Initial Design to Develop a Cadastral System that Supports Digital Cadastre, 3D and Provenance for Singapore

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Key words: SG LandXML, SG LADM, 3D, Provenance

SUMMARY

It is challenging to design and develop a cadastral system that supports digital cadastre, 3D and provenance. Digital cadastre encodes cadastral information in digital format like LandXML, which allows for automation and returns high productivity. 3D enables capturing and representing the third dimension, which is critical for the development in both above and below the earth surface. Provenance allows the management of cadastre through lifespan. This is important in cadastral investigation and analysis for being informed how a cadastral parcel is being evolved over certain time period. The paper discusses the initial design of a new cadastral system called Cadastral Survey Management System (CSMS). The paper shares the SG LandXML, a Singapore profile of LandXML, which is designed based on the ICSM's ePlan model, which in turn has been implemented in Australia and New Zealand. SG LandXML will consolidate the existing forms and data in different formats and to facilitate automation. By having a pre-validation mechanism at the Registered Surveyors' (RS) Web Portal, the submissions by the surveyors through the Portal can be checked upfront before the authority's inspection and approval. This will reduce turnaround times and speed-up the overall approval process. The fundamental of the system is the cadastral data model, which is designed based on the ISO 19152 - Land Administration Domain Model (LADM). The notion of BeginLifeSpanVersion and EndLifeSpanVersion in LADM has been adopted to design the provenance framework for the system. With the framework, every parcel when it is first submitted to the system will be date-stamped and the changes to the parcel will be captured for the parcel's entire lifespan. This will allow the system to retrieve a parcel from its inception and to compare its changes over times. The paper also demonstrates some preliminary investigations on how different types of parcels, both 2D and 3D, can be integrated based on the notion of Level of Details from city modelling. The paper proposes methods how different types of parcels can possibly be encoded in SG LandXML to support 3D Cadastres.

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1. INTRODUCTION

It is challenging to design and develop a cadastral system that supports digital cadastre, 3D and provenance, all in one system. Digital cadastre encodes cadastral information in digital format like LandXML, which allows for automation and returns high productivity. 3D enables capturing and representing the third dimension, which is critical for the development in both above and below the earth surface. Provenance allows the management of cadastre through lifespan. This is important in cadastral investigation and analysis for being informed how a cadastral parcel is being developed over certain time period. In this paper, we discuss the initial design of such a cadastral system. The paper specifically looks into the technical aspect, and leaves the organizational aspect and legal aspect for separate discussions.

The paper discusses the initial design of the new cadastral system called Cadastral Survey Management System (CSMS). The paper describes the SG LandXML, a Singapore profile of LandXML, which is designed based on the ICSM's ePlan model, which in turn has been implemented in Australia and New Zealand. Currently in Singapore, surveyors submit different forms and data in different formats for plan approval at the Singapore Land Authority (SLA). With SG LandXML, administrative data (e.g. surveyor details) and survey data (e.g. observations, parcel geometries) will be consolidated in one SG LandXML file for submission. By having a pre-validation mechanism at the Registered Surveyors' (RS) Portal, a submission can be checked through the Portal before submitting to SLA for inspection and approval. This will reduce turnaround times and speed-up the overall approval process by eliminating some unnecessary errors upfront.

The fundamental of the system is the cadastral data model, which is designed based on ISO 19152 - Land Administration Domain Model (LADM). The notion of BeginLifeSpanVersion and EndLifeSpanVersion in LADM is adopted to design the provenance framework for the system. When a parcel is first created in the database, it will be date-stamped with BeginLifeSpanVersion and EndLifeSpanVersion. When the state of the parcel changes, a new record of the parcel will be created with new BeginLifeSpanVersion and EndLife-SpanVersion, and the old record will become historical but integrated with the new record. When a temporal query is made on the parcel, the system will be able to retrieve and display the entire lifespan of the parcel from its inception to cessation. This framework will allow inspection officers to visualise and analyse the changes both spatially and textually.

