关注点有哪些。从现实意义上来讲，本文讨论了在土地管理任务中发展三维地籍的优先性。

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1. INTRODUCTION

1.1. Background

Urbanisation is an important part of the economic development process of every country, and it is a global phenomenon (World Bank, 2009). Studies conducted over the past years indicated many people now live in urban areas. For example, according to (FIG, 2010), the "urban global tipping point was reached in 2007 when for the first time in history over half of the world's population, 3.3 billion people, were living in urban areas. It is estimated that a further 500 million people will be urbanised in the next five years and projections indicate that 60% of the world's population will be urbanised by 2030". Another study reported that 50 percent of the population of the world lives in urban areas; by the year 2050, this ratio will reach 70 percent (Ho, Rajabifard, Stoter & Kalantari, 2013). The concentration of people in urban areas will put more pressure on already limited land resources. The land is one of the major issues of concern when it comes to urbanisation. When there is rapid urbanisation, what follows is a shortage of land for development in the cities. This leads to the high population density in urban areas.

Population density in urban areas, especially in central business districts, has increased considerably over the past years making urban land use more intense (Stoter & Salzmann, 2003). The consequence of the fierce land uses lead to the development of urban areas towards both the horizontal space and vertical space (Rajabifard, 2014). Some of the problems of urbanisation include pollution, traffic congestion, a decrease in public safety, higher natural resource demands, increase risk from natural disasters and housing scarcity which often leads to unexpected development (Ho, Rajabifard, Stoter & Kalantari, 2013).

Under the situation of increased population density, urban land has been put to vertical use. High-rise buildings, apartment, subways, pipelines and cables, underground parking, all have been constructed in force in urban areas. The phenomena of different land use and land right being above and under land surface challenge the conventional 2D cadastral system. Sustainable urbanisation is a multifaceted challenge and one of the more obvious responses, whether in the right direction or the wrong direction, is the use of high-rise, high-density buildings as the dominant urban form (Rajabifard, 2014). "The social, environmental and economic aspects of these buildings are supported by land administration systems, given their fundamental role in managing and administering information about tenure, value, use, and development of land" (Van der Molen, 2011). According to (UNECE, 1996), land administration is defined as "the processes of recording and disseminating land information about the ownership, value, and use of land and its associated resources."

Land administration systems manage rights, restrictions, and responsibilities in the land. It also supports the social, environmental and aspects of land resources, and gives them an essential role in managing land information about tenure, value, use, and development (Enemark, 2009). The most cardinal pillar of modern land administration is the cadastre.

The main objective of the cadastre is to register the persons with cainterest in the land and the RRRs (Right, Responsibilities, Restrictions) of the persons on this land and to certify legal security in land transactions. Cadastre is also introduced to assist in land taxation for governments. Also, Cadastre can facilitate the estimation of land value (Hopfer, 2003).
In the global context, cadastral systems are mostly founded on longstanding 2D-based practices of recording and representing information concerning land and property rights that are proving to be limited

in facilitating unambiguous and accurate recording and representation of ownership rights that are complex, and rights and responsibilities defined in 3D, such as the high-rise buildings (Rajabifard, 2014). In the main urban areas, the conventional 2D cadastral parcels can hardly sufficiently record rights, restrictions, and responsibilities under the circumstances of vertical land use, multiple land use and land rights existing under and above within one parcel. That means the current parcel-based 2D cadastre are put into the limit.

The 3D cadastre is a cadastre which registers rights and restrictions on 3D property units instead of 2D parcels (J. E. Stoter, 2004). According to (Stoter & Salzmann 2003): "Examples of existing 3D situations are constructions on top of each other, infrastructure above and under the ground, the increasing number of cables and pipes and apartments". 3D parcels include land as well as water spaces both above and below the surface of the earth. The existing 3D situations push the currently used 2D cadastral registration into limits. Due to the complexities of the built and natural environment, new concepts and definitions of real property units are needed to meet the demand as well as balancing the public and privacy interest; particularly in urban areas where there is intensive human intervention, which tends to use the space both above and below the earth. In this situation, the 3D cadastre is necessary for solving the problems inherent in the 2D cadastral system. Therefore, the shift from parcel-based 2D cadastral system to space-based 3D cadastral systems is necessary. It is important to note that 3D cadastre solutions may depend on local situations and be driven by land market needs, the user needs, the legal framework as well as technical possibilities (Oosterom, 2013).

However, there is no fully operating 3D cadastre in the world (FIG, 2011), since the mismatch between the technical development, the legal framework and the organizational structure of land registration. Nevertheless, there are many countries implementing the 3D cadastral technology in their current cadastral systems. Despite the many advantages of 3D cadastre, path dependence regarding the legal framework and the organizational structure has a significant influence on the implementation of 3D cadastre depending on the country context. In this research, path dependence entails the limits for 3D cadastre implementation derived from how the 2D cadastre system has been organized and its legal framework set up.

1.2. Justification

Urbanisation is essential for the economic development process of every country, and it is considered as a global phenomenon (World Bank, 2009). For the past two decades, Urbanisation has been increasing rapidly in China as well. With a million of people moving to urban areas, population density in urban areas has increased considerably. For example, according to (Chen, Jia & Lau, 2008), within the periods of 1986–2000, the number of people living in urban areas in China increased by 3.9% annually which is far higher than the national population growth rate of 1.4%. This situation has put high pressure on the intensive use of limited land resources. For example, major changes in the patterns of land use are occurring in Chinese cities due to the progress in both industrialisation and population growth within the last two decades (Wu & Yeh, 1999). According to the "monitoring data of the Ministry of Land and Resources, a total cropland area of nearly 10 million ha (0.70 million ha per year) was converted into built-up, forest/pastures and horticultural lands or destroyed by disasters in the years between 1987 and 2000" (Tan, Li, Xie & Lu, 2005). For example, in China, it has now become widespread to see high-rise buildings, underground parking, subways and commercial zones in the city centres, which has shown that there have been considerable changes in the land use pattern in the Chinese urban cities with the last two decades.

The phenomena of different land use and land right above and under land surface motivated by industrialisation as well as population growth challenge the current Chinese 2D cadastre system. In such a 2D cadastre system, reflecting the vertical dimension of the legal status of real estate objects is a daunting task (J. E. Stoter, 2004). Therefore, the shift of administration systems from parcel-based to space-based is

positioned as a necessary and urgent response in China (Guo, 2011; Mingru, 2007). To address land-related issues associated with both vertical and horizontal space, the 3D cadastre implementation is needed. A pilot project for the implementation of 3D cadastre is undergoing in some cities, such as Shanghai, Shenzhen, and Wuhan.

There have been some considerable achievements for 3D cadastre research in China. A 3D presentation model has been designed and imbedded in the current cadastral system; this model has been applied in the underground parking space of Nanshan district in Shenzhen (Guo et al., 2013). The Chongqing survey institute has also developed software to integrate and simulate the BIM models in the 3D GIS environment, which is not only about 3D visualisations (Coumans, 2017). However, the research also shows the challenges in implementing 3D cadastre. For example, high-quality 3D information and computation are needed, extra labour is required for well-matching 2D-based routines and 3D representation (Coumans, 2017; Guo et al., 2013). But challenges are not only of a technical nature and not only related to human and computational capacities.

Despite the relevance of 3D cadastral system and the enormous efforts put in place to implement it as mentioned above, path dependence of the legal framework and the organizational structure in cadastre development also influences the implementation of 3D cadastre. According to (Ho, Rajabifard, Stoter & Kalantari, 2013), research on the development of 3D cadastre especially considering its design and requirements in the technical areas have been progressing well. However, there is a lack of studies carried out in the field of legal and organizational areas (Paulsson, 2007). Studies have been carried out in China concerning path dependence in relation to the legal framework and the organizational structure. For example, one of the studies indicated that the current Chinese cadastral system had shown a strong path dependence both in the legal framework and the organizational structure (Lin, Kalantari, Rajabifard & Li, 2015).

Path dependence means the present situation and the future direction of development are the results of what happened in the past (Liebowitz & Margolis, 1999). In this research, path dependence is introduced as an analytical lens to investigate the influence of the legal framework and the organizational structure on the implementation of 3D cadastre system in Shenzhen, China. Path dependence can help to understand the adoption of 3D technology in the Chinese cadastral system through both the legal framework and the organizational structure. Understanding the legal framework and the organizational structure through path dependence will help the development of Chinese Cadastral system and provide a platform for comparative studies to be conducted in different jurisdictions in relation to cadastral issues.

In the legal framework, the relevant laws, Land Administration Law of People's Republic of China and Regulations on implementing Land Administration Law define the cadastre in 2D, but currently, there are some definitions of 3D objects imbedded in the law.

In the organizational structure, China implements the administration of land and building separately (Ji, 2007). The Ministry of Land Resource of the People's Republic of China is responsible for the administration of land, the Ministry of Construction of China is responsible for the registration and certification of buildings. Chinese cadastral systems adopt land and building information from two departments. Cadastral work is implemented by Township Level Office of Land and Resources, and upper-level cadastral departments mainly focus on policy and management work. According to (Lin, Kalantari, Rajabifard & Li, 2015), "subordinate relation between land administration department and cadastral management department is formed." It is important to note that urban land information and rural land information are managed separately because of the non-unified landform in China. Therefore, it is difficult to establish an even cadastral system for the whole country.

1.3. Research problem

According to the background and the justification of the study, discussed above, the development of the 3D cadastral system is pointed as a necessity to meet the needs of urbanisation and industrialisation in the global context as well as in the context of China. The background and justification also indicate the influence of path dependence in both the legal framework and the organizational structure on the 3D cadastral system as well as shortcomings of the 2D cadastral system.

In the legal framework, firstly, there is no complete law or regulations of cadastre in China. This means the Chinese cadastre is not legally enforced. Besides, the definition parcels and registered objects are based on 2D even though in Shenzhen legislation has been passed regarding the definition of 3D objects. The definition of cadastre in 2D in China is the main barrier to implement 3D cadastre since 3D objects cannot be registered without changes in the current legal framework.

Secondly, in the organizational structure, it is hard to develop 3D cadastre under the non-unified land administration framework. Furthermore, separate management of buildings and land brings more issue to register cadastral information. Also, the subordinate relationship between cadastral management and cadastral implementation brings issues regarding daily cadastral work; there is no systematic cadastral workflow in this situation.

The importance of developing a 3D cadastre in China has been elaborated. However, adopting 3D cadastre needs changes from bottom to the top of Chinese cadastral system, because the cadastre implementation is not only about its technical development, but it is supported by its legal framework as well as by its organizational structure. This research aims at analysing the influence of path dependence resulting from the legal framework and the organizational structure on the development of 3D cadastre.

1.4. Main research objective

The main objective of this study is to investigate the influence of path dependence on 3D cadastre development in Shenzhen, China, resulting from the legal framework and the organizational structure.

1.5. Sub-objectives and research questions

This thesis has three sub-objectives:

1. To describe the current 3D cadastral system in Shenzhen.
2. To investigate the path dependence of the 3D cadastral legal framework in Shenzhen.
3. To investigate the path dependence of the 3D cadastral organizational structure in Shenzhen.

For each sub-objective, the following are questions to be answered in the research:

1. To describe the current 3D cadastral system in Shenzhen.

a) What types of 3D cadastre are currently being designed and implemented?
b) How is the 3D cadastre developed in the technical perspective?
c) What developments are needed in the 3D cadastral technical perspective?

2. To investigate the path dependence of the 3D cadastral legal framework in Shenzhen.

a) How have the law, policy, and legislation of the 3D cadastral system been developed in China?
b) How does the path dependence impede the implementation of 3D cadastre in Chinese legal framework?
c) What changes are needed in the Chinese legal framework to embrace 3D cadastre?

3. To investigate the path dependence of the 3D cadastral organizational structure in Shenzhen.

a) How is the 3D cadastre being organized from national level to Shenzhen local level in China?
b) How does path dependence impede the implementation of 3D cadastre in the Chinese organizational structure?
c) What changes are needed in the Chinese organizational structure to embrace 3D cadastre?

In order to answer the research questions mentioned above, methods used to collect and analyse research will be described in Chapter 3 of this study.

1.6. Conceptual framework

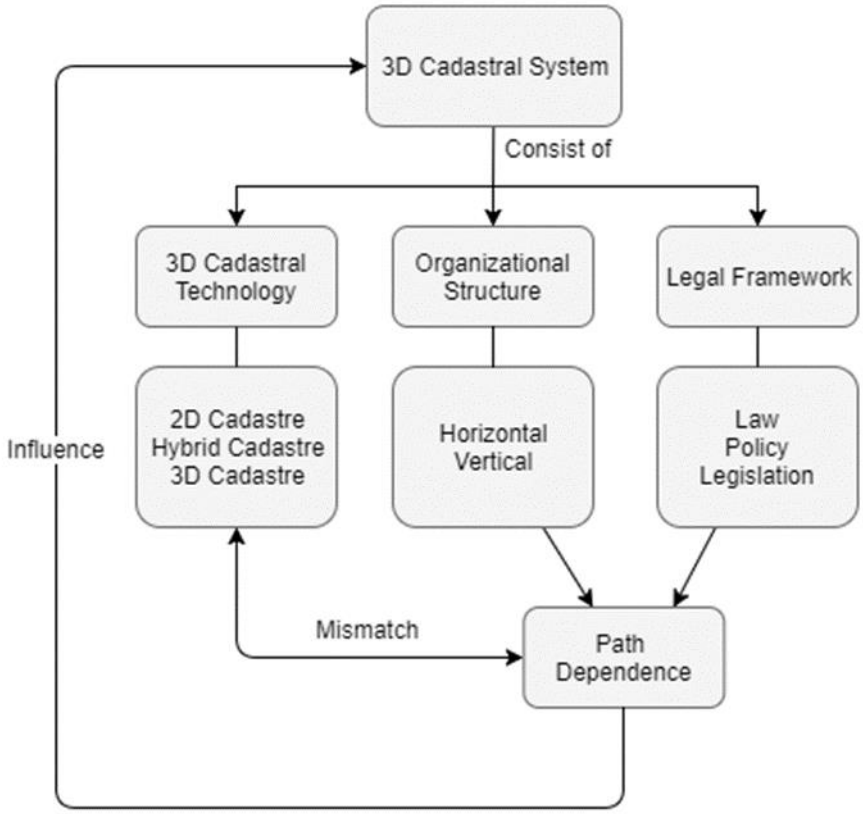

Figure 1 Conceptual framework

The scope of research on 3D cadastre is demarcated by three perspectives that determine the possibilities, needs, and restrictions for the 3D cadastre implementation in cities of Mainland area, in China. These perspectives are the 3D cadastral technology, the organizational structure, and the legal framework.

The 3D cadastral technology perspective considers 3D data acquisition, 3D modelling, visualisation and 3D cadastre database. The organizational structure is related to the horizontal structure and the vertical structure of cadastre. In terms of legal framework, law, policy, and legislation are the main factors.

Path dependence refers to the limits of the historical background and the current situation of organizational structures and legal frameworks put. The path dependence of organizational structure and legal framework would be found out by this research through the administration of semi-structured interviews and the literature review that will be explained in Chapter 3.

1.7. Thesis structure

- **Chapter 1: Introduction**

In this chapter, after background and justification, research problem will be found. Research objectives and research problems are as follows to describe the search problem in detail. A conceptual framework will be applied to show the logic behind. At the end of this chapter, thesis structure will show the major content of this thesis.

- **Chapter 2: Literature review**

In order to understand the 3D cadastral system, the theoretical perspectives on land administration, land administration system, cadastre and 3D cadastral system and their current situation in international and Chinese context will be presented. These contents based on desk research.

- **Chapter 3: Research Methodology**

The research approach, study area, preparation of data collection tools, sources and methods of data collection, data processing will be discussed in this chapter.

- **Chapter 4: Results**

The research questions will be answered in chapter 4, according to primary data and secondary data.

- **Chapter 5: Conclusions**

In this chapter, after reviewing the research process, main findings, other findings, research contributions, thesis limitations and future directions will be presented.

2. LITERATURE REVIEW

2.1. Land administration and cadastral system

The definition of land administration in this research refers to the one set in 1993 by the United Nations Economic Commission for Europe (UNECE) in its Land Administration Guidelines: "the process of determining, recording and disseminating information about ownership, value, and use of land and its associated resources. These processes include the determination (sometimes called ´adjudication´) of land rights and other attributes, surveying and describing these, their detailed documentation, and the provision of relevant information for supporting land markets" (UNCE, 1996).

