Piloting 3D Cadastre in Singapore

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SUMMARY

Since 2000 various initiatives have been carried out to modernise Singapore's digital cadastral survey system by the Singapore Land Authority (SLA). The initiatives include the implementations of coordinated cadastre (2004) and electronic submission (2005), establishment of Singapore CORS network (SiReNT) (2006), and digital cadastre through the implementation of Cadastral Survey Management System (CSMS) (2018). CSMS introduced new digital workflow for land-based cadastral survey submissions and a digital format called SG LandXML, which allows for automated pre-validation against Singapore's cadastral survey rules, to improve the overall productivity. Though SLA has proposed a preliminary roadmap in 3 phases (i.e, feasibility study, pilots and implementation) (Khoo, 2011), and developed CSMS to support digital cadastre (Soon, et. al, 2016), the digitalization for strata survey was excluded in the initial implementation of CSMS.

With the advancement of Building Information Modelling (BIM) technologies, the Architecture, Engineering and Construction (AEC) industry in Singapore has geared towards the adoption of BIM. The submissions in BIM for regulatory building works have been implemented with the launch of CORENT X, a Whole of Government (WoG) submission platform in Singapore in December 2023. This has led to a new digital 3D era in AEC industry and impacted the land surveying industry to investigate the development of 3D digital cadastral submissions, especially for 3D strata survey submission. Consequently as authority for property ownerships, SLA embarked on pilots to implement 3D cadastre.

3D cadastre eco-system is comprehensive and has been studying by domain experts globally. After reviewing the latest 3D cadastre development by domain experts and researchers, SLA decides to focus on 4 core areas, which are 1) digital 3D cadastre survey techniques and workflows; 2) 3D data model and modelling methodologies; 3) regulatory validation and visualization for 3D submission; and 4) legislation and institutions framework. Presently, SLA is piloting the works in the first 3 areas which are more technical in nature.

This paper will introduce the works of the pilots, as well as the corresponding findings.

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1. INTRODUCTION

Since 2000, various initiatives have been carried out to modernize Singapore's digital cadastral survey system by the Singapore Land Authority (SLA). The initiatives include the implementations of coordinated cadastre (2004) and electronic submission (2005), establishment of Singapore CORS network (SiReNT) (2006), and digital cadastre through the implementation of Cadastral Survey Management System (CSMS) (2018). CSMS introduced new digital workflow for land-based cadastral survey submissions and a digital format called SG LandXML, which allows for automated pre-validation against Singapore's cadastral survey rules, to improve the overall productivity. Though SLA has proposed a preliminary roadmap in 3 phases for 3D cadastre development (i.e, feasibility study, pilots and implementation) (Khoo, 2011), and developed CSMS to support digital cadastre (Soon, et. al, 2016), the digitalization for strata survey was excluded in the initial implementation of CSMS.

In Singapore, the current strata survey submission made by industry is in PDF format, which is a non-digital, non-georeferenced, and non-GIS compatible format. Such non-digital format is unable to support machine checking automatically. Hence, the current regulatory process for strata submission in CSMS is manual based. It is tedious and time-consuming using eyeballs to check all the details to assure the data quality based on PDF plan. In downstream usage, the approved strata plan in PDF format could not be overlayed with GIS map directly, and the geospatial linkage between individual strata unit and the residing land lot could not be visualized in GIS map too. There is no doubt that we need the digitalization for strata survey, to increase the productivity for regulatory process, and improve the data quality for the strata survey submission. There are many reasons for why digitalization for strata survey should move to 3D form.

First, the demands on effective land administration and management which based on accurate as-built 3D geometries with RRR information. The 2D digital strata boundary is unable to visualize the vertical geospatial relationship among different lot types in a complex building, e.g, an integration building in the city area which have underground tunnel (subterranean lots), commercial podium on the ground (land lot), overhead bridge to connect to another building or even a bus interchange (airspace) within the building, and multi-story residential units (strata lot). Some buildings are very complex and innovative design in Singapore, such as the examples shown in Figure 1. It is very challenging for surveyor to represent and depict the strata lots in 2D plan for such buildings. Furthermore, the regulatory authorities' officers also have difficulty in reading and interpreting the 2D plans. This suggest that 2D digital strata plan cannot meet the regulatory authority's demands on effective land administration and management.