A preliminary investigation is discussed on how different types of parcels, both 2D and 3D, can be integrated based on the notion of Level of Details from city modelling. The paper also proposes methods how different types of parcels can possibly be encoded in SG LandXML. Recently, Singapore has mapped the whole nation in 3D. 3D models such as buildings, transportations, terrains have been modelled in CityGML and are managed in a separate database. The representations of parcels in different Level Of Details (LOD) will facilitate the integration of parcels with their physical constructs, especially the building models.

In what follows, Section 2 illustrates the background of cadastral survey system in Singapore. Section 3 shows the design architecture of CSMS and the key thrusts CSMS is committed to achieve. Section 4 discusses the initial design of CSMS, especially on SG LandXML, the Registered Surveyors' Portal, SG LADM, which is further elaborated on provenance and 3D.

2. BACKGROUND

Since 1992, the SLA has embarked on various initiatives to modernise Singapore's cadastral survey system. These improvements are needed for the system to stay relevant (Khoo and Soh (2005); Andreasson (2006)). Figure 1 lists the various initiatives that were carried out for the modernisation of cadastral survey system. Further information on Singapore's cadastral survey system is available at the SLA website (http://www.sla.gov.sg).

The most important initiative was the implementation of coordinated cadastre in 2004. This project is key in cadastre modernisation. It enables many other initiatives to improve cadastral information quality and increase productivity.

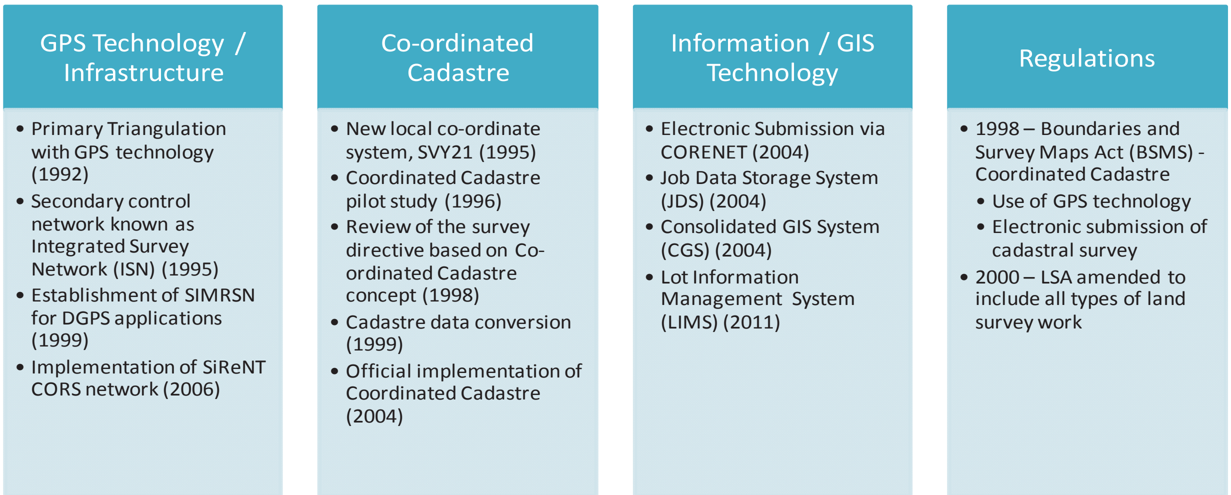

Figure 1. Initiatives to modernise cadastral survey system in Singapore

The cadastral survey workflow based on electronic submission was introduced in 2004. This workflow supports paperless submission via internet (Khoo and Soh, 2005). Figure 2 illustrates the electronic submission workflow. As shown in the figure, after conducting their field survey, registered surveyors prepare data and cadastral plans for submissions at the electronic submission portal called CORENET, which routes the submissions to SLA for inspection and approval. Currently, the submissions contain various forms and data files in different formats, and plans submitted are in non-machine readable format such as images or

PDF. This prohibits productivity when the submissions reaching the SLA for inspection and approval, and later in data management and dissemination.