Land administration system is an infrastructure that manages rights, restrictions, and responsibilities in land. The Land administration system is based on land information, supports land tenure, land value, land use and land development for sustainable development in economic, social and environmental aspects. The cadastre is a parcel-based land information system (FIG, 2017), and it is recognized as the core in land administration systems (Rajabifard, 2014) since land information is the basis for all decision making in terms of land management. It records land information and provides information for land market and land use management. The cadastre also supports land taxation and land tenure for governments.

In many developed and developing countries, achievements have begun to establish a cadastral system (Enemark, 2005). As Figure 2 (Enemark, 2006) shows, cadastral systems provide administration functions in land tenure, value, use, and development.

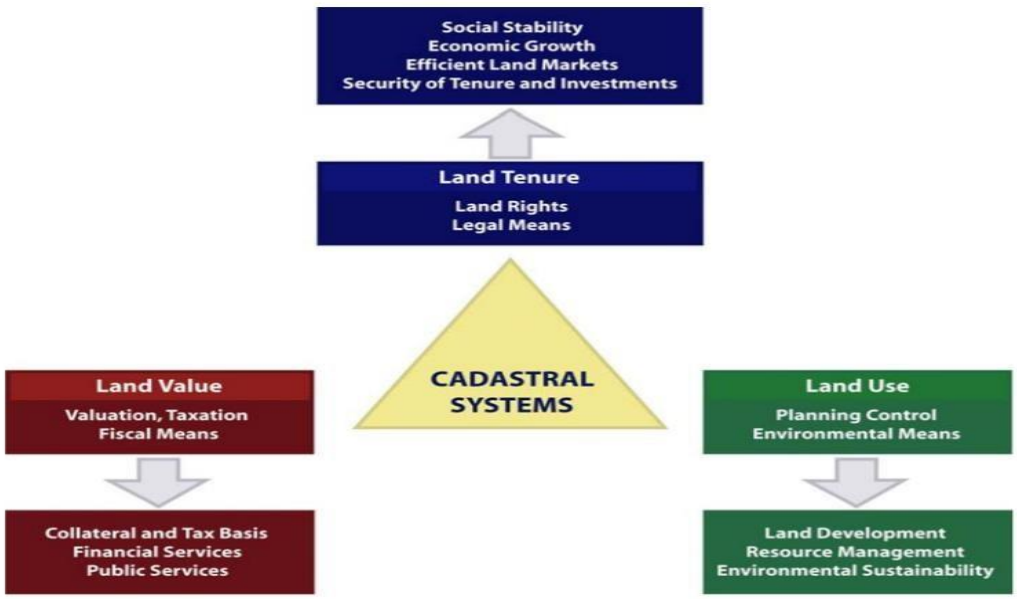

Figure 2 The concept of multipurpose cadastral systems

2.2. Development path of 3D cadastre

In the international context, the current cadastre is generally based on 2D maps, which are 'parcels' (Stoter & Salzmann, 2003). Parcels are considered as pieces of land, registered to a person, which is entitled to the right over the parcel. However, intensive urban land use is pushing development vertically, which puts conventional 2D cadastre into the limit, especially when it comes to 3D situations. According to (Stoter & Salzmann, 2003), examples of 3D situations are as following: "Constructions on top of each other; infrastructure above and under the ground; The increasing number of cables and pipes (as well as the increasing number of owners of cables and pipes due to privatization processes); Apartments." The boundary of the land parcel is broken by the existence of objects in 3D situations (Mingru, 2007). To meet these challenges, the development of 3D cadastre is now positioned as a necessary step for land administration (Rajabifard, 2014).

The possible solutions to register 3D situation are distinguished as follows:

2.2.1. A full 3D cadastre

Figure 3 shows the conceptual data model of full 3D cadastral registration (J. E. Stoter, 2004). The full 3D cadastre system requires a clear definition of 3D property rights. The 3D objects are registered as 3D volume parcels without overlapping or gaps. Relevant law, real estate transaction protocols and registration models should support 3D rights (Chai, 2006). In another word, full 3D cadastral registration implies the update of the entire cadastral system, which is a long-term process (Stoter & Salzmann, 2003). However, in most of the countries which are implementing 3D cadastral registration, 3D objects are registered on 2D cadastral maps. This solution is working fine for most of the 3D situations. What is more, a 3D cadastre is only needed in intensive land use areas. Therefore, currently, there is no country implementing full 3D cadastral registration.

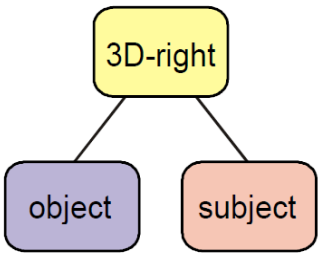

Figure 3 Conceptual data model of a full 3D cadastre

2.2.2. A hybrid cadastre

Figure 4 below shows the conceptual data model in hybrid cadastre (J. E. Stoter, 2004). When a legal framework cannot cope with a 3D property right, a hybrid solution could solve the conflicts. It basically registers 3D objects under or above parcels within one part of the cadastral datasets. As a result, the 2D cadastral system is maintained with necessary registered 3D objects, and 3D objects become a part of 2D geographic datasets (Hassan & Abdul-Rahman & Stoter, 2006). This approach is very accessible under the current legal and organizational settings of 2D Cadastre. Both 2D and 3D information can be stored and well-organized in current cadastral systems. No revolutionary changes are needed in terms of cadastral legal and organizational settings.

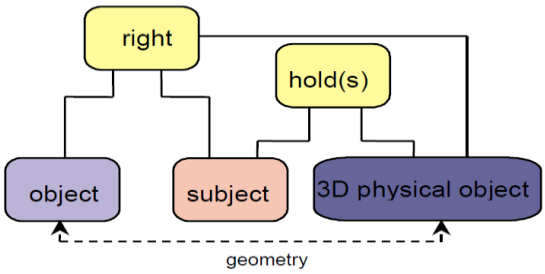

Figure 4 Conceptual data model of a hybrid cadastre

The current Dutch cadastral system is implementing a hybrid cadastre. One case of fully 3D registration of rights on 2D parcels was applied to a case in Delft; it combined city hall and underground train station (Stoter, 2012). In this type of 3D cadastre, 3D objects can be registered in 2D parcels. Although there is no legal framework for 3D descriptions of parcels, 3D parcels can be regarded as the legal volumes formed with real rights (Stoter, Oosterom & Ploeger, 2012). In the State of Victoria, Australia, 3D objects RRRs are registered. In terms of legal definitions, 3D objects are defined by the type of 3D RRRs (Rights, Restrictions, Responsibility) and the boundaries of the objects (Aien, Rajabifard, Kalantari & Wiliamson, 2011).

2.2.3. A 2D cadastre with 3D tags

Figure 5 below shows conceptual data model for 2D cadastre with 3D tags (J. E. Stoter, 2004). This solution preserves 2D cadastre with an external explanation as for the reference on 3D situations. It is also regarded as an ad hoc solution for 3D objects' registration, which would not change the current cadastral framework (Oosterom, 2013). 3D Tags can be embedded simply in the registration without changing the conventional legislation, administration, and 3D technology. Tags can also be visualized in 3D format, for instance, a CAD-drawing, which is a user-friendly solution for an easier understanding of information about 3D situations (Stoter, 2002; Oosterom, 2013). However, it is not a practical solution for the long-term application; it is not a lasting or sustainable solution for 3D registration (Chai, 2006) since the 3D situations could not be queried in this kind of system.

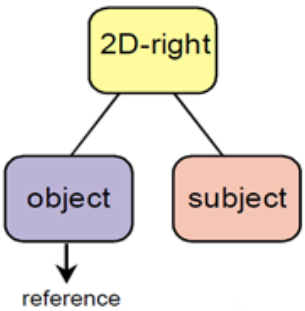

Figure 5 Conceptual data model for a 2D cadastre with 3D tags

In Costa Rica, 3D objects are recorded in 2D models with tags, the legal definition of 3D objects are in 2D but with different kind of levels above and under land surface. There is no description of 3D elements in cadastral maps in Costa Rica (Vargas, 2004). In Argentina, 3D objects are registered in the 2D model with reference to the 2D cadastral system. The legal definition of 3D objects is in 2D but with multiple levels. So far, no rights can be registered in 3D (Erba & Graciani, 2011).

2.3. 3D cadastral issues in the international context

At present, there is no fully operating 3D cadastre in the world, since the current technical issues, the legal framework, and the organizational structure of land registration do effect on 3D cadastral implementation (FIG, 2011). Nevertheless, many countries are implementing the 3D cadastral technology in their current cadastral systems.

2.3.1. 3D cadastre technical issues

A technical perspective on implementing 3D cadastre mainly comprises the discussion on the method to implement 3D geo-objects in the current cadastral geo-DBMS in which the 2D parcels are stored (J. Stoter & Salzmann, 2003). The 3D geo-objects implementation on DBMS is based on 2D currently, the application with 3D registration thus needs technology development. In addition, Topology should be considered together with this geometry.

In an international context of 3D cadastral technology, 3D cadastral visualisation is another problem. According to literature (Van Oosterom, 2013), some key problems are as follows: "(1) how to visualize dense 3D volumetric partitions such as in a complex building because the first visible outside layer of 3D spatial units blocks a view of the others, (2) how to display open or unbounded parcels, (3) how to include the earth's surface and/or other reference objects for 3D cadastral parcels, (4) how to provide the proper depth cues for subsurface legal spaces related to utilities."

2.3.2. 3D cadastre legal issues

In the legal framework of 3D cadastre, the laws regarding land tenure (land law) refer to the legal instruments for the creation of 3D cadastre. Thus, while discussing the legal aspects of the 3D cadastre, it is essential to know about the laws and regulations that deal with the land registration as such (legal principles of land registration), and the laws regarding land tenure (FIG, 2011).

The main aim of a 3D cadastral legal point of view is to make the 3D properties certain and transferable. By doing this, we make the multi-use of land practical, possible, and attractive to the market (FIG, 2002). This primary issue of rights drives the legal mandate, where the objective is to establish and define land and property RRRs (Rights, Restrictions, Responsibility) unambiguously (Ho, 2013).

2.3.3. 3D cadastre organizational issues

The organizational structure forms the foundation and lays the ground work for any land administration. However, cadastre will only be substantial if they are operated within an organizational context where proper rules and regulations concerning the property rights, mechanisms of acquisition, and the roles and responsibilities of the public administration designated to register are clearly defined. (Aien, Rajabifard, Kalantari, & Williamson, 2011) indicated that this also applies to 3D cadastre. If the third dimension in property regimes are not defined, 3D cadastre proves meaningless (Van der Molen, 2003). The land registration system and a cadastral registration are two major components of a cadastral system (Hassan, Abdul-Rahman & Stoter, 2006). According to Hassan & Yaakop (2006) "experiences in developed countries have shown that stand-alone or isolated approaches where data and processes were maintained separately are not sustainable". A case study in Shenzhen City of China done by Guo (2013) shows the existence of gaps in the current administrative procedures when applying a 3D cadastre in the administrative process of land use and development. Some divisions could not see advantages of 3D cadastre from the point of their own divisions and find that preparing descriptions of 3D extent is their additional work. This may lead to a redesign of the cadastral organizational structure.

2.4. Path dependence

In this section, path dependence's general definition, the disciplines where it is often applied to, the definition in this research, the three dimensions of path dependence, path dependence in legal systems and organizational structures, and the way to break through path dependence (path creation) will be discussed and explained.

2.4.1. Path dependence definition and background

Liebowitz & Margolis (1999) provide a general definition of path dependence: "path dependence means that where we go next depends not only on where we are now but also upon where we have been. History matters." The origin of path dependence could be traced to David (1985)'s description of the keyboard evolution in economic study, in order to illustrate the reasons why markets are locked-in a certain inferior technology.

Path dependence has been adopted across a variety of disciplines to explain the difficulties to adopt new technology, the inflexibility within organizational structures and legal frameworks. In economic studies, Liebowitz & Margolis (1999) illustrated that path dependence means equilibrium allocations depend on history. Economic allocation could not only be predicted by its relevant knowledge or its decisive factor but also influenced by its history. In biological theory, path dependence means evolution constrained the previous natural selection. Liebowitz & Margolis (1999) demonstrated the connection between "natural selection" and path dependence: "The related idea of path dependence is called contingency - the irreversible character of natural selection." Which means the possibilities of future evolutionary changes are determined by the previous changes, which are selected by environment. In law studies, path dependence is used as an analytic tool to explain the influence of history in common law system (Hathaway, 2003). Under the doctrine of stare decisis, the current decisions are following previous decisions of higher courts, which lead to inflexibility in the law system. In organizational research, path dependence indicates the imprinting effects of decision-making and organizational inertia on organizational behaviours, and it leads to organizational rigidities, stickiness, or inflexibility.

In this thesis, path dependence means that the current situation and future development path are shaped in specific ways by the historical path constraining current and future development. In the Chinese 3D cadastral system, with the gradual development in the technical perspective, it is important to match it to the organizational and legal context, in order to take advantages of 3D cadastral technologies. However, the switch from 2D cadastre to 3D cadastre has barriers in the legal framework and the organizational structure. This thesis applies path dependence as an explanatory concept to analyse the barriers to adopt a 3D cadastre. A case study in Shenzhen City of China done by Guo (2013) shows the existence of a gap in the current administrative procedures when applying a 3D cadastre in the administrative process of land use and development. Some administrative divisions are not confident with 3D cadastre from the point of their own divisions and find that preparing descriptions of 3D extent is not easy to implement. They are satisfied with the 2D cadastre because they have been using it for a long time. Guo (2013) also points to the large costs and personnel training needed for switching to 3D cadastre, which is another reason for difficulties to develop 3D cadastre in China. In the legal framework, although The Property Law supports the 3D properties and associated rights, the further advanced legalization of 3D cadastre is needed to break the recognition of cadastre in 2D, conflicts are also existing between national law and 3D cadastral implementation in pilot project cities.

2.4.2. Dimensions of path dependence

In this paper, I catalogized path dependence in three dimensions which are rooted from economic, biology and social science fields: "increasing return path dependence", "evolutionary path dependence", and "sequencing path dependence". In each, path dependence has specific characteristics.

The first dimension of path dependence is **increasing return path dependence**. It grows out from economic studies. This dimension posits that once an object steps into a certain path, it will be bound on the chosen path (Z. Lin, 2012). David (1985)'s description of the development history of the keyboard is the archetypal example of path dependence theory in the economic field. According to this case, there were many possible keyboard arrangements. However, QWERTY typewriters dominated the market initially due to people being more used to it. Some trading publications such as "Computers and Automation" discussed the higher efficiency of using another kind of keyboard, the DSK keyboard, during the early 1970s. Also, the US Navy had also proven the increased efficiency of using the DSK keyboard. However, using a keyboard with a different arrangement required new typing skills and typing habits. Keyboard users were not willing or were more resistant to adopting the DSK keyboard. In addition, adopting DSK keyboard request high cost of software "conversion". Consequently, with more people using the QWERTY keyboards, the market became locked-in in QWERTY keyboards, people then could only buy typewriters with QWERTY keyboards, and only these would be produced.

Increasing return path dependence is identified by decisive internal factors, which is similar to inertia in Physics. In this case, internal factors refer to stakeholders' own acceptance and willing of change in terms of adoption a new technology or a process. Hence, if path dependence plays a role in the adoption of a new technology or a process in an organization, the researchers would have to formulate the research in ways that it will capture the large switching cost and inertia that influence the future path of the organizations.

The second dimension of path dependence is **evolutionary path dependence**. It draws on biological evolution. Evolutionary path dependence reflects on the "punctuated equilibria" and "natural selection" theory: long-term stability followed by sudden change is based on external factors. According to research in the law system (Hathaway, 2003), such evolutionary path dependence theory "provides a useful lens on the process of legal evolution in a common law system." Pettersson (2003) indicated the path dependence of the legal regimes involved in the wind power development: The legal rules regarding construction and access to transmission lines as well as the green certificate system is well defined and have not been subject to any major legal disputes. However, the right to use private land for energy purposes is unregulated. It needs certain land expropriation guarantee, which is not present in the legal framework supporting wind power. The land expropriation is without the windmill development structure, but it hinders the windmill establishment. The land expropriation regulation hence impedes on windmill establishment as an evolutionary path dependence of legal structure.

Evolutionary path dependence is marked by "contingency", and it emphasises on external factors. External factors refer to factors and constraints outside the scope of the field being itself, these are factors that are influencing the object but over which it has little to no control of. Thus, according to if the evolutionary path dependence, attention needs to be paid on sudden changes caused by external factors, because these will influence the object.