Second, there is a trend on 3D transformation in Singapore. The importance of 3D cadastre is illustrated by SLA's vision statement containing an explicit 3D component: ''Limited Land – Unlimited Space'' (van Oosterom, P., 2013). As a land-scare country, a reliable 3D cadastral dataset can help the urban planners to synergize the land development from aboveground to underground better in Singapore. From Digital Twin development perspective, a reliable 3D strata dataset could associate with high quality information at unit-level, e.g. to manage and analysis the approved use and energy consumption for individual unit in a 3D environment.

a. Ferrell Residences c. The Interlace

Figure 1. Some examples of complex and innovative development design in Singapore

Third, with the advancement of Building Information Modelling (BIM) technologies, the Architecture, Engineering and Construction (AEC) industry has geared towards the adoption of BIM in Singapore. The submissions in BIM for regulatory building works have been implemented with the launch of CORENT X, a Whole of Government (WoG) submission platform in Singapore in December 2023. This has led to a new 3D era in AEC industry and impacted the land surveying industry to investigate the development of 3D digital cadastral submissions, especially for 3D strata survey submission.

Hence, for strata digitalization, we should move to 3D directly rather than 2D digital form. With the advancement of rapid 3D data capturing and modelling technologies, such as laser scanning, BIM etc, which are getting more and more mature and affordable, SLA is continuously leading the 3D cadastre development and have been embarking some pilots to leverage laser scanning and BIM technologies for as-built 3D digital strata survey submission. This paper focuses on the piloting works that SLA has been doing. The paper is organized as such: Section 1 introduces the needs for 3D cadastre; Section 2 reviews the 3D cadastre researches and initiatives from different jurisdictions; Section 3 introduces SLA's pilot works and findings; Section 4 produces concluding remarks.

2. INTERNATIONAL 3D CADASTRE RESEARCH AND INITIATIVES

Over the last few decades, rapid urbanization has resulted in substantial pressure on development and use of land in urban environments across the world. The growth in complex building structures, possess new challenges for current 2D-based land administration systems globally. To address these challenges, the 3D cadastre has been researched and prototyped by domain experts in many different jurisdictions.

During the last decade, many jurisdictions investigated the 3D cadastre initiatives, including The Netherlands, Australia, New Zealand, China, Korean, and Malaysia etc. These jurisdictions' researchers notably contributed to practical implementations of 3D cadastre concepts. Many practices and literature have provided numerous publications related to 3D cadastre development, which have been documented in the FIG Best Practices 3D Cadastres (Oosterom (2018)). The research and demonstration of 3D cadastre across the world have been up to a certain level. For example, in The Netherlands, Stoter et al.(2016) describe how a 3D PDF was registered as legal document in the Dutch Kadaster with RRR. In Australia, the 3D ePlan prototype have been developed to illustrate how the legal and physical objects of a building subdivision plan can be stored, visualised and queried in a 3D digital system (Olfat et al. 2016), see Figure 2. In China, a 3D cadastral system has been developed to visualize 3D property formation in Shenzhen (Urban Planning, Land and Resources Commission of Shenzhen Municipality) (Ying et al. 2012), as shown in Figure 3.

Figure 2. Land Use Victoria 3D ePlan Prototype, Australia (https://www.spear.land.vic.gov.au/spear/pages/eplan/3d-digital-cadastre/3dprototype/prototype.html)

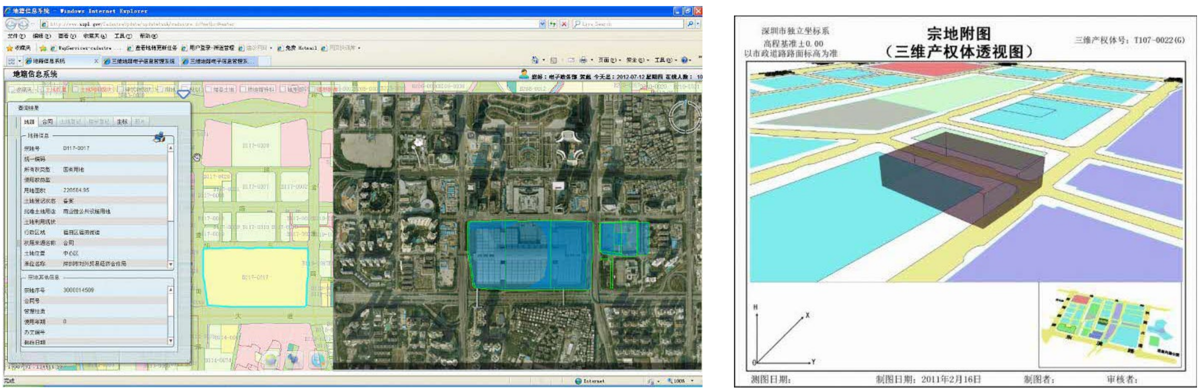

Figure 3. 3D Cadastral System based on B/S architecture, Shenzhen (Source: Ying et al. 2012)