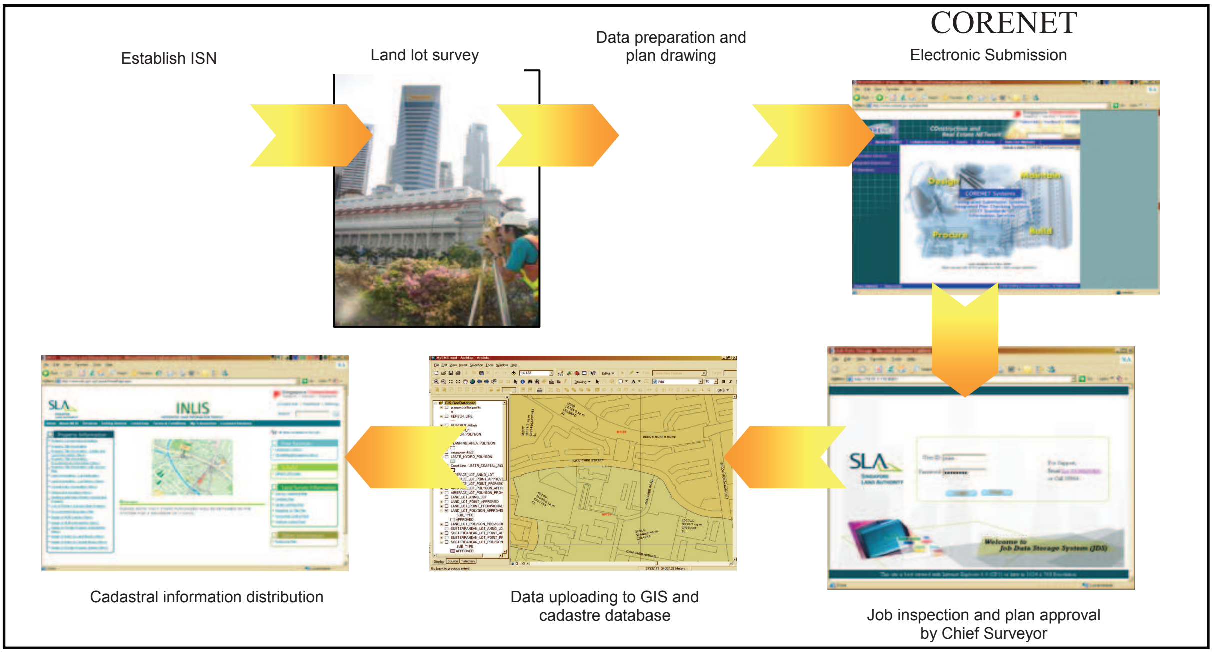

Figure 2. Cadastral survey electronic submission workflow

3. NEW SYSTEM – CADASTRAL SURVEY MANAGEMENT SYSTEM (CSMS)

To increase productivity and to meet challenges ahead, the Land Survey Division of Singapore Land Authority has embarked on the design of a new cadastral system called Cadastral Survey Management System, CSMS. CSMS is committed to achieve the following three key thrusts:

I. *Adding the vertical dimension and time*
The current 2D cadastral data are no longer capable of representing complex scenarios that involve the developments above and below the earth surface that are currently happening in Singapore. The legal boundaries showing the third dimension are crucial for property transaction. In addition, cadastral boundaries are never static; they evolve over times beginning when a lot number was firstly allocated. The provenance management of cadastral lots becomes significantly important. Being able to visualize and analyse the changes of a parcel over times will certainly help for any cadastral investigations.

II. *Adopting open standard for automation and data interoperability*
To increase productivity, automation plays a very important role. Open standard, LandXML allows machine to parse its content for validations. When cadastral plans are formatted in LandXML, plan inspection can be performed by machines to achieve automation. Open standard also enables data interoperability where data can be integrated independent of operating systems.

III. *Providing a proactive communication platform with registered surveyors*
Currently CORENET plays the role as a staging server to route submissions from the registered surveyors to SLA. CORENET does not facilitate any cadastral validations on the submissions or any interactive communication is possible between surveyors and SLA. A web portal is crucial to facilitate the communication, where registered surveyors can consult directly with SLA for job-related enquiries and receive latest updates. The registered surveyors can also pre-validate their job submissions at the portal before submitting to SLA. This will save the turnaround times and will speed up the entire process from submission to approval.