The third dimension of path dependence is **sequencing path dependence**. "Sequences are chains of temporally ordered and reactively connected events. These sequences are reactive in the sense that each event within the sequence is in part a reaction to temporally antecedent events" (Mahoney, 2000). It means

each step in the chain depends on prior steps as a sequence. Sydow, Schreyögg, & Koch (2009) put forward a "three phases model" for sequencing path dependence; figure 6 shows the concept of this model. It formalizes the emergent steps of path dependence along three stages and explains how the organizations become path dependent in temporal order. The most prominent feature of the first phase is a wide range of options. In the second phase, the various factors began being constrained by previous options. In the third phase, the pattern is gradually fixed and eventually evolved into a dominant model, which leads to a certain outcome. The options are quite limited in the last phase. Pettersson (2003) indicated the sequencing path dependence of the resource management provisions in Sweden. The Environment Code balanced the opposite interests of resources' provision, it had an ambiguous content, allocating the natural resources efficiently. In 1998 the rules of The Natural Resources Act were adopted into The Environmental Code for preventing damaging activities for natural resources. The development of wind power as exploitation activity against preservation was limited by The Environmental Code, even if it was for public interest. Thus, the resource provision was inefficiently promoting or protecting interests. The previous decision-adoption of The Natural Act constrained the wind power development.

The sequencing path dependence places the emphasis on the internal factors, which are the barriers within the organizations and the legal framework themselves. Attention needs to be paid to previous decisions and set of rules that constrain the current path in organizational and legal research.

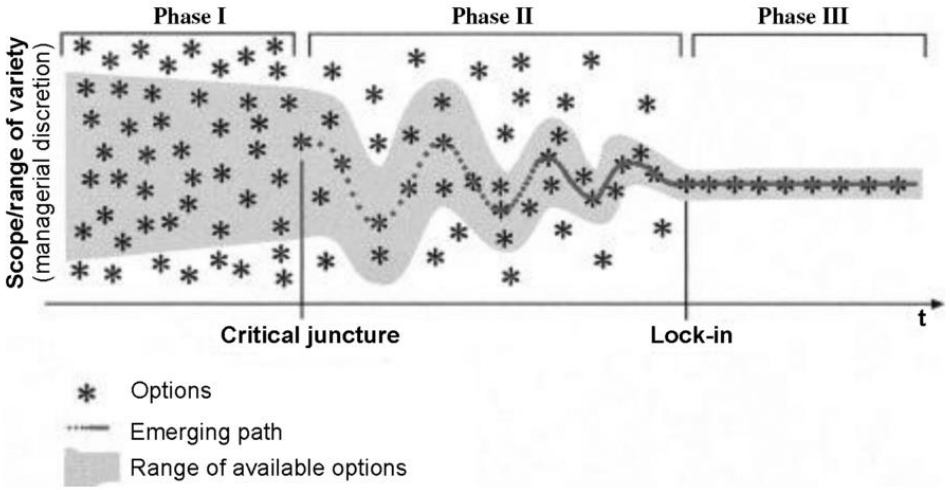

Figure 6 Three phases model of sequencing path dependence

2.4.3. Path dependence within legal studies

Hathaway (2003) demonstrated the relationship between law and path dependence, because of the "doctrine of stare decisis": Decisions made by upper courts are controlling subsequent cases involving similar legal issues. Firstly, path dependence results from increasing returns. Once a rule has been made, it would be less costly and more efficiently to follow that same rule for subsequent cases. Hence, people are used to follow existing decisions and are less willing to change, they tend not to accept the new decisions. As a consequence, the previous decisions of law bring inflexibility into law system. Secondly, path dependence results from an evolutionary process, where the decision-making capacity of law is based on the existing precedents, which also form the foundation for future cases. Hathaway also claimed that the modern common legal system is the legal version of Darwin's paradigm, since the evolution of the legal system leads to the efficient legal rule. Thirdly, path dependence in law results from sequencing path dependence: "The order in which cases are presented to the courts will have a significant influence on the legal rule selected", said Stearns (1995). The previous decisions of initial legal issues influence the following similar legal issues. Because sudden changes, which selected by the environment determine the possibilities for now and future, cannot be reversed, thus the evolution process is constrained by changes and natural selection in the past. Such phenomenon arises when legal issues appeal for the first time, the decisions made by supreme courts determine the current legal system, the long periods stability within law are hence produced due to law-following.

The case of wind power development shows the path dependence in the legal system (Pettersson, 2011). The legal definition of using private land for energy resources is not clear, it is out of the energy resources law but limited the windmill construction, which reflects the evolutionary path dependence. Also, the legal definition of land use had been implementing for over 100 years. Thus, it was not easy to change the law due to people's acceptance and usual practice, which is the increasing return path dependence was in the legal system. The Environmental Code chose to prevent damage from natural resources, which is against exploitation activities, and as a sequence, development of windmill was limited by law due to sequencing path dependence.

2.4.4. Path dependence within organizational studies

In organizational studies, Heffernan (2003) put forward the reasons why path dependence occur in organizations. Firstly, increasing return path dependence results from habits. Training, experience and knowledge in certain types of situations develop habits, such as routine, solutions, and regulations. These habits are developed to solve problems and they tend to persist over time. In addition, people may also ignore the advantages of a new technology or process because of existing habits of experience and practice, which lead to lack of acceptance of the new technology or process. Increasing returns is also coupled with large switching costs. The switching costs are not always efficient for the individual. Also, it might be a barrier for organizations. Since for the individual, it takes training, or commitment to switch to new technology, for organizations it takes the cost of funds or structural change. But, the switching would receive efficiency in long-term. Secondly, in evolutionary path dependence and sequencing path dependence, the inefficient long-term predominance, such as habits or technologies that have been used for a long time, are the results of the path-dependent organizational structure. The inefficient long-term predominance was set up owing to some previous decisions mainly through network externalities leading to a lock-in. In addition, for evolutionary path dependence, the initial choice could be random (David, 1994). Inflexibility and rigidity are hence found their way into organizations. As results, a strict organizational setting that is difficult to change, the development path is constrained in certain ways.

In the 1990s, IKEA one of the world's largest users of catalogue paper declared a new environmental policy, the story behind indicates the path dependence in organizational path dependence (Håkansson & Waluszewski, 2002). IKEA received pressure from environmental organizations, as they claimed IKEA should consider the problems of "cutting down trees" and "waste disposal problem". Therefore, IKEA had produced an environmental policy based on paper production, which would be "chlorine free" and "use secondary fibre". However, the paper was supplied by other companies, and the paper producers regarded the new policy as an impossible mission, they didn't accept the new policy since it would decrease the quality of the paper. Furthermore, the technology couldn't fill the gap yet; some producers even refused to cooperate with IKEA anymore. The lack of acceptance of the environmental policy, reflected on the increasing return path dependence because the paper producers had not accepted the environmental policy yet. The previous decision to use the high-quality paper supplied by other companies was sequencing path dependence, because of the gap between new policy, acceptance and technology. Also, the pressure paper producers received from environmental organizations reflects on evolutionary path dependence because the environmental organizations are not in the scope of paper's supply and demand. However, the environmental organizations require the technological innovation of paper production.

2.4.5. Ways for breaking path dependence: Path creation

Although the main objective of this thesis is to investigate the path dependence of 3D cadastral system in the legal framework and the organizational structure, it is worth to mention the methods of breaking with path dependence to allow for further development of the Chinese 3D cadastral system. Raghu & Peter (2002) are the pioneers of path creation studies, and according to them, path creation emphasizes on organizational initiatives, also, individuals should navigate a flow of events to break the path dependence rather than passively exist within the system. According to research (Heffernan, 2003; Ji, 2010; Lin, 2012), the main path dependence breaking methods could be summarized in five ways: firstly, when the external environment of the organization changes drastically, in the moment of crisis, the organization needs to break through inertia of behaviour and inertia of cognition, and generate new cognition to a new environment in order to effectively allocate various resources and abilities. Secondly, significantly improve the technique level, to one with more superior performance, for example, this could mean that a new technology such as 3D cadastral could be accepted more easily. Thirdly, experts' perspectives from different fields will distinguish the different strategic opportunities. Fourthly, with a tolerance of more experimentation under crisis, people would be more likely to change the existing patterns of responses and consider the way to improve the process. Furthermore, time is a crucial element in path creation processes. Individual initiatives require time to get mature and succeed. (Raghu & Peter, 2002).

The development of paper produced under IKEA's environmental policy mentioned earlier is an example of path creation (Håkansson & Waluszewski, 2002). Although some paper producers couldn't accept IKEA's new policy for producing paper, in 1989, one company who was open-minded decreased the brightness-request of paper and produced deinked pulp from wasted materials. Similarly, in 1991, another company produced paper with chlorine-free technology. The paper was not a full-bright pulp, but bright enough for the production of the IKEA catalogues, because the main necessary characteristics were intact. Afterwards, the technology was accepted gradually by other paper producers, and it also has been further developed. As a result, by 1993, the environment-friendly paper was almost impossible to distinguish from the traditional paper by customers.

2.4.6. Conclusions

This thesis will apply path dependence to analyse the organizational and legal barriers to the adoption of the 3D cadastral system in China. The cause of path dependence and methods of path dependence breaking to be used in 3D cadastral context are summarized in the following three forms:

Table 1 Triggers of path dependence in 3D cadastral context

	Increasing Return Path Dependence	Evolution	Sequencing Path Dependence
Organizational Structure	• Inertia (From habits of training and experience); • Switching Cost; • Lack of Acceptance	• Contingency (without the cadastral organizational structure)	• Previous Decision (within the cadastral organizational structure)
Legal Framework	• Decision of Upper Courts; • Lack of Acceptance	• Contingency (law without the cadastral legal system)	• Previous Decision (within the legal system)

Table 2 Path creation methods

	Increasing Return Path Dependence	Evolution	Sequencing Path Dependence
Organizational Structure	• The moment of crisis; • Technical Improvement; • Individuals' different perceptions of the world and different knowledge; • Tolerance of Experiments; • Time		
Legal Framework			

3. RESEARCH METHODOLOGY

This section describes the overall research methodology that has been applied to address the formulated research questions. The section also contains the description of the study area, sources of data, data collection methods as well as how the data collected will be analysed.

3.1. Overall approach

The overall research approach adopted for this research was the qualitative research approach. The qualitative method was used to obtain the information about current cadastral information about the case study area from the Internet and from 3D cadastral experts in the case city. The qualitative approach provides some level of flexibility to study various attitudes, values, and perceptions related to a particular phenomenon (Bryman, 2015). The main objective of this research is to investigate the influence of path dependence on the development of 3D cadastral system in China. To carry out an in-depth study of this nature and to achieve the research main objective through answering of the research questions, I used a case study approach in order to gain understanding of 3D development based on a specific locality where it is currently being implemented in order to draw broader conclusions through theory that may be applicable elsewhere.

3.2. Study area

3.2.1. Description of the study area

The study area of this research was the city of Shenzhen which is located in Guangdong province in China. Shenzhen is located close to Hong Kong, and it has 7 administrative districts. Figure 7 shows the location of Shenzhen in China, and Figure 8 shows the administrative map of Shenzhen.

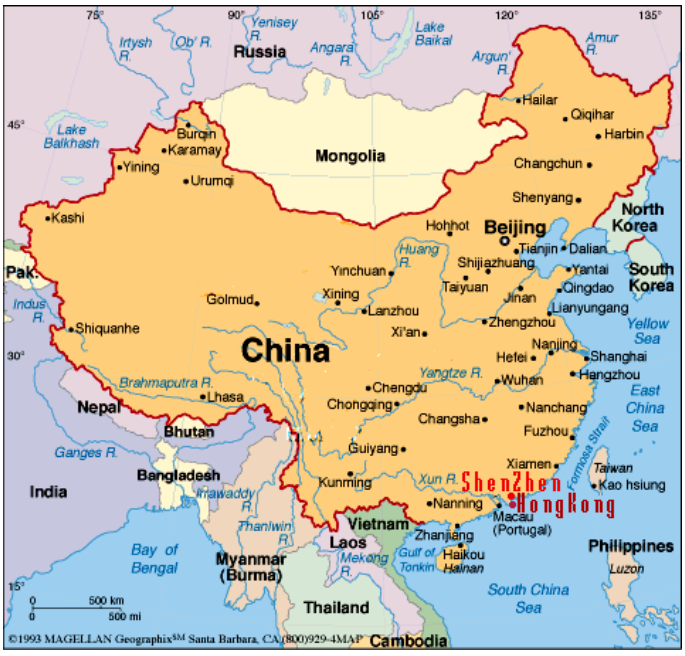

Figure 7 Location of Shenzhen city in China

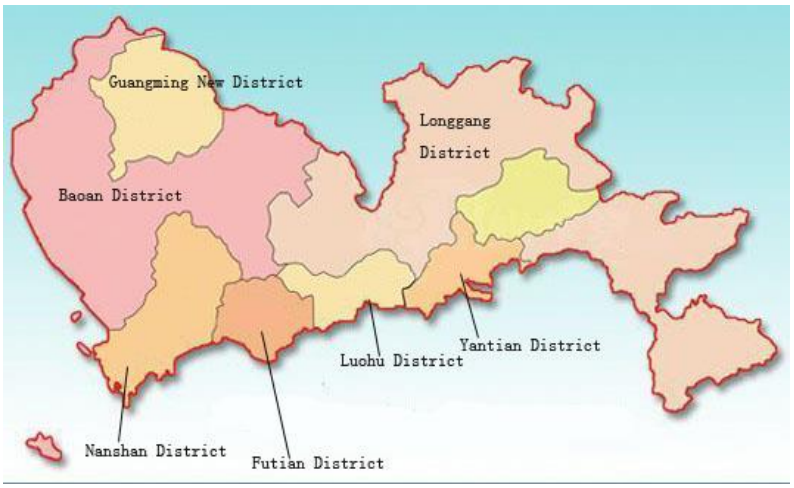

Figure 8 Administrative map of Shenzhen city

Shenzhen holds sub-provincial administrative status, and it is one of the most developed and economically advanced cities of China. Shenzhen has experienced rapid urbanisation since the last several decades. According to Shenzhen Statistic Book 2016 (Yang & Hong, 2016), it has a total population of about 11.4 million and its land area is about 1,991 square kilometres. The population density of Shenzhen is about 5,697 million per square kilometre, ranking the first place of the most densified cities in China. In addition, Shenzhen is also featured as a city with contemporary buildings, many skyscrapers and high-rise apartments stand in this city. Commercial areas and parking areas are widely built underground in the CBD areas in Shenzhen. Such space should be effectively managed to prevent legal conflict in the cadastral system. Thus, implementation of 3D cadastre is pointed as necessary in Shenzhen.

Shenzhen is in the pilot project of 3D cadastre implementation in China meaning it is undergoing 3D cadastre implementation. Shenzhen is a special economic zone, which has special legislative power. Shenzhen started applying a vertical land administration system in 2005 when an underground space was independently used for commercial use. From a technical perspective, relevant research on 3D cadastre development is going on in Shenzhen, such as object definitions, 3D modelling and data processing, visualisation and topological analysis of the property objects (Guo, 2012). In the organizational structure, Shenzhen is the first city to have implemented 3D cadastre in China. The Urban Planning, Land and Resources Committee of Shenzhen city is applying the 3D cadastral system for land administration work. Research institutions such as the Shenzhen Research Centre of Digital City Engineering, Shenzhen Urban Planning and Land Resources Research Centre, and Shenzhen Urban Planning and Land Resources Information Centre are conducting the 3D cadastral research. Therefore, Shenzhen is a representative case for 3D cadastre research in China.

3.3. Preparation of data collection tools

3.3.1. Data collection methods and data sources

The data collected for this research included both primary and secondary data. The primary data is usually obtained directly from the field through various data collection techniques. The primary data for this thesis was obtained through semi-structured interviews, focus group discussions with 3D cadastral experts in research institutions and cadastral officials in Shenzhen city. These data collection methods were used to address sub-objectives 1, 2, and 3.

3.3.2. Semi-structured interviews

According to (Kumar, 2015), an interview is "any person-to-person interaction, either face to face or otherwise, between two or more individuals with a specific purpose in mind. Semi-Structured interviews provide flexibility, and the interviewer has the space to ask further questions based on interviewee responses" (Bryman, 2012). The interviews were conducted in a semi-structured form. Semi-structured interviews were applied for seven government officials and researchers in public institutions. The use of semi-structured interviews helps to get in-depth information by asking flexible questions. To ascertain the path dependence of relation to both the legal framework and the organizational structure, and how they influence 3D cadastre development, interviews' questions were tailored according to speciality or working position of interviewees. Interview template is shown in appendix 2.