All these initiatives are very insightful and have made a big move in 3D cadastre development. It is notable that 3D cadastral information modelling and 3D cadastral data visualisation are two of the most focusing aspects over the years. However, there are still technical difficulties which need to be resolved. The common issues are insufficient 3D measurements and contents due to the challenges in 3D data capturing onsite, and incompletion of the vertical information of the existing 2D plans regarding elevation, height, and depth etc., which resulted in the 3D cadastral modelling difficulties and 3D models reliabilities. This suggest that the 3D cadastre implementation needs further development of technical solutions for 3D data acquisition and modelling process.

The latest research and developments show that the technical aspects have been investigated significantly across world. These technical aspects typically refer to various stages of the digital data lifecycle, not only 3D data acquisition, and 3D data model and standards, but also including 3D data visualization and storage, 3D data validation, 3D data queries and analysis (Olfat et al. 2021). Compared to the technical aspects, the studies of legal and administrative domains received less research attention, though these two aspects have been deep dived into in the early studies in different jurisdictions.

Some international standards such as LADM (2012), CityGML (2012), and IndoorGML (2014) have been developed, and keep updating over the years due to the raise of requirements on the standardization and data interoperability. Korean and Singapore have designed and implemented their cadastral system based on LADM. With the advantages of Building Information Modelling (BIM) development, the integration of BIM data into 3D cadastre is relatively new field of research too. The researchers from Australia, Sweeden, Korean etc have published some research paper on how to utilise BIM for 3D cadastre modelling and information integration during the building lifecycle, e.g. Atazadeh et al. 2016 proposed an extension to the openBIM standard, which is implemented in a prototype BIM model to showcase the potential capability of using BIM for high-rise land administration and for modelling 3D ownership rights in Australia. Sweden also initiated a research project which leverage on BIM-based approach for 3D cadastral management across the lifecycle of the building (Sun et al. 2020).

Overall, the development of 3D cadastre has been studied with significant milestone achievements in legal and technical research, international standardization, and practical implementations across jurisdictions over the years. However, a 3D cadastre implementation solution always depends on the local situation and is driven by user needs, land market requirements, the legal framework, and technical possibilities. Hence, to develop a practical solution for 3D cadastre implementation at nation-level is still a big challenge for many countries. This motivates the authors to write this paper to share the piloting works in Singapore, to contribute the practical experience, and look forward to gaining more insights and feedback from the global experts.

3. PILOTING 3D CADASTRE IN SINGAPORE

SLA has been exploring 3D cadastre development since 2011, and actively participating in FIG, 3D GeoInfo, UN-GGIM conferences related to effective land administration and management. After learning the ideas and experiences from the global domain experts via the literature review, SLA decided to step into the pilot stage to gain more practical experience for 3D cadastre development. According to Singapore's situation, i.e. the strata submission is non-digital, SLA prioritized the implementation of 3D strata submission by leveraging laser scanning and BIM technologies. The core work areas are: 1) digital 3D strata survey techniques and workflows; 2) 3D data model and modelling methodologies; 3) regulatory validation and visualization for 3D submission; and 4) legislation and institutions framework, shown as Figure 4. Presently, SLA is piloting the works in the first 3 areas which are more technical in nature. The current legislation in Singapore supports digital form submission regardless in 2D or 3D, which could be further investigated and then to make necessary amendments for 3D cadastre submission enforcement from regulatory perspective in near future.

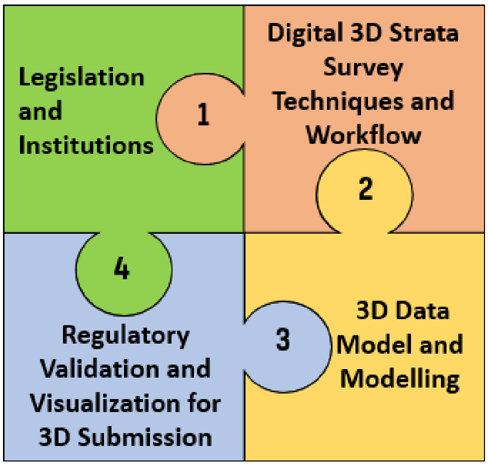

Figure 4. Singapore's 3D Cadastre Works Areas

3.1 Pilot 1 - Digital 3D Strata Survey

3.1.1 <u>Objective</u>

This pilot is a co-creation initiative between SLA and its panel Registered Surveyor, Surbana Jurong Pte. Ltd. It aims to figure out the technical challenges, time spent, and identify the suitable workflow by conducting the as-built 3D digital strata survey using laser scanning and BIM technologies.