3.1 The design Aachitecture

Figure 3 demonstrates the design architecture of CSMS in order to achieve the three thrusts outlined in the last section.

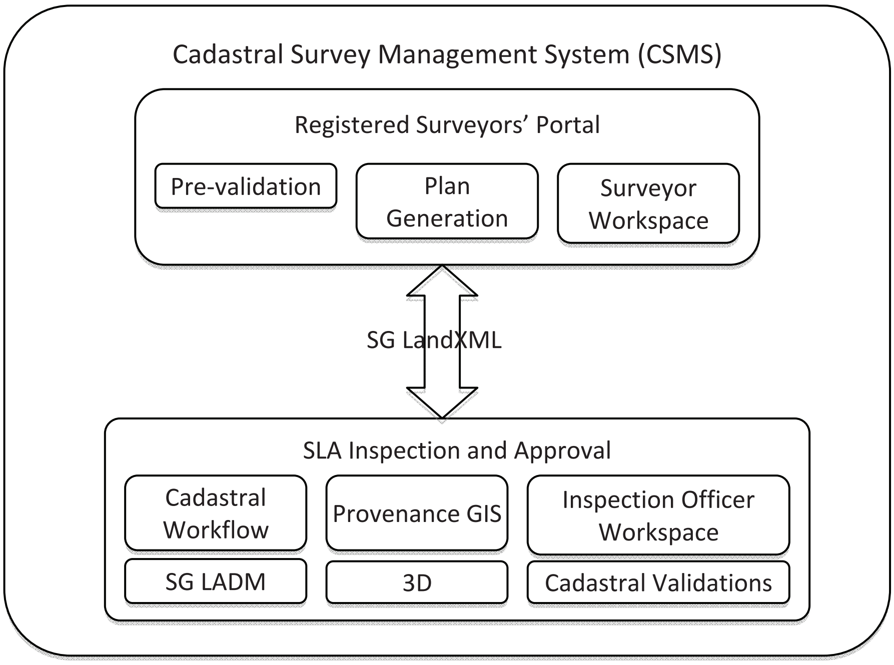

Figure 3. The design architecture of Cadastral Survey Management System, CSMS

In this design architecture, SG LandXML, which is customized according to Singapore's local context, plays the vital role to increase productivity. The SG LandXML submissions by registered surveyors will be pre-validated at the RS Portal. The validated data in SG LandXML will then be transported from the registered surveyors to SLA using the RS Portal.

Registered surveyors will prepare their SG LandXML submissions in office. The RS Portal will provide facility for registered surveyors and their assistants to pre-validate their submissions, to generate cadastral plans from the submitted SG LandXML to receive updates and consultations from SLA.

After passing the RS Portal, the job submission will be routed to inspection officers at SLA based on certain processing workflow for detailed inspections and cadastral validations. As all submissions will be validated upfront at the Portal, no major errors should be expected when reaching the SLA. The Chief Surveyor will approve the plan when the jobs are ensured to be in proper order. The cadastral data from the SG LandXML submissions will then be stored in the database, which is designed based on SG LADM.

4. INITIAL DESIGN

This section discusses the foundations that supports the design architecture and streamlines the overall cadastral processing workflow. The foundations include SG LandXML, which will allow the system to perform automated cadastral validations; SG LADM, which will support both 3D and provenance, and the Registered Surveyors' Portal, which will provide interactive communications with the registered surveyors. The following will describe each of these components in detail.

4.1 SG LandXML

LandXML (http://www.landxml.org) has been used for exchanging surveying data in land development applications (Crews, 2003). Government agencies, such as Intergovernmental Committee on Surveying and Mapping (ICSM, http://www.icsm.gov.au) in Australia (Cumerford, 2010b) and Land Information New Zealand (LINZ)'s LandOnline (Haanen and Sutherland, 2002) have been using LandXML as a national standard for cadastral electronic lodgement. The Land Survey Division of the Singapore Land Authority (SLA) has been developing the SG LandXML schema based on the ePlan model from the ICSM (Cumerford, 2010a) to replace the existing in-house cadastral submission formats for Smart Cadastres (Khoo, 2012).