3.3.3. Focus group discussion

Focus group discussion is a form of strategy in qualitative research in which opinions and attitudes towards a topic are explored through a free and open discussion between members of a group and the researcher (Kumar, 2011). Focus group discussion was ideal for finding out policy, future development, and strategy issues in 3D cadastral organizational structure through discussing with the group of cadastral staff. Since "It is also a useful tool in social and urban planning for identifying issues, options, development strategies, and future planning and development directions", according to Kumar (2015). Focus group discussion was applied to investigate the path dependence of organizational structure in land use office where was obligated of cadastral work in Qian Hai special Zone. A group of land use officials had an open discussion of 3D cadastral organizational structure with the researcher. Actually, Researcher's original intention was to have a semi-structured interview with officials from land use office. However, the officials preferred to talk in a group. The focus group discussion was used to answer research sub-objective 2.

3.3.4. Email correspondence

Email correspondence is a valuable and low-cost data collection tool for organizational researchers in revealing middle managers' daily work experience and their personal opinions. Additionally, it is not limited by the distance between respondents and researcher (Parris, 2008). Due to the absence of a respondent during researcher's fieldwork period, email correspondence was used by the researcher, in this case, in order to collect the data of 3D cadastral organizational structure, and 3D cadastral technical changes needed in Shenzhen.

Table 3 Overview of primary data collection

Data collection method	**Respondents (as referred to in text)**	**Organizations and positions**	**For answering which research questions**	**Limitations**
Semi-structured interview	Interviewee 01	Shenzhen Research Centre of Digital City Engineering; Researcher	1abc; 3a	Respondent was not willing to share the technical limits
Semi-structured interview	Interviewee 02	Shenzhen Research Centre of Digital City Engineering; Researcher	2abc; 3abc	N/A
Focus group discussion	Respondent 01; Respondent 02; Respondent 03	Land and Real Estate office in Qian Hai Administration Department	2a; 3abc	Respondents were not familiar with 3D cadastral implementation in practice
Semi-structured interview	Interviewee 03	Land Management Division in Bao An Administration Branch	3abc	N/A
Semi-structured interview	Interviewee 04	Real Estate Office of Urban Planning, Land and Resources Committee of Shenzhen city	1abc; 3abc	Respondent was not familiar with 3D cadastral implementation in practice
Semi-structured interview	Interviewee 05	Shenzhen Urban Planning and Land Resources Research Centre	2abc; 3abc	N/A
Semi-structured interview	Interviewee 06	The first team of Shenzhen Cadastral Surveying and Mapping Office	1abc (with data acquisition); 3bc	N/A
Semi-structured interview	Interviewee 07	Policy and Law division of Shenzhen Real Estate Registration Centre	1a (with registration process); 3bc	N/A
Email correspondence	Interviewee 08	Shenzhen Urban Planning and Land Resources Information Centre	1a	N/A

3.3.5. Secondary data collection method and data sources

Desk research conducted for collecting secondary data to address sub-objectives 1,2, and 3. Desk research is considered as a method which can collect data without conducting direct fieldwork. Mostly it refers to searching library and the Internet. The desk research was used to obtain information concerning the theories and concepts of 3D cadastre system and path dependence in order to understand the concepts.

To understand the 3D cadastre system, academic papers, textbooks, academic journal papers, reports and documents of land administration, cadastral system, and 3D cadastre were searched. To investigate the involvement of 3D technology and the path dependence of the legal framework and the organizational structure in the current 3D cadastral system in China, documents, academic papers, news and reports of Chinese land administration system and the cadastral system were also collected by desk research. Table 4 shows the documents reviewed to understand the current Chinese 3D cadastral system in its technical, legal, and organizational dimensions.

Table 4 Documents for secondary data

Organizational	Legal
• The organization structuring of Ministry of Land and Resources • The organization structuring of Urban Planning, Land and Resources Committee in Shenzhen	• Interim Regulations on Real Property Registration • The Property Law • Measures for Land Registration • The Land Administration Law • The Implementation Rules of The Provisional Regulations on Real Estate Registration • the Measures of Housing Registration • The Urban Real Estate Administration Law

3.4. Data processing

In this research, data processing includes two procedures which are data editing and data analysis.

3.4.1. Data editing

According to (Kumar, 2011), data editing is to make the raw data free of incompleteness and inconsistency. In this research, data is regarded as recording and transcriptions of interviews, focus group discussion, and e-mail communication. The incompleteness and inconsistency of the transcription or records could result from the omission to ask a question, a mistake in writing responses, or errors in speaking by respondents. Data editing helped in improving the quality of the transcriptions and recordings.

3.4.2. Data analysis

The collected data were analysed by adopting a thematic data analysis method (Bryman, 2012). After collecting and editing the data from the semi-structured interviews and focus group discussions, it was analysed by categorizing the data into themes based on research questions and sub-objectives.

In order to identify the pattern of 3D cadastre systems, the constitution, functions, and characters of 3D cadastre system were selected as analysis themes; To investigate the involvement of 3D technology in the current cadastral system in China, the current organizational structure, the legal framework and the 3D cadastral technology being applied during analysis I specifically looked for themes related to the path dependence of the legal framework and the organizational structure of 3D cadastre in China according to the literature review.

3.5. Ethical considerations

In this research, the data collected from semi-structured interviews and focus group discussions was not used for any other purpose except for analysis in this research. In addition, in case the respondents want to see the results of the analysis, the results will be shared with them upon request.

4. RESULTS

4.1. Current 3D cadastral registration system in Shenzhen

In this section, the 3D cadastral registration system in Shenzhen will be described regarding its current type, its technical design, and future development needs.

4.1.1. Type of 3D cadastre being implemented in Shenzhen

The cadastral registration system in Shenzhen is currently being described as "3D tags in the current cadastre (J. E. Stoter, 2004)". The cadastral system has a multi-interface and includes the traditional 2D cadastral interface, registration interface, and 3D cadastre interface. "We are using a 'One Map' system, which includes registration system and cadastral system" (e-mail communication respondent, researcher in Shenzhen Urban Planning and Land Resource Information Centre). Guo (2013) claimed that "it is an ad hoc 3D cadastre solution for the management of urban land space in Shenzhen city."

The parcels are in 2D in the cadastral system in Shenzhen. According to the interviewees 01 and 04, the researcher of Shenzhen Research Centre of Digital City Engineering and the deputy division chief of Real Estate Office of Urban Planning and Land Resources Research Centre, the land parcels in the cadastral system refer to construction land for land grant activities, and the parcels are stored in 2D in the cadastral system. 3D situations are stored with 2D parcels in a 3D cadastral system.

The 3D situations are described by external reference in the registration system in Shenzhen. In general, the text description or elevation are added as reference in the cadastral system to 3D situations. When it comes to the 3D situations that cannot be presented by text description or elevation precisely, those 3D situations would be displayed in 3D and stored in an external 3D cadastral interface to prevent conflicting land use. Figure 9 shows the integration of 2D cadastre and 3D cadastre in Shenzhen. Besides, in the land grant procedure, projection drawings and perspective drawings are added to the legal documents as external reference, to illustrate the 3D situations. An example of an external 3D reference in land grant legal document is shown in appendix 3. However, text description and elevation are still the dominant solutions for managing 3D situations. "Most 2D. With description, or elevation", (interviewee 04, the deputy division chief of Real Estate Office of Urban Planning and Land Resources Research Centre). "The 2D cadastre still takes the majority, and it can solve the majority of problems. The 3D cadastre is not popularized", (focus group discussion member, engineer of Land and Real Estate office in Qian Hai Administration Department). According to Xiao, Zhao, & He (2015), from a management point of view, the dominant management method is still the traditional 2D cadastre. A 3D cadastral application is for the minority of cases that couldn't be presented by 2D cadastre.

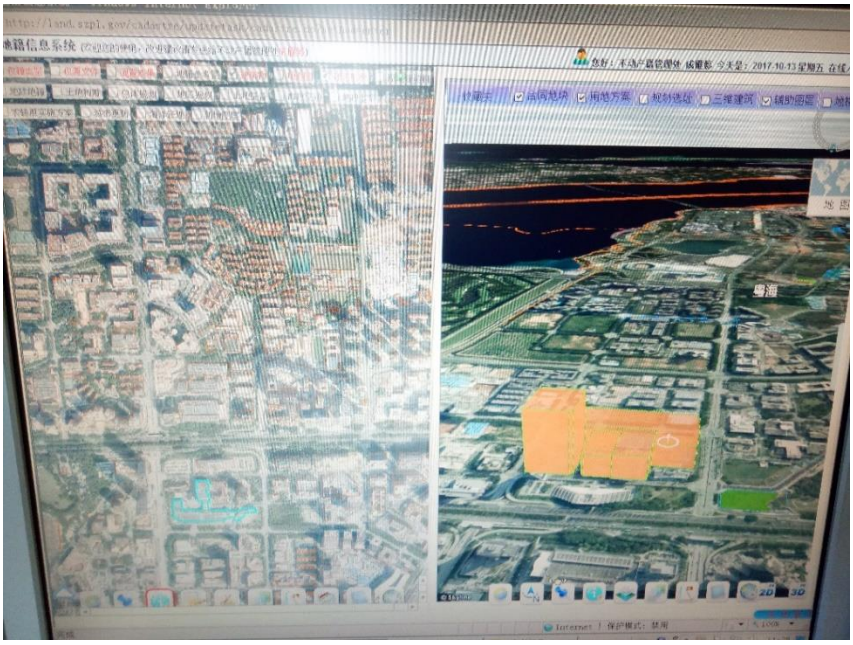

Figure 9 Integration of 2D cadastre and 3D cadastre in Shenzhen

4.1.2. The cadastral development in a technical perspective

The 3D cadastral acquisition methods are mainly satellite image, total station, and mobile GPS. The cadastral data refers to the construction land use right. "We apply total station and mobile GPS for cadastral data acquisition, to collect the parcel information for land grant. After finish building, the same method applied for finish construction building" (Interviewee 06, the team leader of Shenzhen Cadastral Surveying and Mapping Office). There is no independent data collection for 3D cadastre. Only in few cases has oblique photogrammetry and laser scanning been applied for experiment. "We use satellite image, also the data collected by cadastral surveying and mapping office, for the finish construction surveying" (Interviewee 04, the deputy division chief of Land and Real Estate office in Qian Hai Administration Department).

The 3D data model is B/S (Browser/Server) mixed with C/S (Browser/Server) mode, it is established in WAN (Wide Area Network) and LAN (Local Area Network). The 3D data model has three modules, which are built based on the 3D land and planning database: 3D data generation module, 3D query-platform and 3D mapping module. "We have a 2D/3D cadastral data model system. The accurate representation of 3D objects has achieved. The software is managing the 2D/3D data in one platform, it is based on B/S and C/S system, integrated with WebGIS. This system is compatible with the traditional (2D) cadastral system" (interviewee 01, researcher in Shenzhen Research Centre of Digital City Engineering). Figure 10 shows the 3D cadastral system framework.

According to (Xiao et al., 2014), regular 3D data refers to polygons with altitude which could be generated by extrusion, which is generated with B/S mode. Irregular data is the data of 3D situations with concaves or holes, such as subway entrance at underground space and some complex-structured buildings. Under these situations, B/S+C/S mixed model is applied. "B/S mode offers an interface for interacting with database and visualisation toolkit while C/S mode offers Boolean operation module to generate irregular solid and detection module to do conflicts detection" (Xiao et al., 2014). SketchUp is used to generate 3D data and detect conflict for irregular data. The workflow for irregular data generation is shown in Figure 11.

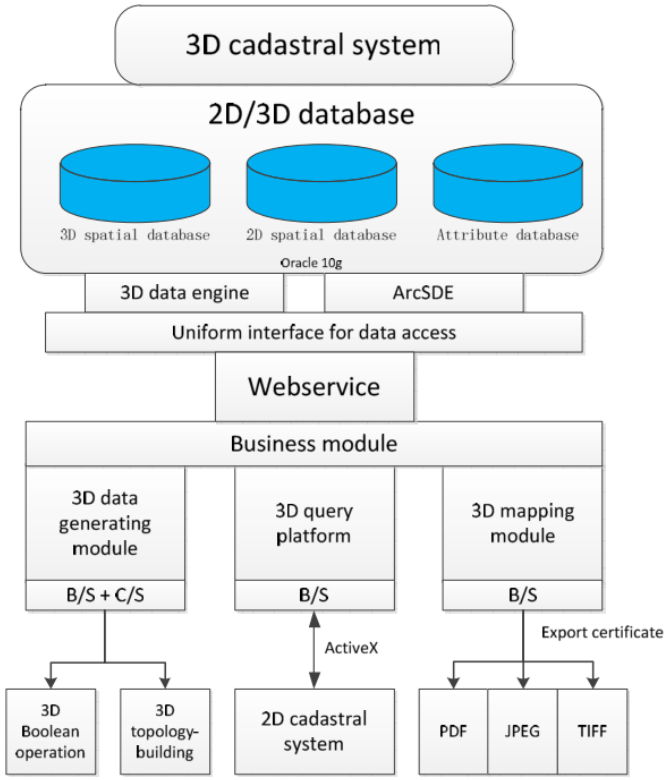

Figure 11 3D cadastre conceptual framework in Shenzhen

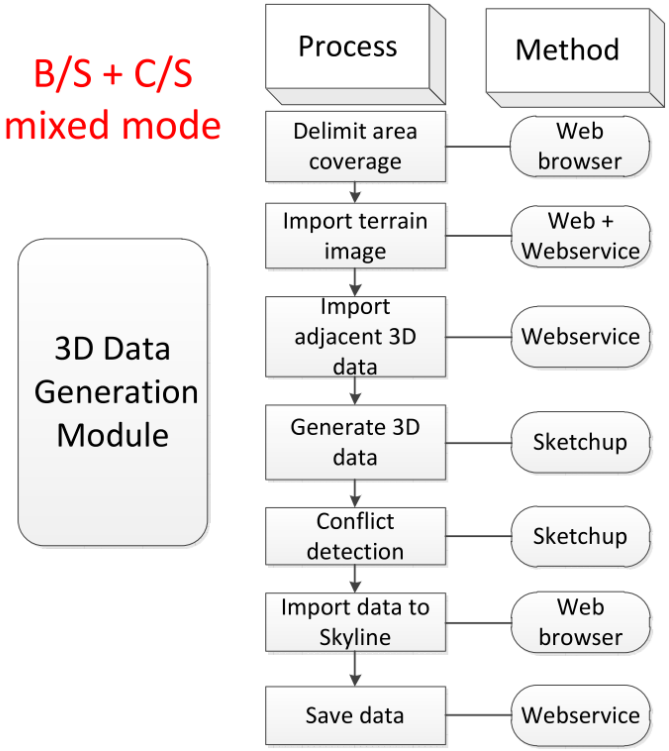

Figure 10 Irregular 3D Cadastral Data Generation WorkFlow

4.1.3. Developments needed for 3D modelling

Although the 3D cadastral technology has been achieved, there are still some developments required. The developments mainly needed are on: Software development and 3D automatic modelling technique. The commercial software such as ArcGIS and SketchUp are suitable for 3D data visualisation, but 3D cadastre requests the more particular parcel and building information to show the RRRs (rights, responsibilities, restrictions) in 3D. According to interviewee 04, deputy division chief of Real Estate Office of Urban Planning, Land and Resources Committee, "the commercial 3D software, Sketchup is not precise enough to present the 3D objects". A case study in Shenzhen also claims the limits of commercial software for 3D cadastre (Guo et al., 2011): "Some interfaces among the functions from different software do not match well such as data structures and capacity of 3D geometric computation." Furthermore, the work report from official website reveals the current task for 3D cadastral technology development is to tackle the 3D automatic modelling technique based on oblique photogrammetry (Urban Planning Land and Resources Committee of Shenzhen City, 2017).

4.2. Path dependence of the 3D cadastral legal framework in Shenzhen

In this section, the current legal 3D cadastre definition will be presented to make the pattern of current 3D cadastral framework in Shenzhen. The path dependence of the 3D cadastral legal framework and required changes are also presented in the following text, which is analysed according to path dependence theory.

4.2.1. Legal definition of 3D cadastre

Current Legislative framework for 3D cadastre

In China, there is no law of cadastre. The Chinese cadastre's relevant definition is mainly introduced by *The Property Law*, *The Land Administration Law*, and *The Interim Regulations on Real Property Registration*. The 2D cadastre has been recognized by law since the 1980s in China. With the high-rise development in Chinese urban areas, there is demand for more intensive land use. Against this background, the national policy, *The Thirteenth Five Year Plan of Land and Resources* has the goal to develop 3D land use: "The development and utilization of underground space in the ground shall be formulated, and the multi-purpose three-dimensional development and composite utilization of the land will be promoted." In 2007, *The Property Law* introduced the concept of 3D for cadastre: Article 136 states that "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 states that land space occupied by buildings, fixtures, and affiliated facilities shall be contained in a contract with the transfer of construction land rights.