Diverging from Australia and New Zealand, where LandXML is only submitted at the final stage of cadastral development, SG LandXML will be submitted in different stages of cadastral jobs from the moment when a lot number of a parcel is firstly allocated, a parcel is caveated (i.e. becoming live, where the parcel can only be legally considered for property transaction), to plan submission.

In Singapore, the registered surveyors are required to submit field details such as wall and fence. SG LandXML is designed to store these occupational details. If any of these occupational details encroaches to legal boundaries, the surveyors shall indicate the encroachment detail in SG LandXML. SG LandXML schema will allow for such indication.

4.2 Registered Surveyors' Portal

The Registered Surveyors' Portal (RS Portal) will be a one-stop portal for the surveyors to perform job-related operations such as communications (e.g. updates about new policies), obtaining lot information, pre-validation of SG LandXML submissions, seeking consultations on job-related matters.

To ensure the SG LandXML submission and plan submitted by the surveyors are consistent, the RS Portal is also designed to generate plans directly from the submitted SG LandXML. Understand that presenting certain annotations on the plan is technical challenging, if overlapping texts exist, the plan generation tool will allow surveyors to do some slight adjustments like rotating texts. To achieve consistency, no additional texts or annotations will be allowed to be entered on the generated plan. Texts can and should only be obtained from submitted SG LandXML directly, no other sources.

4.3 SG LADM

The existing data model implemented in the current database has been designed purely based on layers of points and polygons. These layers are not integrated. This design poses challenges when a point is removed from a point layer, but its corresponding polygon(s) is not reflected with the removal.

For integrating land administration information and to alleviate some issues due to the existing data model, a new cadastral data model is designed based on ISO 19152 Land Administration Domain Model (LADM) (ISO, 2012). The resulted cadastral data model is called SG LADM. SG LADM is designed based on the current ISO standard with specialization on Singapore cadastral database context.

To transport the SG LandXML submission data from the surveyors, SG LandXML schema will be mapped with SG LADM. In addition to relevant data elements be stored in the database, the SG LandXML file itself will be stored as XMLType for further queries into the file's content.

4.3.1 Provenance framework

LADM specifies all LA objects as VersionedObject, which has mandatory attributes BeginLifeSpanVersion and EndLifeSpanVersion. These two attributes define the temporal aspect when an object becomes existence or ceased. SG LADM adopts the notion of BeginLifeSpanVersion and EndLifeSpanVersion to represent the provenance of a cadastral lot in CSMS.

In Singapore, a new lot number has to be allocated before any cadastral survey is carried out. The surveyor has to make the lot number to live, of which the process is often referred to as the activation of lot. When a lot is activated or caveated, it can then legally be transacted (e.g. for property buying), although at this point no cadastral survey is conducted and no cadastral plan has been produced for the lot. A cadastral plan will only be produced at the Registrar of Title (RT) Plan stage or Certified Plan (CP) /Strata Certified Plan (CPST) stage, depending upon if the lot is required for provisional approval or a cadastral survey has been carried out. For a lot where a cadastral survey is difficult to be set up due to field condition (e.g. foreshore) but is urgently needed for development, often times a RT plan can be approved first. However, RT plans are limited to airspace lots, subterranean lots, foreshore lots and reclaimed land lots only, and in a RT plan, the boundaries are provisional. A RT plan will be superseded by the CP plan after a ground survey has been carried out.

All lots have to be surveyed and be shown in certified plan and submitted to SLA for inspection and approval. After the inspection and approval, the cadastral lot boundaries are final and the area can then be used for the issuance of Certificate of Titles. For the details of cadastral survey processes and plans, the reader can refer to the SLA website at

http://www.sla.gov.sg/.
Under the provenance framework, CSMS will capture all cadastral lot boundaries from the very beginning of a cadastral process, i.e. from allocation, to activation, to RT, and finally to CP. With this framework, CSMS will be able to study and analyze the development of a cadastral lot, both spatially and non-spatially, from its origin to its cessation over times.