Parcel definition: Still in 2D

According to *Measures for Land Registration*, Article 5, "The land shall be registered by the unit of land parcel. The term 'land parcel' refers to the block or space closed by land ownership boundaries." However, in the full 3D cadastre, "space" should be referred to 3D spatial extent. The current land registration is still using 2D parcels in practice.

Real estate registration and definition of 3D property rights

In 2007, the Ministry of Land and Resources issued *The Measure for Land Registration* which guides land registration. In 1994, Ministry of Housing and Rural-Urban Planning issued the *Urban Real Estate Administration Law*, in order to oversee the administration of building property rights. Hence, land registration and housing registration in Chinese urban areas have been separated for a long time. In 2014,

the State Council of China issued the *Interim Regulations on Real Property Registration*, "The state applies a uniform registration system for real estate", introduced by article 4. Accordingly, in 2016, The *Implementation Rules of The Provisional Regulations on Real Estate Registration* was issued, to guide the unified real estate registration in practice. Furthermore, the current laws and regulations couldn't provide a precise definition of property rights in 3D spatial extent.

Legal definition of easement

The concept of easement is defined by *The Property Law* as, "An easement holder shall be entitled to make use of the real property of someone else according to the contract to increase the efficiency of his real property." (Article 156); Additionally, it is based on a contract, "The easement shall be established as of the effectiveness of an easement contract. In case the parties concerned think it necessary to have it registered, they can apply for easement registration with the registration organ; otherwise, they shall not challenge any bona fide third party." (Article 158). However, the concept of easement is not used in local registration practice in the case of Shenzhen at this moment.

4.2.2. Increasing return path dependence of the 3D cadastral legal framework

Lack of acceptance due to legal uncertainty

Although the breakout of 3D land use has been made by *The Property Law* under the national policy underground development, however, according to its definition, the 3D land use is considered as multiple layers which still limit the 3D object's registration.

"According to *The Property Law*, the construction land could be depicted through multiple layers, but each layer is still in 2D (parcel), this impedes on the 3D objects or 3D property. Since in the full 3D cadastre, 3D objects should be registered in 3D volumes which shouldn't be restricted by 2D layers." (interviewee 05, researcher of Shenzhen Urban Planning and Land Resources Research Centre). Figure 12 shows an example of construction which could not be presented well by multiple layers registration methods.

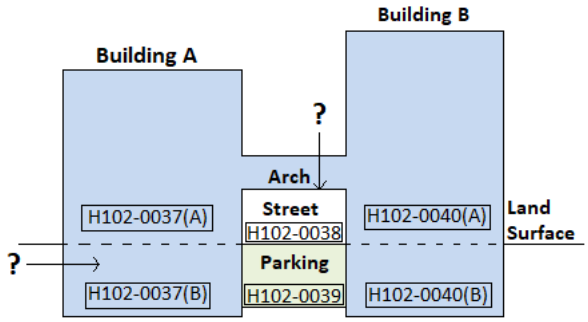

Figure 12 A construction profile

Additionally, the definition of space is not evident in law. *The Property Law* doesn't mention the dimension of space. However, "the construction land could be depicted through multiple layers" seems to imply the cadastre in 2D. "Current *the Property Law* makers do not accept the 3D property yet. They claimed to guard 'the purity' of *The property law*." (interviewee 02, 3D cadastral researcher in Shenzhen Research Centre of Digital City Engineering). Furthermore, the multi-layered land use is not mentioned by *The Interim Regulations on Real Property Registration*. A case study of 3D cadastre in Shenzhen (Guo et al., 2011) also shows the limits of the current legal framework, "the current laws and regulations cannot 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."

To sum up, the current cadastre is still introduced as 2D by law in China. No definition of 3D parcels, 3D objects or 3D property right exist, which means the 3D cadastre is not taken into account by law in the Chinese context.

Decision of upper courts

Upper court decisions are reflected in national law, but the latter conflicts with local department regulation. In Shenzhen, the cadastral implementation office is registering 3D objects according to a draft regulation of 3D cadastre. According to this regulation, '3D property' refers to a spatial envelope containing the construction built with the land space, parcel is used to present the 3D object. In some cases, the property line of parcels is not closed due to the complexity of 3D objects. "Sometimes, 3D property line is not closed, which is conflict with *Measures for Land Registration*." (Interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering).

Furthermore, in Shenzhen, the utilization of land parcel for 3D registration is also in conflict with the *Measure for Land Registration*. "In the 3D land use cases; the land surface has a parcel number, the underground has a parcel number, the above may also have parcel number. It is a multi-layered parcel. With elevation attached, the parcels cannot be used separately, in another word, they are together to present one 3D land use case. But a parcel should be a registration unit independently. I think it should be reconsidered in a legal perspective since parcels should be registered independently, which is a clear concept in *Measure for Land Registration*." (interviewee 07, staff of Policy and Law division of Shenzhen Real Estate Registration Centre). "According to the current regulation for 3D registration in Shenzhen, multiple parcel code is used to present one 3D object's underground space and surface. But it poses an inconvenience for the following management work, especially when it comes to the last step, registration. Since it may cause some misunderstanding, it should be one 3D object, not different parcels." (interviewee 04, vice dean of Real Estate Office of Urban Planning, Land and Resources Committee of Shenzhen city).

4.2.3. Evolutionary path dependence of the 3D cadastral legal framework: "contingency"

The *Civil Air Defence Law* hinders 3D cadastral registration as a law outside the cadastral legal framework. According to *Civil Air Defence Law*, article 14, "In constructing trunk lines of underground traffic and other underground projects in a city, consideration shall be given to the needs of civil air defence." Therefore, in Chinese urban areas, some underground space is constructed for civil air defence. However, this type of underground construction could not be registered into 3D cadastral system, because its obtain construction land usership type is not guaranteed by cadastral law. In China, there are two kinds of methods to gain construction land usership from government according to *The Property Law*, article 137: land grant and land allocation. The land for civil air defence is allocation land; the ownership is state-owned. However, according to *The Interim Regulations on Real Estate Registration*, article 5, it doesn't introduce the registration for state-owned land ownership. In addition, the current 3D cadastral is only applied in the land grant process. Therefore, the underground space for civil air defence use could not be registered by 3D cadastre in Chinese urban areas, this kind of underground space could be a missing part for 3D cadastral registration due to legal definition.

To sum up, the underground construction for civil air defence usage is evolutionary path dependence of 3D cadastral registration in Chinese urban areas. It is introduced by *Civil Air Defence Law* which is outside of the Chinese 3D cadastral legal framework. But this type of underground construction could not be registered in 3D cadastral system.

4.2.4. Sequencing path dependence

The separation of housing registration and land registration impedes 3D cadastral registration in cadastral framework. In China, the registration authority separates land and housing because of individual executive land administration and housing management. Accordingly, *The Measures for Land Registration* was issued by Ministry of Land and Resources, to govern the land registration work; *The Urban Real Estate Administration Law* issued by Standing Committee of the National People's Congress in order to guide the real estate work. The land registration and housing registration disaggregated each other and operated independently. Although in *The Property Law* and *The Interim Regulations on Real Property*, the unified real estate registration has been set up as a national goal. The historical separation resulted in cadastre referring to land parcel and property line for land administration, and the land use right is registered as whole construction parcel. No exact geometric location for individuals would be registered (further explanation is given in 4.3.1.4.). In addition, there is no definition for 3D property. As a consequence, the current 3D cadastral in Shenzhen could only register land use right for a whole parcel. "It is not clear from the house right, since there is no exact location for house right. Land right is allocation according to house ownership proportion when it comes to land registration. So, the current cadastre only registers land rights." (interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering)

In conclusion, the history of separation registration of land use right and house ownership result in unclear registration method for 3D cadastral registration, which is considered as path dependence of Chinese cadastral organizational structure.

4.2.5. Changes needed for the cadastral legal framework

To cater for 3D cadastral development, some changes are needed in the current cadastral legal framework. First of all, the specific legal definition of 3D cadastre is needed. In China, there is no law of cadastre or 3D cadastre. The cadastre is defined by *The Property Law*, *The Land Administration Law*, *Measures of Land Registration*, *The Urban Real Estate Administration Law*, and *The Interim Regulations on Real Property*. 3D land right is legally forced by *The Property Law*, but "There is no law of cadastre or 3D cadastre, but cadastral elements and process are mentioned by other law and regulations. 3D cadastre doesn't have a standardized workflow." (interviewee 05, researcher of Shenzhen Urban Planning and Land Resources Research Centre). Therefore, besides updating the legal framework to enable 3D cadastre development, standardization in the workflows to implement laws are required.

The explicit definition of 3D property right, 3D parcels, and 3D objects are required in the legal framework for 3D cadastral development. The lack of clarity leads to 3D cadastral implementation has conflicts with current law. For instance, currently, one 3D object may be registered with several parcel codes to distinguish the underground and aboveground situations. However, under current law, one parcel number represents one object, which could be transited independently. In this case lack of 3D objects 'definition is a change needed in cadastral law. Therefore, 3D cadastre and its relevant elements should be defined percisely by law, in order to legally guarantee 3D cadastral implementation in China.

Additionally, the legal definition of easement should be improved. The current easement is based on the agreement between two parties; it would be valid after registration the agreement contract. However, the contract-based easement may impede on 3D land use, in case the citizens would not agree with underground land utilization. "The easement is defined in *The Property Law*, it should be agreed by both parties, which may impede on 3D land use. For instance, the pipeline cannot be constructed under someone's house without the house owner's agreement, neither does subway. In 3D situations, easement should be involved more frequently, the current mode of easement would impede on 3D cadastre's implementation." (interviewee 05, researcher of Shenzhen Urban Planning and Land Resources Research Centre) Therefore,

easement should be improved to the mode without registering contracts, in order to cope with 3D land use.

4.3. Path dependence of the organizational structure in Shenzhen

In this section, the Chinese land tenure system and real estate registration methods are explained in order to give the pattern of the cadastral organizational structure in Shenzhen. The path dependence of the 3D cadastral organizational structure and changes needed are presented afterwards.

4.3.1. Land administration and cadastre in Chinese context

This section first introduced the land tenure system, then the cadastral system from Chinese national level to Shenzhen local level will be explained, included housing registration and land registration. The current two kinds of registration method were also demonstrated by text and figures.

4.3.1.1. Land ownership, land use right, other rights, and rights on buildings

In China, three types of rights exist in land tenure system: Land Ownership, Land Usership, and Other rights.

According to *Land Administration Law*, article 2, "the People's Republic of China practices socialist public ownership of land, namely, State Ownership by the whole people and Collective Ownership by agriculture collectives. Ownership by the whole people means that the State Council exercises the right of ownership of State-owned land on behalf of the State." All the land is owned by State or Collective in China. Table 5 shows the coverage of two types of ownership.

Table 5 Land ownership and its coverage (Zhang, 2006)

Ownership	Coverage
State-owned land	• Urban areas; • Rural land not for agriculture use; • Rural and suburban area that is confiscated, requisitioned, expropriated; • Forestland, grassland, hills, wasteland, mineral resources, mountains, unclaimed land, flood land and other types of land, which the state has not determined to be owned by collectives
Collective-owned land	• Rural and suburban areas except the land is confiscated, requisitioned, expropriated • Rural land for agriculture • House sites and private plots of cropland and that of hilly land

In China, "Land use rights" could be transferred to the private individuals and entities, which is part of the government's goal of establishing land market transactions (Ji, 2007). That is to say, in urban areas, all the land is owned by state, private individuals or entities can hold the land in a valid term regarding land use right.

Currently, two types of other rights exist in China: Mortgage and lease right.

The ownership of buildings is apart from the land ownership in China. In urban areas, Chinese citizens or entities could own the buildings, with limited land use right, while the state is the owner of land. The current rights on buildings are ownership and other rights (lease right and mortgage).

4.3.1.2. Land use types

In China, land use type restriction is based on land use planning, and the land is mainly categorized into Farming land, Construction land, and Unused land. The table below indicates the categories of land in China (Ji, 2007).

Table 6 Categories of land in China

Farming Land	• Farmland • Garden land • Woodland • Grassland • Other farming lands
Construction Land	• Commercial land • Industrial & mineral land • Public utility land • Public construction land • Residential land • Traffic land • Water conservancy land • Special land
Unused Land	• Unused land • Other lands

4.3.1.3. Ways to obtain the land usership from the state

Regarding the construction land which is state-owned in urban areas, a private person or entities can get the land usership with a specific period from the state in two ways: Land grand and Land allocation. Accordingly, two kinds of land usership in terms of construction land exist in urban area: granted land usership and allocated land usership.

The land usership obtained by allocation could not be transferred, leased, or mortgaged. But the granted land could be transferred, leased, and mortgaged.

In Shenzhen, the Land ownership, land use right, other rights, rights on buildings, and the ways to obtain the land usership are same with national level.

4.3.1.4. Cadastral system from Chinese national level to Shenzhen level

According to Ji (2007): "Real estate registration is the main task of cadastral management, and real estate registration is actually cadastral registration in China." In Chinese urban areas, there are two methods of real estate registration: land and house separate registration, unified real estate registration. Although on 1st of March 2015, *The Interim Regulations on Real Property Registration* commenced with the plan to establish a unified real property registration system in three years for the whole country, the currently commonly applied registration type is "land and house separate registration system".

Land and house separate registration system

According to the *Measures of Land Registration* and *The Measures of Housing Registration*, the registrations of land and housing are separate. For urban housing registration in China, the house owner has to register with two separate authorities to obtain two different entitlement certificates: certificate of housing ownership with the housing authority, and a certificate for a land use right with land administration authority. This type of registration system is mainly because land administration and house are managed separately by MLR (Ministry of Land and Resources) and MOHURD (Ministry of Housing and Urban-Rural development). In provincial level, the Department of Land and Resources and Department of Housing and Rural-Urban Development are responsible for Land registration management and House registration management.

Land registration was implemented by authorities of land and resources in different administrative levels in China. Land registration in China has initial land registration and change land registration, which registers ownership, usership, and other rights on both State-owned land and collective-owned land.

Under the separate registration system, administrative departments of housing and urban-rural development in different administrative levels are the authorities of housing registration. Building registration is the process of recording building ownership and other rights.

Unified real estate registration system

According to *The Interim Regulations on Real Property Registration*, land use right for construction land and housing ownership should be registered together. In urban areas, the house owner registers with local authorities of real estate registration departments to obtain one certificate of construction land use right and housing ownership.

Under the unified real estate registration system, cadastral data includes land information and housing ownership. The construction land's land use right is granted to a real estate developer, while after building construction and house sale, the land use right is registered together with housing ownership for house owners. The land ownership is allocated to the house owners according to the house's proportion of the whole building (exclude the public-use areas of this building).

Figure 13 shows the real estate construction and sale process: the real estate developer grants a parcel of construction land from government and becomes land use right holder. After construction and sale, house owners become land use right holders of this parcel of construction land and housing owners. Figure 14 and Figure 15 demonstrate examples of unified real estate registration and separate real estate registration. In the following graphs, purple squares symbolize land parcels, the person who is in suit symbolize the real estate developer; percentage symbolize house owners' land use right of the whole parcel's land use right (exclude the land use right for public areas, such as elevator, passageway, etc.)

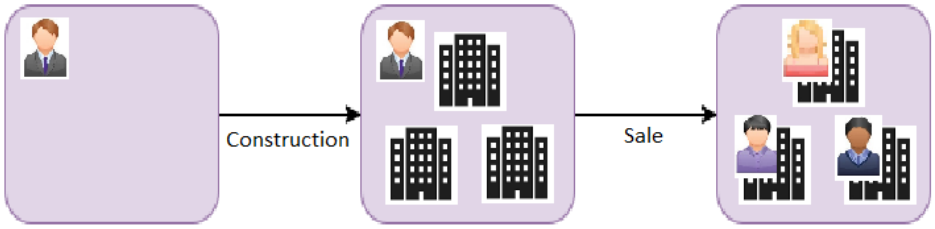

Figure 13 Real estate construction and sale process

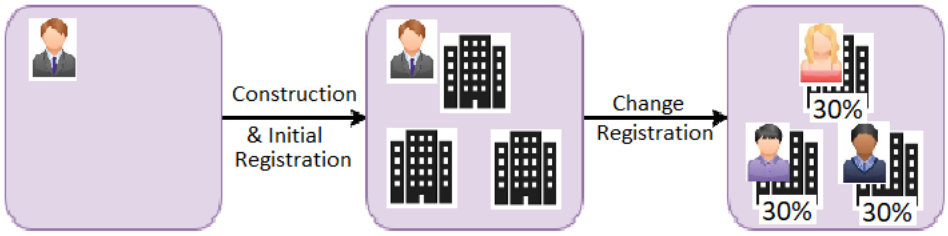

Figure 14 An example of unified real estate registration

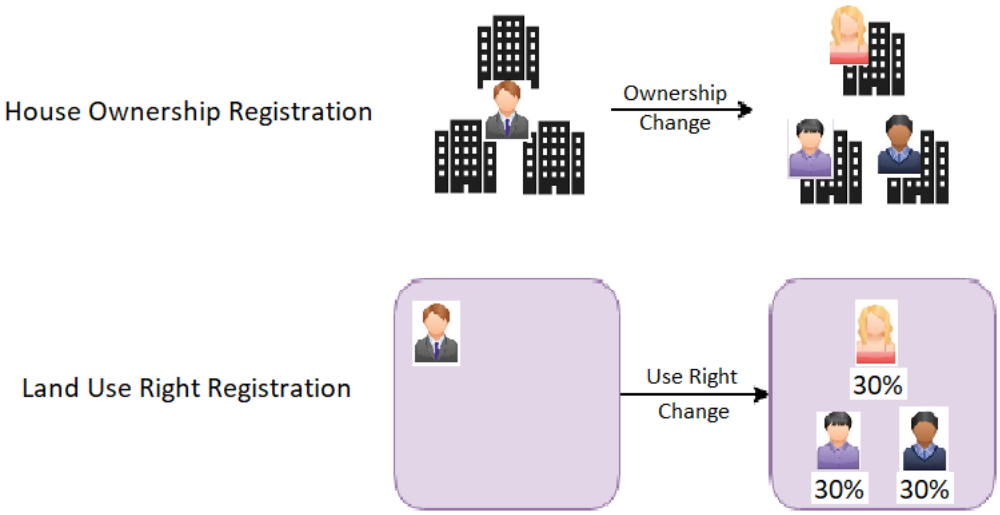

Figure 15 An example of separate real estate registration

Land administration and cadastral system in Shenzhen

In Shenzhen, the housing and urban-rural development and land resources department are merged, which is UPLRC (Urban Planning, Land and Resources Committee of Shenzhen city). It is the subordinate administrative department of Ministry of Land and Resources (national level), Ministry of Housing and Urban-Rural Development (national level), Department of Land and Resources of Guangdong Province (provincial level), and Department of Housing Urban-Rural Development (provincial level). There is no cadastral office in Shenzhen. The land use office is responsible for management of land administrative and cadastral work.

Land use offices in Shenzhen planning and Land Resources Bureau Direct Branches (county level) supports land administrative work and cadastral work for UPLRC in 8 districts in Shenzhen as supporting units. Land and Real Estate Office in Qian Hai Administrative Department is responsible for management of land administration and cadastral work in Qian Hai special economic zone.

In Shenzhen, cadastral management and implementation are separate. Five public institutions provide cadastral technology and research support for governmental institutions and special zone management institutions. Shenzhen Cadastral Surveying and Mapping Office is responsible for cadastral data acquisition; Shenzhen Urban Planning and Land Resources Information Centre and Shenzhen Research Centre of Digital City Engineering are responsible for cadastral database set up, updating, and maintenance. Shenzhen Urban Planning and Land Resources Research Centre is responsible for research of urban planning and land administration. Shenzhen is applying unified real estate registration system. The real estate registration

centre implements the registration work. Figure 16 shows the cadastral from national level to Shenzhen local level.

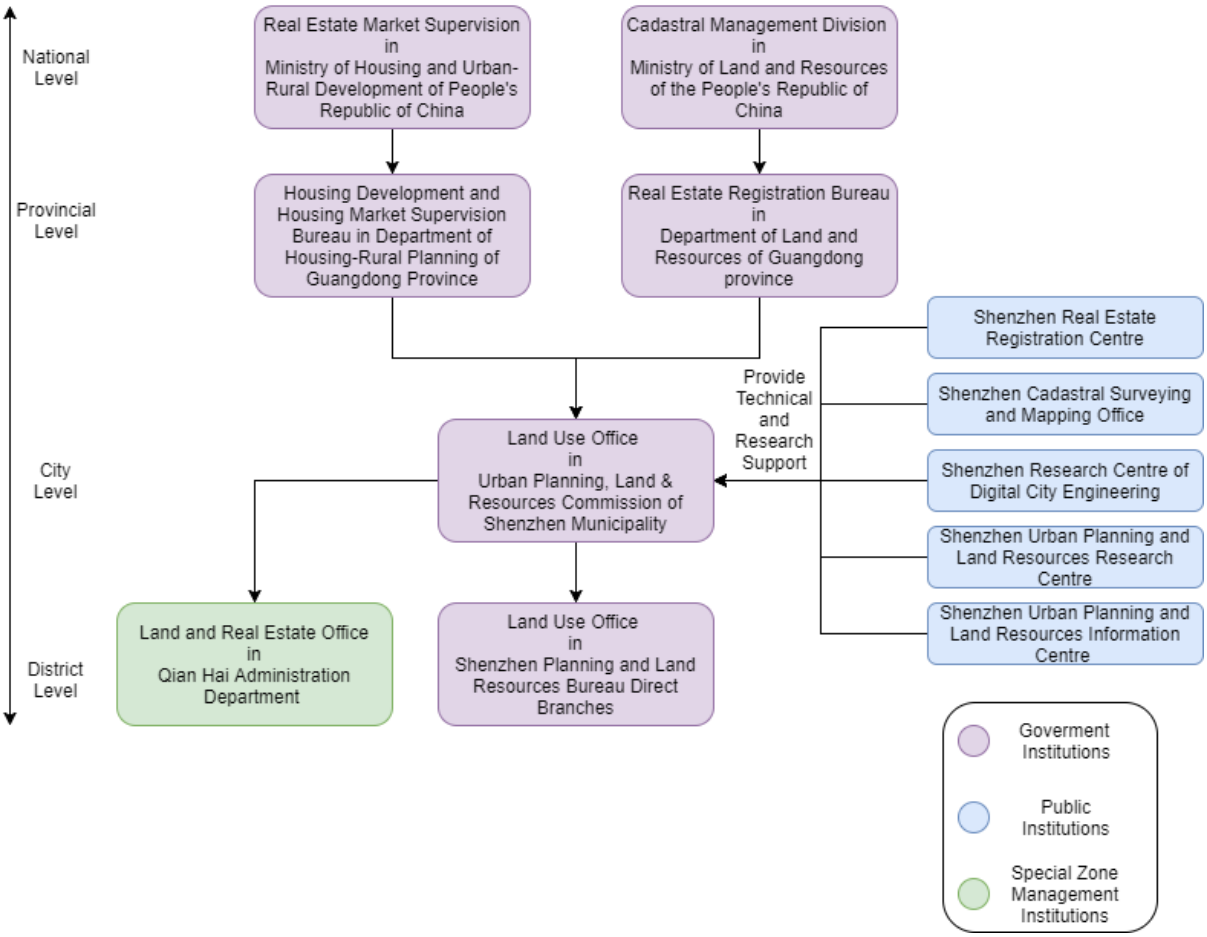

Figure 16 The cadastral organizational structure from Chinese national level to Shenzhen level

Land administrative workflow and stakeholders in Shenzhen

In Shenzhen, UPLRC manages urban planning and land administration work. The 2D cadastral workflow is: First of all, urban planning department makes land allocation plan, and selects a site for construction in Shenzhen. After that, the land administrative department approves the land use according to the land allocation plan. Then, Shenzhen Cadastral Surveying and Mapping Office survey the approved construction land parcel. After assessment by land administrative department, the construction land would be granted to real estate developers. Before real estate developers design their construction project, approval of Project Planning by Urban Planning department is needed. After project design, urban planning department approves the building construction and real estate developers implement construction project. The finished construction would be surveyed by Shenzhen Cadastral Surveying and Mapping Office, in order to verify the construction does not exceed the area of parcel. The building data would be registered into cadastre database in the majority cases of 2D. Shenzhen Urban Planning and Land Resource Information Centre and Shenzhen Research Centre of Digital City Engineering are responsible for cadastre database set-up and updating; they also provide research support together with Shenzhen Urban Planning and Land Resource Research Centre. The last step of cadastral workflow is real estate registration, which is implemented by Shenzhen Real Estate Registration Centre.

In Shenzhen, there is no systematic workflow for 3D cadastre. The 3D cadastre is implemented for minority cases. When it comes to land grant, the 2D cadastre cannot present the land information precisely, or if the government wants to grant land for underground space, 3D cadastre would be implemented. "When it comes to land grant, the construction land parcel attaches with complex buildings; land information cannot be presented clearly by 2D cadastre. In that situation, we sometimes use the 3D cadastre." (interviewee 04, vice dean of Real Estate Office of Urban Planning, Land and Resources Committee)

The Land use office manages the 3D cadastral system, and the Shenzhen cadastral Surveying and Mapping Office collect 3D cadastral data. However, only a few researchers from the Shenzhen Research Centre of Digital City Engineering and Shenzhen Urban Planning and Land Resources Information Centre know 3D cadastral technology well and are responsible for 3D cadastral building and information updating. To sum up, there is no unified goal to implement 3D cadastre from the Chinese national level to the Shenzhen local level. In terms of hierarchy, there is no cadastral department since cadastre is subordinate under land administration in Shenzhen. Additionally, there are not enough professional 3D cadastral workers to implement this new technology. Figure 17 shows the cadastral workflow and stakeholders in Shenzhen.

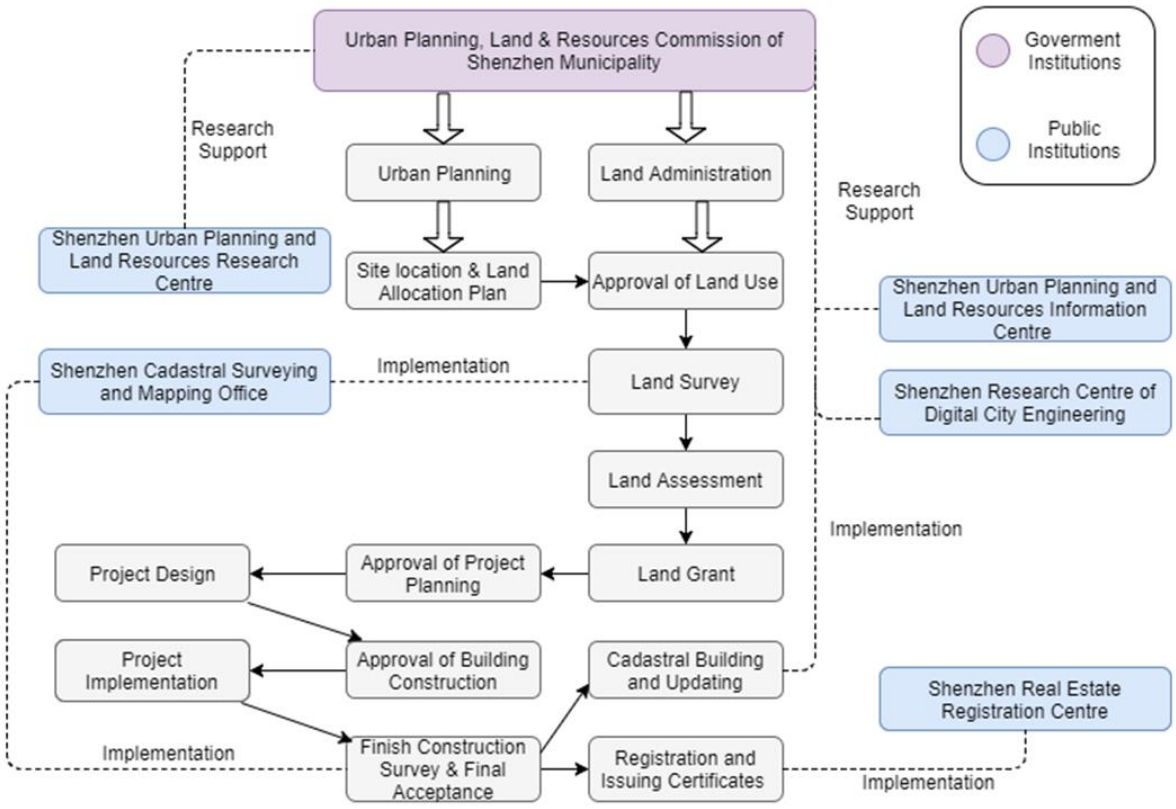

Figure 17 Cadastre workflow and stakeholders in Shenzhen

4.3.2. Path dependence of 3D cadastral organizational structure in Shenzhen

In this section, the path dependence of 3D cadastral organizational structure in Shenzhen will be presented, based on increasing return path dependence, sequencing path dependence, and evolutionary path dependence.

4.3.2.1. Increasing return path dependence in organizational structure

Inertia

In Shenzhen, cadastral officials are lazy to switch 3D cadastre from 2D cadastre. In the cadastral management and implementation departments, people generally don't have strong motivation to develop 3D cadastre, although they know 3D cadastre would be more efficient for cadastral management because there is lack of support to learn new skills (3D cadastre) for cadastral workers. Additionally, the existing professionals are more familiar and satisfied with existing routines (2D cadastre), they don't want to adopt 3D cadastre.

For cadastre managers in governmental organizations think the current 2D cadastre with 3D tags could cope with 3D registration. "In general, everyone knows 3D cadastre is good. But when it comes to implementation or development, some leaders are not willing to change. And as I mentioned before, they think 2D cadastre with text description and elevation could solve the problems so far; even they know 3D cadastre is good." (interviewee 05, researcher of Shenzhen Urban Planning and Land Resources Research Centre).

For the cadastral implementation departments, people's task is implementation, they are lazy to change the current workflow. "Most of the staff of cadastral implementation departments are satisfied with 2D cadastre, actually they may not really satisfy, they are just lazy to change. That is another reason why 3D cadastre is difficult to develop." (interviewee 04, vice dean of Real Estate Office of Urban Planning, Land and Resources Committee).

The inertia exists in organizations because 2D cadastral has been used for a long time, and it is working well generally. "Traditional 2D cadastre has been implementing for a long time. It is a mature technology. In recent years, some arisen cases cause property conflicts in traditional 2D cadastre. The traditional solution in 2D cadastre is extra text descriptions, which is fussy and not convenient, but they are minority cases. Besides, 2D cadastre could manage the land information well." (interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering).

Large switching cost

The large switching costs are another path dependence of organizational structure which hinders 3D cadastral system development and implementation. According to interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering, "It (3D cadastral development) needs the cost of research which includes technical aspect, institutional aspect, and legal aspect. Also, the cost of implementation which includes personnel training and system development. In addition, the public awareness of 3D cadastre is week, publicizes cost is also needed."

The switching cost of 3D cadastre is large. According to interviewee 04, vice dean of Real Estate Office of Urban Planning, Land and Resources Committee, "So far, we have spent around 6 million to 7 million CNY (around 901,000 Euro) for research, around 5 million CNY (around 643,000 Euro) for 3D cadastral establishment." While according to observation of the 3D cadastral system in Shenzhen, the system has

not been updated since 2011, which means the 3D cadastral may need more cost for maintaining and applying in practice.

Lack of acceptance

In Shenzhen, many cadastral divisions haven't accepted 3D cadastre yet. They think 2D cadastre is working well, there is no necessity to use 3D cadastre. "The implementation departments think 2D cadastral system is good, it has been using for many years, and it seems working fine. Why use 3D cadastre?" (interviewee 04, vice dean of Real Estate Office, who is also the 3D cadastre manager in Shenzhen) "In Shenzhen, some departments such as Urban Planning, Land and Resources Committee of Shenzhen city and our research centre have been aware the importance of 3D cadastral implementation. But some other departments may not be confident with 3D cadastral implementation." (interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering)

Many cadastral departments haven't seen the advantage of 3D cadastre, also because they are not familiar with 3D cadastre in practice. During the focus group discussion with leader and engineers from Land Use Office of Qian Hai Administrative Department, respondents showed their lack of understanding and acceptance of 3D cadastre. "We are more satisfied with BIM. Since BIM has the construction information in detail." "I think the 2D cadastre can present the parcel information better." (respondent 02,03, engineers of Land Use Office of Qian Hai Administrative Department).

4.3.2.2. Evolutionary path dependence: "contingency" outside cadastral structure

3D cadastral institutional aspects are considered as land titling, land registration, and information supply in 3D. (Van der Molen, 2003). In Chinese urban areas, the real estate registration is actually the cadastral registration (Ji, 2007), since there is difference between land ownership and house ownership. Therefore, 3D cadastral institutional aspects are considered as real estate titling, real estate registration, and real estate information supply in Chinese urban areas. But in general, the house ownership and land use right are managed by two different authorities: housing and urban planning department and land & resources department. The 3D cadastre is directly controlled by land & resources organizations, housing and urban planning are managed and implemented by the housing and urban planning departments which are outside of land administrative structure in China. As a consequence, the separate organizational structure impedes on titling, registration, and information supply of 3D cadastre as contingency evolutionary path dependence.