In other words, with every cadastral lot being associated with BeginLifeSpanVersion and EndLifeSpanVersion, CSMS can manage cadastral lots temporally. By performing certain temporal queries, CSMS will be able to retrieve the related geometries of a cadastral lot over certain time period.

4.3.2 3D
Some preliminary investigations have been carried out to look into the integration of 2D and 3D based on the notion of Level of Detail from city modelling (Biljecki et. al, 2014). As shown in Thompson et. al. (2015) and Thompson et. al. (2016a), current research has defined a taxonomy of different possible types of parcels. Figure 4 illustrates the alignment of different types of parcels to different Level of Details used in city modelling.

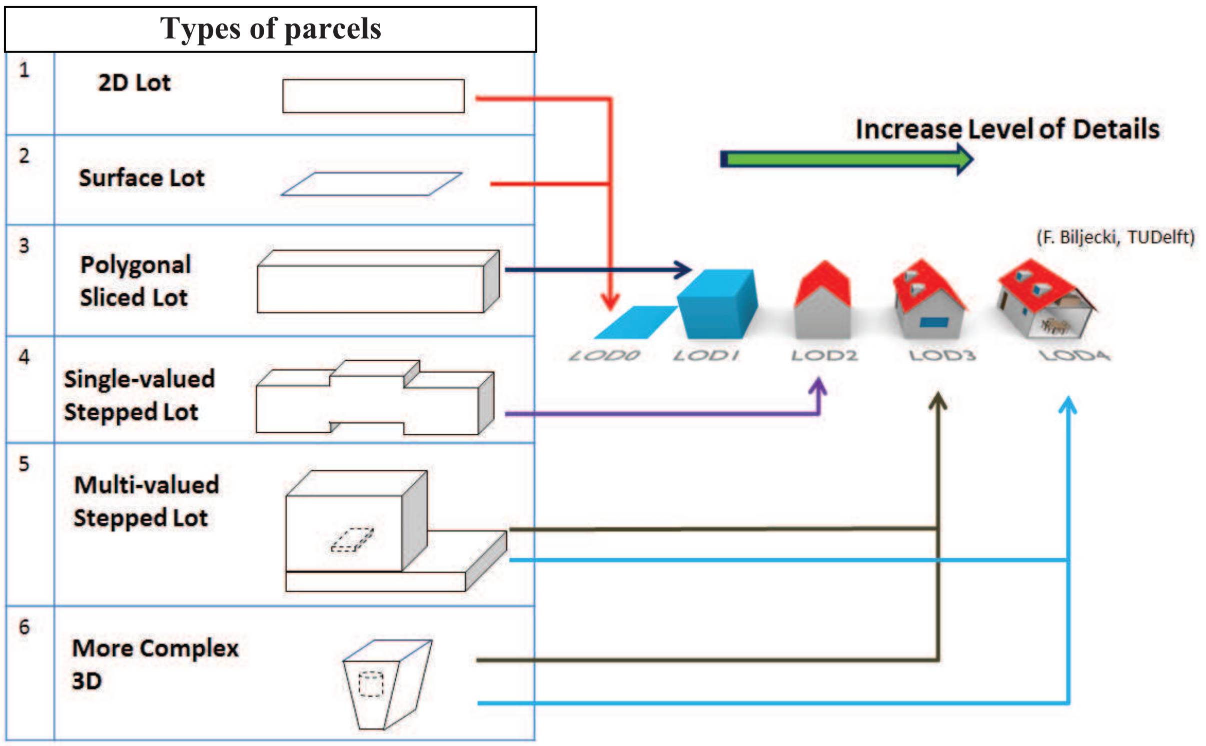

Figure 4. The alignment of different types of parcels with the notion of Level of Details in city modelling