Separate organizational structure hinders 3D cadastral titling, registration, and information supply. In Shenzhen, the housing and urban planning department is merged with land administration department. In addition, Shenzhen is implementing unified cadastral registration for more simplified titling, the house ownership and land use right are titled in one certificated, and the house ownership and land use right are stored in one system, which brings more efficiency for 3D cadastral management. According to interviewee 01, researcher and 3D cadastre builder in Shenzhen Research Centre of Digital City Engineering "Firstly, the workflow is better connected. Also, for house owners' convenience when they want to conduct titling and registration service. Secondly, the information is better communicated, since housing and land administration information is shared on one platform. For instance, the planning department plan the land use, produce the "Planning Map" which could be the gist of the follow-up land administration."

However, in China, the real estate titling, registration, and information supply are still implemented by two different authorities, which is complicated for 3D cadastral management. "In national scale, the Planning and land administration departments should be merged, for unified management system and matched land& housing information." (interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering)

4.3.2.3. Sequencing path dependence: barriers inside cadastral structure

In Shenzhen, the current 3D cadastral organizational structure obstructs the 3D cadastral implementation, and the main reasons are: lack of systematic workflow and 3D cadastral implementation is separate with management.

There is no systematic workflow for 3D cadastral system in Shenzhen. The 3D cadastre is considered as a technology that could not be utilized in practice. According to interviewee 02, cadastral researcher of Shenzhen Research Centre of Digital City Engineering "The current 2D cadastral registration has a workflow. The 3D cadastral registration doesn't have a workflow yet, which is a challenge for 3D cadastral development." In fact, 3D cadastre is in pilot project in Shenzhen. In 3D cadastral researchers' point of view, 3D cadastre is in exploring stage. "3D cadastre is in exploring stage. And there is no specific objective to manage or develop 3D cadastre." (interviewee 01, 3D cadastre builder and researcher in Shenzhen Research Centre of Digital City Engineering).

The 3D cadastre implementation departments and management departments are separate in Shenzhen. The 3D cadastre is managed by governmental organizations and implemented by researchers in public organizations. Interviewee 04, cadastral manager of Real Estate Office of Urban Planning, Land and Resources Committee of Shenzhen city showed the confidence about separate management organizational structure, "We have been managing and implementing 2D cadastre for a long time, I personally believe it would also work for 3D cadastre." However, the 3D cadastral researchers and builders in public organizations hold the opposite point of view. "Their (cadastral managers) understanding of 3D cadastre is not at the same level with researchers. They don't understand the 3D cadastre so they cannot manage it well, they don't know how to adjust the management strategy to cope with 3D cadastral implementation." (interviewee 01, 3D cadastral researcher and builder in Shenzhen Research Centre of Digital City Engineering).

4.3.3. Changes needed in cadastral organizational structure

In order to cope with the 3D cadastral implementation, there are some changes needed in current Chinese cadastral organizational structure. According to Stefan (2013), three characteristics are used to illustrate the defining features of organizations in modern society: membership, goals, and hierarchies. Organizations take an ultimate goal, then break it down to sub-goals. In order to accomplish those sub-goals, specific divisions, departments within the organizational hierarchy are hence established. Then, the suitable members are recruited to fill the positions. Therefore, the 3D cadastral organizational structure in Shenzhen would be evaluated according to "goals", "hierarchies", and "membership".

Firstly, a unified goal to develop 3D cadastral from national level to local level is needed. Currently, there is no unified goal to develop 3D cadastre in China, since 3D cadastre is only needed in the construction-intensive urban areas. Shenzhen is on pilot project of 3D cadastre implementation. "There is no unified goal to develop 3D cadastre from Chinese national level to local level. In Shenzhen, we are in pilot

experiment of 3D cadastre. Actually, 3D cadastre is only needed in intensive land-use areas, in first-tier cities and second-tier cities at the moment." (interviewee 04, deputy division chief of Real Estate Office of Urban Planning and Land Resources Research Centre). In researchers' point of view, the strategy of 3D cadastre development is "developing technology to promote organizational motivation" (Guo et al., 2014), which is incoherent with goal-oriented strategy for organizations. Since there is no unified goal to develop 3D cadastre in China, 3D cadastral development doesn't take the priority in land administration work. Currently, there are no united motivations to implement 3D cadastre from bottom to top. 3D cadastral development is hence impeded. Therefore, a unified goal is needed for developing 3D cadastre in China.

Secondly, the matched hierarchies are needed for 3D cadastral development. In China, the current cadastre is subordinate to land administration departments. There are hardly cadastral departments. Usually, land use office takes charge of the cadastral work. "Cadastre offices are departments under urban planning and land& resources department. Sometimes, there is even not a cadastre office, the land use office takes charge of cadastral works, such as the Land Use Office in Urban Planning and Land Resources Commission of Shenzhen Municipality." (interviewee 05, researcher of Shenzhen Urban Planning and Land Resources Research Centre) However, 3D cadastre is being explored by some research centres as a new technology in pilot projects. Therefore, there is no systematic workflow for 3D cadastral implementation. "The 3D cadastral registration doesn't have a workflow yet, which is a challenge for the 3D cadastre implementation." (interviewee 02, 3D cadastral researcher in Shenzhen Research Centre of Digital City Engineering) Without unified goal or matched departments for 3D cadastral implementation, the development of it is thereby hindered. Therefore, matched 3D cadastre hierarchies are also needed for 3D cadastral development.

Thirdly, personnel allocation is needed for 3D cadastral development. Currently, only several people with doctoral degree can execute 3D cadastral projects in Shenzhen, and these people are mainly from Shenzhen Research Centre of Digital City Engineering and Shenzhen Urban Planning and Land Resources Research Centre. However, it is not realistic to implement 3D cadastre only by them, "I personally think there is issue about personnel allocation. Since now people who are implementing or managing 3D cadastre, their background is surveying, their view is limited for 3D cadastre. Also, even all of them at least have a BSc degree, the 3D cadastral implementation is still too difficult for them at this moment, which is also a problem of popularization of 3D cadastral technology" (interviewee 04, deputy division chief of Real Estate Office of Urban Planning and Land Resources Research Centre). Lack of 3D cadastral technicians also brings barriers to 3D cadastral implementation. Thus, personnel allocation is needed for 3D cadastral development.

5. CONCLUSIONS

In this section, the research will be first reviewed to summarize the workflow of this research. The findings relevant to path dependence, but also those not related to path dependence will be outlined next. Finally, the contribution of this research and its relevance to practice, as well as its limitations of, will be explained.

Research Review

This research aimed at finding out the influence of path dependence on 3D cadastre development in Shenzhen, China, resulting from the legal framework and organizational structure. In order to address the main objective, I conducted fieldwork in Shenzhen (case study area), reviewed documents and literature which are relevant to the cadastral organizational structure or the cadastral legal framework in Shenzhen. Also, I looked into path dependence literature, because my expectation was that path dependence could partly explain the status of 3D cadastre adoption in the Chinese cadastral context.

By reviewing path dependence literature, I summarized the main path dependence factors related to the legal framework and the organizational structure, in order to generate questions for primary data collection. During the fieldwork, I visited the cadastral organizations to collect primary data in the form of semi-structure interviews, focus group discussion, and email communication. According to documents and literature review, secondary data was collected in order to understand the current cadastral organizational structure and legal definition of 3D cadastre in Shenzhen.

Main Findings: Where is path dependence evident

By analysing the primary data and secondary data, the path dependence of the legal framework and the organizational structure mainly features in the dimensions of increasing return path dependence, evolutionary path dependence, and sequencing path dependence." Increasing return path dependence implies that objects tend to stick to existing paths, due to their resistance or inertia to make changes. Evolutionary path dependence means that external factors may impede on objects' development. Sequencing path dependence posits that each step in the development chain depends on previous steps as a sequence. These three dimensions of path dependence will be further illustrated first for the legal framework and then for the organizational structure of the Chinese cadastre as evident in this study.

In the Chinese cadastral legal framework, increasing return path dependence is evident in the lack of clear definition of 3D cadastre, 3D parcel, 3D objects, or 3D property right. The main reason is a lack of acceptance of 3D cadastre, in the perspective of lawmakers and cadastral officers, cadastre is still in 2D. As a consequence, 3D cadastre is not legally guaranteed by law at the moment in China. Additionally, the current application of parcels in 3D cadastral regulation (draft) in Shenzhen conflicts with the definition of parcel in Measures of Land Registration in Chinese national level. It is evident in "upper courts decisions" reflected in national law, which hinders 3D cadastre adoption in terms of the local legal frameworks. Furthermore, there is evidence of evolutionary path dependence in the legal framework. The Property Law introduces civil air defence land as allocated state-owned land. Accordingly, Interim Regulations on Real Estate Registration introduces cadastral registration, but not for state-owned land. Therefore, the underground construction of civil air defence (introduced by Civil Air Defence Law) could not be registered by 3D cadastre. Sequencing path dependence results from in the long period of separation of housing registration and land registration in the Chinese urban context, which interrupts workflows in registration.

The Measures for Land Registration and The Urban Real Estate Administration Law are laws of land registration and housing registration, respectively, and both spheres are important for 3D cadastre registration. The current challenge of a non-unified cadastral legal framework was caused by this separate registration.

In the Chinese organizational structure, increasing return path dependence, evolutionary path dependence, and sequencing path dependence is also obvious. Firstly, in terms of increasing return path dependence, cadastral officials are not motivated to switch the 2D cadastre to 3D cadastre, the main reasons are because the long period of practicing 2D cadastral brings resistance for cadastral officials to switch. Also, lack of acceptance by cadastral officials associated with the large switching costs are the main factors which hinder 3D cadastral adoption. Secondly, in China, housing and urban planning organizations have been separating with land administration organizations for a long time, which reflects evolutionary path dependence, because the housing registration is managed by housing and urban planning organizations, while land organizations manage cadastral registration. However, housing registration is involved in 3D cadastral registration. In this situation, the separate organizational structure causes non-unified cadastral workflow which hinders housing information sharing with cadastral departments. Thirdly, when it comes to sequencing path dependence, there is no systematic 3D cadastral workflow at the moment in China due to the separate cadastral organizational structure. The separate cadastral organizational structure is a previous administrative decision, and it hinders 3D cadastral development.

Other Findings: Issues outside path dependence theory

According to the fieldwork in the case study area, some 3D cadastral technical issues are hindering 3D cadastral implementation. Regarding 3D cadastral technology, for example, the 3D cadastral technology should be improved in terms of software development and 3D automatic modelling technique. With the development of 3D cadastral technology, cadastral workers would see more advantages with 3D cadastre, and would thus be more confident to switch to 3D cadastre.

In terms of 3D cadastral organization, there is no unified goal to establish 3D cadastre. The 3D cadastre is at a stage of being explored. Accordingly, no systematic workflow to achieve 3D cadastral implementation exists yet. Additionally, there are not enough 3D cadastral experts to conduct research or implementation of 3D cadastre in a 2D environment.

The practical significance of research findings: Does 3D cadastre development take the priority?

It is obvious that 3D cadastre is a future trend to be developed. However, the priority of 3D cadastral development for Chinese land administration should also be considered.

In Shenzhen, the 3D cadastre should be developed after completing the current 2D cadastre database. At this moment, although Shenzhen is the first city to implement 3D cadastre in China, the 3D cadastral registration still applies to the minority of cases. Furthermore, the current 2D cadastral data is not complete, and it still has a long way to be completed. According to interviewee 08 (researcher of Shenzhen Urban Planning and Land Resources Information Centre): "The current (2D) cadastral data is not complete in Shenzhen, the main reasons are: Firstly, in Shenzhen, we don't do ownership investigation in field, we only check on satellite image. The satellite image may not reflect the newest land information precisely. Secondly, in the early years, there was no digitalized cadastral information, some of them already lost. Thirdly, there

are many illegal constructions in Shenzhen, the proportion of them is around 50 percent. In addition, the public land is not included in registration. Urban transportation, communications, energy, water supply and drainage systems, public green space, school education, hospital are not included. Especially the underground space, we don't know the underground circumstance, which is also a barrier for establishment of 3D cadastre for underground space."

Before even considering large-scale implementation of 3D cadastre, the 2D cadastre development stills need legal and organizational improvements. In addition, the current 2D cadastre could solve the majority of daily cadastral work. Furthermore, the 2D cadastre still needs improvements in its legal framework and its organizational structure: there is no cadastral law in China, and there is no specific cadastral organization with systematic 2D cadastral workflow generally in China. Also, the switch from separate real estate registration to unified real estate registration in China is still in process, and there is no consolidated real estate registration method in China at this moment. Thus, the 2D cadastre development should take the higher priority, while 3D cadastre is not urgent to be developed.

In China, the 3D cadastre development may even take lower priority than that in Shenzhen in land administration system. Shenzhen is on a pilot project of 3D cadastre because it is one of the most economically advanced and highly densifying cities in China. There is a trend to implement and popularize 3D cadastre in some areas in China. But it would not be a nationwide effort because 3D cadastre is a 'classy' and 'minority' technology. Also, the 2D cadastre is working fine generally. There is no need to implement 3D cadastre for the whole country." (interviewee 02, researcher of Shenzhen Research Centre of Digital City Engineering).

In conclusion, it is currently neither urgent nor feasible to build the 3D cadastral system for Shenzhen or China in general.

Ways to break path dependence of 3D cadastral system: Path creation

According to literature path creation is a way to break path dependence, and this may also be a possibility for the Chinese 3D cadastral system to develop further. According to literature review section, the main path creation ways are technical improvement, integration of different perceptions, tolerance of experience, using moments of crisis and time. Based on this several recommendations can be made.

First of all, the 3D cadastral technique should be improved. According to research (Guo et al., 2011), some cadastral divisions are not satisfied with the current 3D cadastral system, because it is not easy for them to execute their tasks. Software development and 3D automatic modelling technique are main changes needed in current technical perspective. After technical improvement of 3D automatic modelling, the advantage of 3D cadastre for registration would be more noticeable, also a better software development would be more user-friendly for cadastral officials. The acceptance of 3D cadastre would hence be increased.

Then, individual's different perspectives of the current cadastre's situation and future development should be integrated into the technical and organizational design processes for better understanding of 3D cadastre. Currently, in Shenzhen, the cadastre managers and cadastre implementers have gaps in terms of understanding of 3D cadastre. According to interviewee 04 (vice dean of Real Estate Office of Urban Planning, Land and Resources Committee of Shenzhen city): "The current cadastre managers' academic background is mainly surveying, it is hard to find someone who studied land administration, law, or public administrations." Researcher of Shenzhen Research Centre of Digital City Engineering (interviewee 02)

also believes 3D cadastre development needs more attention on legal and institutional perspectives: "The research of 3D cadastre is mainly focused on the technical dimension in Shenzhen. There is lack of research on the relationship between 3D cadastral technology, the organizational structure and the legal frameworks. Moreover, the technical experts don't understand law or institutions; the cadastral managers don't understand technology." It is obvious that 3D cadastral development needs not only technical improvement but also legal development and organizational development because 3D cadastral technology couldn't work without an appropriate legal framework or a coordinate organizational structure. Hence, the legal and organizational experts should be involved in 3D cadastre studies to bring these multiple perspectives to the table and in so doing help to break path dependence for 3D cadastre development in China.

Moreover, tolerance of experience and the moment of crisis would also work for breaking path dependence of 3D cadastre in China. Currently, 3D cadastral is implemented as a pilot project in Shenzhen, it is the first Chinese city where started implementing 3D cadastre. But even in Shenzhen, 3D cadastral registration takes the minority. That is to say, 3D cadastre is not well-introduced for cadastral officials or public. It is a potential need of highly urbanizing urban areas, such as Shenzhen, where pressures for expansion are pushing vertical development. With more introducing and implementing of 3D cadastre to governmental institutions, public institutions, and citizens in highly urbanizing cities, 3D cadastre would be accepted in the future.

Cadastral case being implemented, 3D cadastre is a trend which would be more accepted. In addition, with more land market trading activities running in Chinese urban areas, the underground space use will be of higher demand, potentially forming a sort of crisis that gives impetus for developing 3D cadastre more widely. Hence, 3D cadastre would be applied more frequently in practice, when the implementation of 3D cadastre reaches a certain level 3D cadastre would be popularized as a trend.

Lastly, all the path creation ways mentioned above need enough time to be achieved. The 3D cadastre is at an experimental stage in Shenzhen specifically and in China at large. Lining up the advanced 3D cadastre technology with an appropriate legal framework and a coordinated organizational structure requires time to become developed and established.

Limitations of this research and future directions

In this research, the limited time and confidentiality of the Chinese cadastre were two main limitations of this research. The limited time (3-week fieldwork-period) did not allow the researcher to study more than one city, namely Shenzhen with a pilot project of 3D cadastre in China. However, there are also other cities, namely Wuhan and Changchun, which are implementing pilot 3D cadastre and which could serve as additional or comparative cases. At the same time, China is a big nation of 34 provincial-level units and considering this scale, but the few cities such as Shenzhen, Wuhan, Changchun, which are implementing 3D cadaster are very few; which makes the drawing of conclusions based on these pilot projects difficult. In addition, cadastral information is regarded as confidential in China, especially for a researcher who is studying abroad. Hence, some 3D cadastral information could not be made public; some interviewees were not willing to share the changes needed in 3D cadastral technology and only claimed that "there is no change needed in technical perspective in Shenzhen".

Several unanswered questions are found by going through the findings and limitations of this research. Future research could focus on those aspects: path dependence of 3D cadastre in other Chinese cities,

further path creation methods, governance, the significance of 3D cadastre for property owners and public authorities.

Firstly, the path dependence of 3D cadastral development of other Chinese cities could be investigated by using the same method as in this research. Due to the limited time, other Chinese cities where are also in pilot project of 3D cadastre could not be studied. However, it is important to find out the influence of path dependence also in other pilot cities, as the organizational structure or the legal framework might be different in other cities. It would give a deeper understanding of Chinese 3D cadastral system.

Secondly, the ways how to break path dependence of Chinese 3D cadastral system could be further studied. This research's main objective is to investigate the influence of path dependence of 3D cadastral development in China, path creation was discussed as advice for 3D cadastre development. However, the path creation methods of 3D cadastral system should be addressed accordingly to path dependence, to give the ways to break path dependence of Chinese 3D cadastral system.

Thirdly, more attention should be paid to Chinese governance for 3D cadastral studies. Same as this research's limitation, the confidentiality of Chinese cadastre would also be challenging for other 3D cadastre studies. Protecting the cadastral data from privacy is crucial. However, it is also important to share the cadastral data and organizations openly, allow researchers and Chinese citizens participant in cadastral development, in order to find out exist issues for 3D cadastral development by receiving feedback from researchers and Chinese citizens. In addition, the separation of the management and the implementation of cadastre within the Chinese organizational structure might also be a barrier to Chinese 3D cadastral development. Researchers could also pay attention to these aspects to investigate the influence of governance on 3D cadastral development.

Fourthly, how implementing 3D cadastre would influence the relationship between people leasing property in Chinese areas, and public authorities should be answered by further research. Because, in principle, having access to 3D cadastre technology might generate more opportunities for property owners to be aware of what are the property interactions on their property. Also, 3D cadastre might also require different types of relationships between property owners as input of information and public authorities. How these relationships would be shaped and how they would influence each other are unknown yet. Thus, future studies should also pay attention to these aspects.

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APPENDICES

Appendix 1: Research matrix

Table 7 Research matrix

Research Sub-objectives	Research Questions	Data collection Methods	Data analysis theme
1. To describe the current 3D cadastral system in Shenzhen.	a. What types of 3D cadastre are currently being designed and implemented?	• Semi-structured interview • Focus group discussion • Email correspondence • Desk research	• 3D Cadastre type
	b. How is the 3D cadastre developed in technical perspective?		• 3D data model • Visualisation
	c. What developments needed in 3D cadastral technical perspective?		N/A

2. To investigate the path dependence of the 3D cadastral legal framework in Shenzhen.	a. How have the law, policy, and legislation of 3D cadastral system been developed in China?	• Semi-structured interview • Focus group discussion • Direct observation • Desk research	• 3D cadastre legislation • Definition of 3D property • Definition of parcels
	b. How does the path dependence impede the implementation of 3D cadastre in the Chinese legal framework?		• Increasing return path dependence • Evolution path dependence • Sequencing path dependence
	c. What changes are needed in the Chinese legal framework to embrace 3D cadastre?		N/A

3. To investigate the path dependence of the 3D cadastral organizational structure in Shenzhen.	a. How is the 3D cadastre being organized from national level to Shenzhen local level in China?	• Semi-structured interview • Focus group discussion • Direct observation • Desk research	• Vertical and horizontal structure
	b. How does path dependence impede the implementation of 3D cadastre in the Chinese organizational structure?		• Increasing return path dependence • Evolutionary path dependence • Sequencing path dependence
	c. What changes are needed in the Chinese organizational structure to embrace 3D cadastre?		• Unified goal • Organizations structure • Personnel ratio

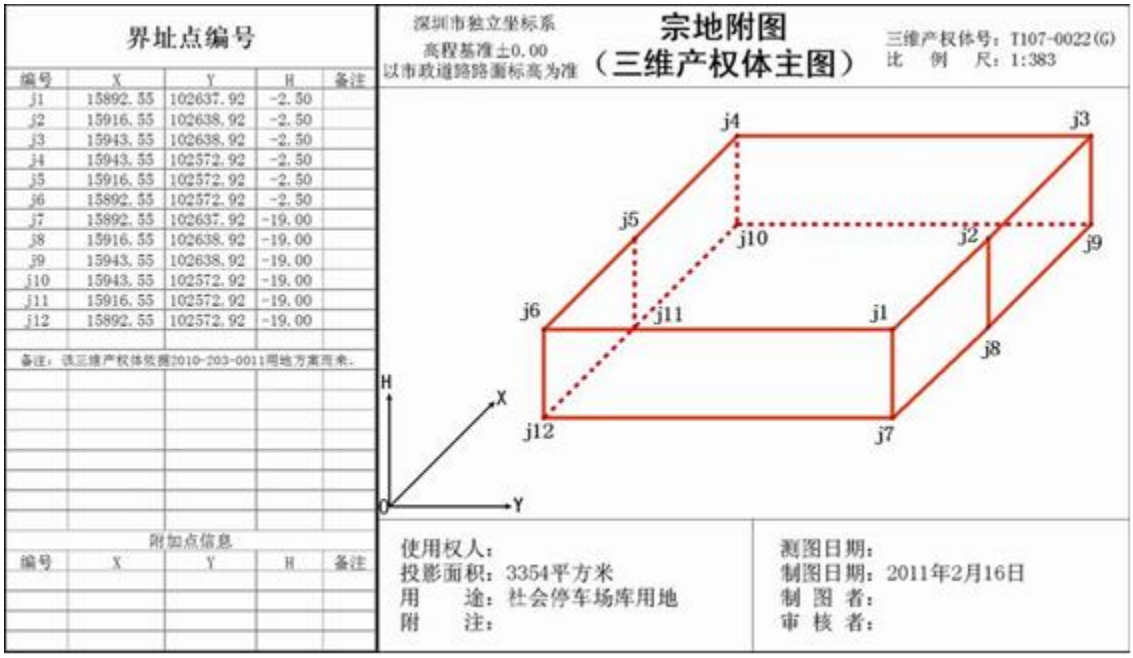
Appendix 2:

Table 8 Interview template

Research Sub-objectives	Research Questions	Interview Questions
1. To describe the current 3D cadastral system in Shenzhen.	a. Which type of 3D cadastre is currently being designed and implemented?	• Is the 3D objects' property right in 3D or 2D? • Which dimension are the parcels in? • In which dimension of the 3D objects registered in cadastral systems? If in 2D, is there any extra reference to explain the 3D situations? • Which data model is currently being applied (2D, 2.5D or 3D)?
	b. How is the 3D cadastre developed in the technical perspective?	• Which method is being applied for 3D data acquisition (Laser scanning: airborne and terrestrial; Digital imagery: aircraft, UAV and terrestrial; Mobile mapping systems)? • On which level have 3D modelling and data processing achieved? • How do 3D objects be presented on cadastral maps (2D, 2.5D, 3D)? • How do 3D objects be managed and stored in cadastral database? • What developments needed toward a 3D cadastral system?
	c. What developments are needed in the 3D cadastral technical perspective?	• What developments needed in 3D cadastral technical perspective?
2. To investigate the path dependence of the 3D cadastral legal framework in Shenzhen.	a. How have the law, policy, and legislation of 3D cadastral system been developed in China?	• Which laws, policy and legislation are relevant to the Chinese cadastral system? How do they introduce 3D cadastre system? • How is the legislation status of 3D cadastre in China? • How is real property defined in law? • How are parcels defined in legal system (2D, 3D)? • Are the 3D object situations defined by law? • What are the existing 3D objects and which of them could be registered in 3D? • How is 3D property defined in legal system? • Which rights can be registered in 3D?

	b. How does the path dependence impede the implementation of 3D cadastre in the Chinese legal framework?	• What are the impacts of the existing cadastral legal framework on 3D cadastral implementation? Are they easy to modify? • What are the impacts of cadastral legal process on 3D cadastral implementation? Are they easy to change? If no what is the reason? • According to(Q. Lin et al., 2015), "there is no complete law of cadastre" Do you agree? If yes, what is the impact of 3D cadastre implementation?
	c. What changes are needed in the Chinese legal framework to embrace 3D cadastre?	• What are the needed changes in the legal systems for the transformation from 2D to 3D?
3. To investigate the path dependence of the 3D cadastral organizational structure in Shenzhen.	a. How is the 3D cadastre being organized from the national level to Shenzhen local level in China?	• What is the vertical organizational structure of cadastre? Which of them involved 3D cadastre implementation? • What are the departments and institutions involved about 3D cadastral implementation and research? What are the relationships between them? • What is the relationship between land administration system and cadastral system (cadastre as a functional department in land administration system)?
	b. How does path dependence impede the implementation of 3D cadastre in the Chinese organizational structure?	• Is 3D cadastral implementation as a goal from national level or only Shenzhen local level? • How do cadastre departments satisfy with 2D cadastre? • To what extent do the cadastral implementation departments understand/accept the 3D cadastral system? • To what extent do the cadastral implementation departments realise the need for 3D cadastral system? • What are the costs required to switch from 2D to 3D in cadastral system? And are they affordable? • What rules do cadastre departments apply in their daily work? Do they limit 3D cadastral development? • How does the uneven land registration framework impede on 3D cadastral implementation?
	c. What changes are needed in the Chinese organizational structure to embrace 3D cadastre?	• What changes are needed in the organizational structure to embrace 3D cadastre?

Appendix 3: An example of external 3D reference in land grant legal document



界址点编号

编号	X	Y	H	备注
j1	15892.55	102637.92	-2.50	
j2	15916.55	102638.92	-2.50	
j3	15943.55	102638.92	-2.50	
j4	15943.55	102572.92	-2.50	
j5	15916.55	102572.92	-2.50	
j6	15892.55	102572.92	-2.50	
j7	15892.55	102637.92	-19.00	
j8	15916.55	102638.92	-19.00	
j9	15943.55	102638.92	-19.00	
j10	15943.55	102572.92	-19.00	
j11	15916.55	102572.92	-19.00	
j12	15892.55	102572.92	-19.00	

备注：该三维产权体依据2010-203-0011宗地方案而来。

附加点信息

编号	X	Y	H	备注

深圳市独立坐标系
高程基准±0.00
以市政道路路面标高为准

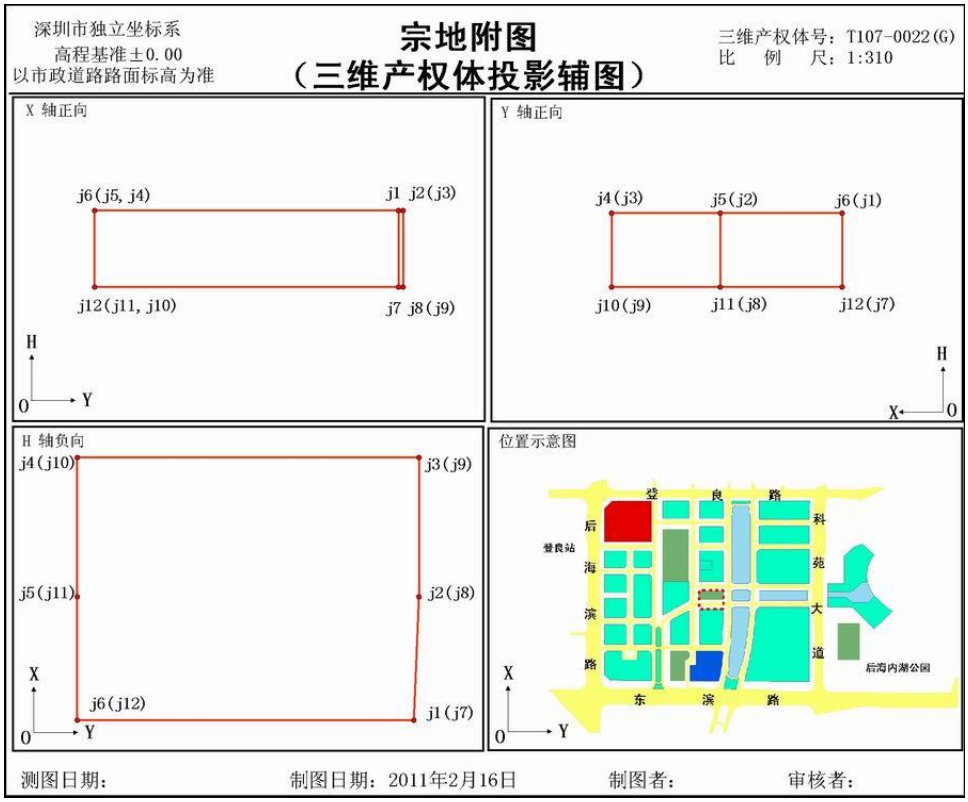
宗地附图
（三维产权体主图）

三维产权体号：T107-0022(G)
比　例　尺：1:383

使用权人：
投影面积：3354平方米
用　　途：社会停车场库用地
附　　注：

测图日期：
制图日期：2011年2月16日
制 图 者：
审 核 者：

Figure 18 Attachment drawing of 3D situation



深圳市独立坐标系
高程基准±0.00
以市政道路路面标高为准

宗地附图
（三维产权体投影辅图）

三维产权体号：T107-0022(G)
比　例　尺：1:310

测图日期：　　制图日期：2011年2月16日　　制图者：　　审核者：

Figure 19 Projection drawing of 3D situation

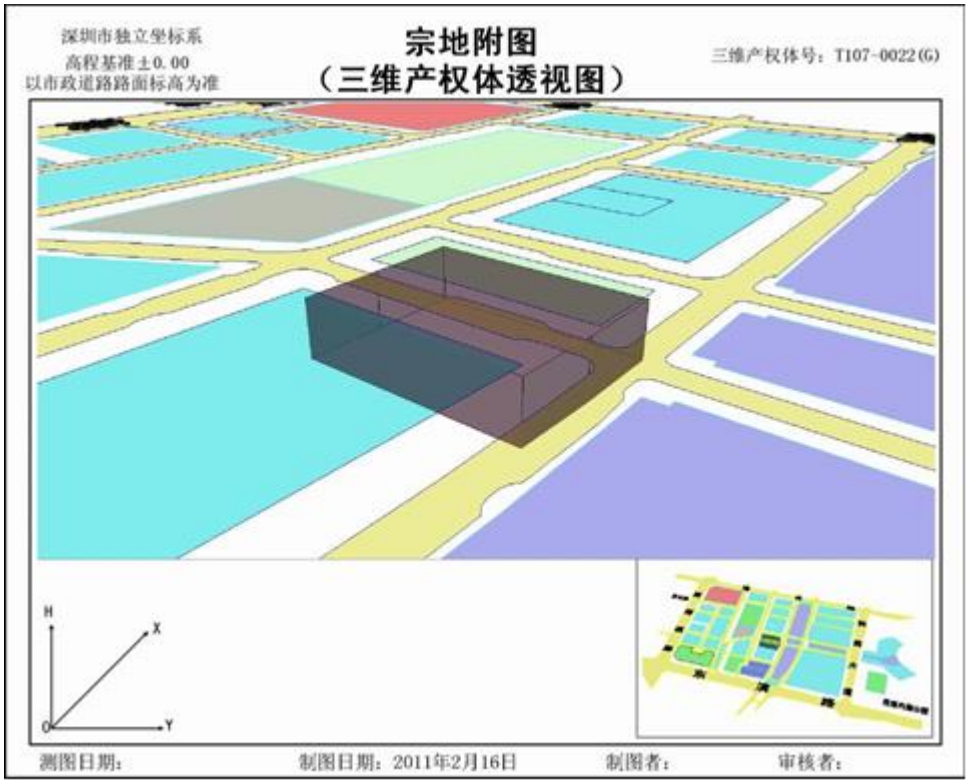


Figure 20 Perspective drawing of 3D situation