As the taxonomy has been discussed in detail in Thompson et al (2015) and Thompson et al (2016a), the paper will not discuss the taxonomy further. Generally in this paper, Type 1 refers to the existing 2D parcels, be it land lots, airspace lots, subterranean lots or strata lots as of the case in Singapore. Type 2 refers to surface parcels of which in addition to 2D coordinates, the parcel has the elevation, z. This type of parcel can be created by draping the existing 2D land parcels on a Digital Terrain Model (DTM) or by a surveying method to obtain the elevation. Type 3 refers to parcels that have a common height for the entire spatial unit. This type of parcel commonly refers to the airspace and subterranean lots. Type 4 has different heights for the entire unit like LOD 2 in city modelling, where detailed roof structure with different heights is captured and represented. Strata lots can sometimes be grouped under this type of parcel. Type 5 refers to any combinations of Type 3 and Type 4. This type can also have an empty void within the spatial unit itself. Thus far, the types being mentioned refer to the vertical surface that is perpendicular to the ground. Type 6 refers to other more complex 3D parcels, where for instance the vertical surface may be slanted and the bottom surface is not identical with the top surface.

The benefits of classifying different types of parcels based on Level of Details are threefold: in visualization, database management and SG LandXML encoding. In visualization, when parcels and building models are visualized and analysed in the same level of details, it helps to investigate the actual situation for example to see if certain building structure has indeed been encroaching the boundaries. The taxonomy will be found useful when integrating with the 3D building models that SLA has recently created for the entire nation (Soon et al, 2015).

From the database management perspective, it should not be performance expensive to manage the first three types. Thus the database can then be designed to manage the first three types differently and separately from the rest, which may require more performance power. In defining the data type for the geometry in the database, multi-surface and solid may only be required to define the first three types, while multi-solid may be needed for Type 4 and onwards.

The different types of parcels can also be encoded in SG LandXML. Figure 5 demonstrates that Type 1 to Type 6 can be encoded in two methods: the simple faces method and the nested parcels method (Soon et al, 2014; Thompson et. al. 2016a). The simple faces method can group all types within one <Parcel> element. Within this element, it defines 2D parcels in <CoordGeom> element and 3D parcels in <VolumeGeom> element. However with the simple faces method, the same face will be encoded twice or more across different <Parcel> elements.

Conversely in the nested parcels method, a common face will only be encoded once. In the nested parcels method, each face is defined as a <Parcel> element, which can be applied to all types of parcels mentioned. A complete parcel, which itself is a <Parcel> element too, is then formed through referencing to all related <Parcel> elements. The nested parcels method can possibly be encoded with topology as well (Thompson et. al., 2016b).

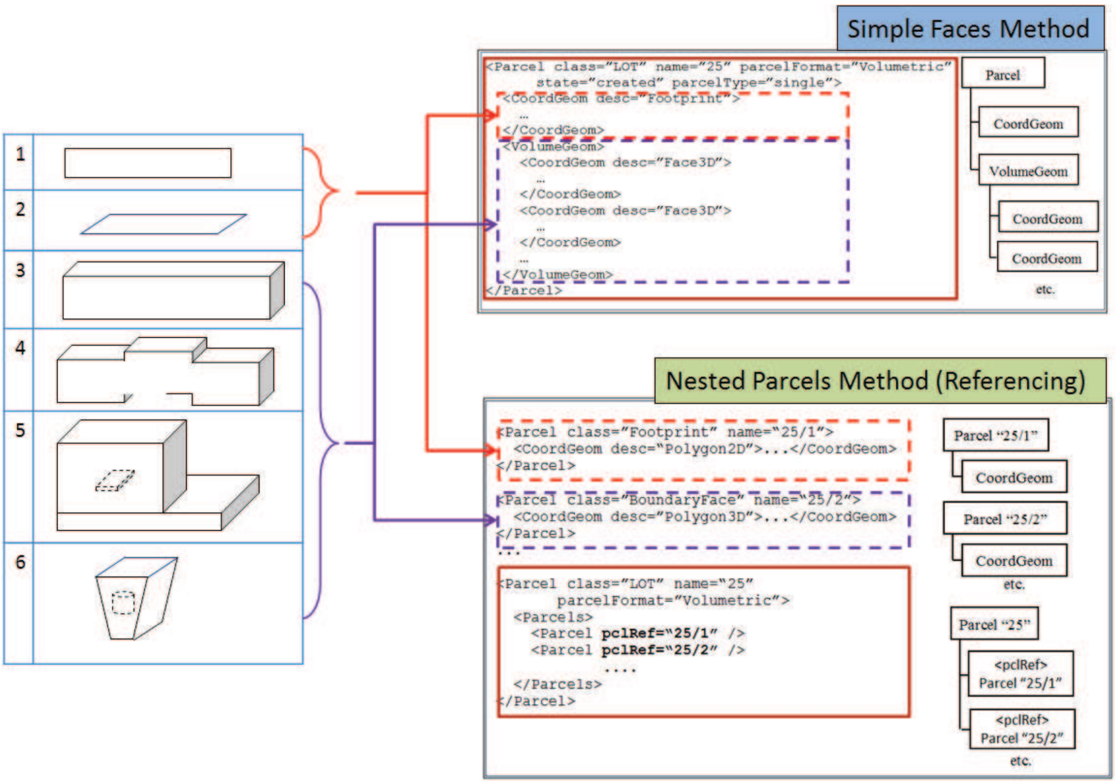

Figure 5. The 6 different types of parcels can be encoded in the simple faces method and the nested parcels method

5. CONCLUSIONS

The paper shared the initial design of a new cadastral system called Cadastral Survey Management System (CSMS) for Singapore. CSMS is committed to achieve 3 key thrusts: (i) automation and data interoperability, (ii) 3D and provenance (time), and (iii) a proactive communication platform for registered surveyors.

To achieve the key thrusts, the paper discussed the fundamental components of CSMS namely SG LandXML, the Registered Surveyors' Portal and SG LADM, which in turn will support 3D and Provenance. SG LandXML is designed based on ICSM's ePlan model. The adoption of SG LandXML will increase the productivity through automation. With the submission prepared in SG LandXML, registered surveyors will be able to pre-validate their submissions at the RS Portal before submitting to SLA for inspection and plan approval. The RS Portal will be a one-stop portal for surveyors to perform job-related operations such as obtaining lot information, pre-validations, and communications with SLA.

As the core of Singapore cadastral data model, SG LADM will form the foundation to support 3D Cadastres and provenance. Based on the existing notion of BeginLifeSpanVersion and EndLifeSpanVersion in LADM, the provenance framework will allow inspection officers to study and analyse the changes of a cadastral lot over times.

The paper also presented some preliminary investigations how 2D and 3D can possibly be integrated based on the notion of Level of Details from city modelling. The paper proposed two possible methods how 2D and 3D can be both encoded in SG LandXML in order to support 3D Cadastres.

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BIOGRAPHICAL NOTES

Kean Huat Soon is a Principal Surveyor at the Land Survey Division of Singapore Land Authority. He is involved in the development of the new cadastral system in the Division to support 3D Cadastres and automated cadastral processing. He also leads the development of CityGML schema for the 3D National Mapping project. He earned a Msc in Geography from the Pennsylvania State University, a Msc in Geoinformatics and Bachelor of Surveying (Land) from University of Technology Malaysia. His research interests include semantic interoperability, data modeling, cadastral information system and ontology.

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Victor Khoo is a Deputy Director at the Land Survey Division of Singapore Land Authority (SLA). He received his Ph.D. and Master of Engineering from the Nanyang Technological University (NTU), Singapore and his Bachelor degree in Land Surveying from the University Technology of Malaysia (UTM). Victor is a Registered Surveyor; a professional surveyor registered under the purview of Singapore's Land Surveyors Act. He works in diverse geospatial related subjects that encompass the collection, management and dissemination of geospatial data. His specific areas of interest include Differential GPS, Cadastral Surveying and Spatial Data Infrastructure.

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