Figure 5. Pilot Site – Block 213C at Woodleigh Hill Estate

The pilot site locates at Woodleigh Hill Estate in Singapore, which is a newly built public housing estate by Singapore's Housing & Development Board (HDB). The Block 213C (Figure 5) was selected for this pilot, due to it is a typical newly built building and is ready for strata survey. There are 16 floors in this building, including 130 housing units, lift cores, staircases, with long corridors connecting the two main blocks of the building, as well as a childcare center at ground level.

3.1.2 Workflow

To achieve the pilot's objective, we carried out the digital strata survey using the laser scanning technology. The workflow could be as follows:

1) **Site survey**

The as-built 3D digital strata survey must be based on the Singapore national geographic coordinates system (SVY21) and Singapore Height Datum (SHD). To ensure the survey data is accurate and the subsequent 3D strata modelling could refer to the control points for georeferencing, the first thing is to establish horizontal and vertical ground control points based on SVY21 and SHD for Block 213C. The nearest existing vertical control point (VCP80118) is about 0.9km away. The engaged surveyor established 2 RTK points (MK11 & MK12) nearby the estate (Figure 6a) using SiReNT, and then transferred level from VCP80118 to the RTK points by digital level. Thereafter, conducted the traverse using total station, to transfer the Northing, Easting and Elevation to the newly established control points surrounding the Block 213C. The layout of the control points is shown as Figure 6b.

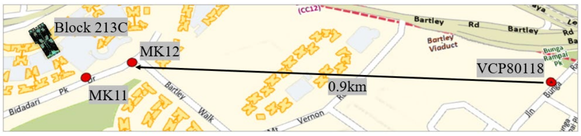

Figure 6a. Nearest VCP and new RTK points

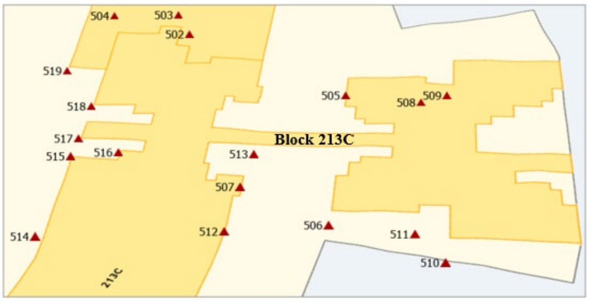

Figure 6b. Newly established control points surrounding Block 213C

2) **Scanning on site**

There are different reality capture solutions available in the market, e.g. terrestrial laser scanners (static scanners, mounted on the tripods), handheld laser scanners, and mobile laser scanners (mounted on a platform such as a trolley or backpack). To choose a scanner for 3D strata survey, several factors should be considered, such as accuracy, range, portability, and ease of use. High-end terrestrial laser sacnners often provide better accuracy compare handheld and mobile scanners. Handheld and mobile scanners offer greater flexibility and ease of use in indoor environments, and tend to be more affordable compared to static terrestrial laser scanners.

The engaged sureveyors used the terrestrial laser scanners (LiDAR Trimble X7) in this pilot. The main reason is the consideraion of high accuracy requriement(not more than 3cm) in cadastral survey in Singapore. Howerver, the disadvantages are obvisouly, which inlcuding the range limitation of the scanners due to the limited spaces within the units and surrounding

of the building. Also it is unable to scan some external corrners which block by building structures such as walls.
The scanning works including scan the exterior for the entire building, and then scan every individual unit, staircases, corridoors, aircon ledge etc., floor by floor, see Figure 7. As the building was scheduled to be handed over to HDB, the scanning works were delayed by on-going renovation and inspection works too. Hence, additional surveyors and scanners were deployed (Reigl VZ400). To make sure there were adequate overlapping point clouds were capured for post porcessing, multiple scans at each station were conducted. It took almost 1 month to complet the scanning works for all the units, which delay a lot due to the above reasons.

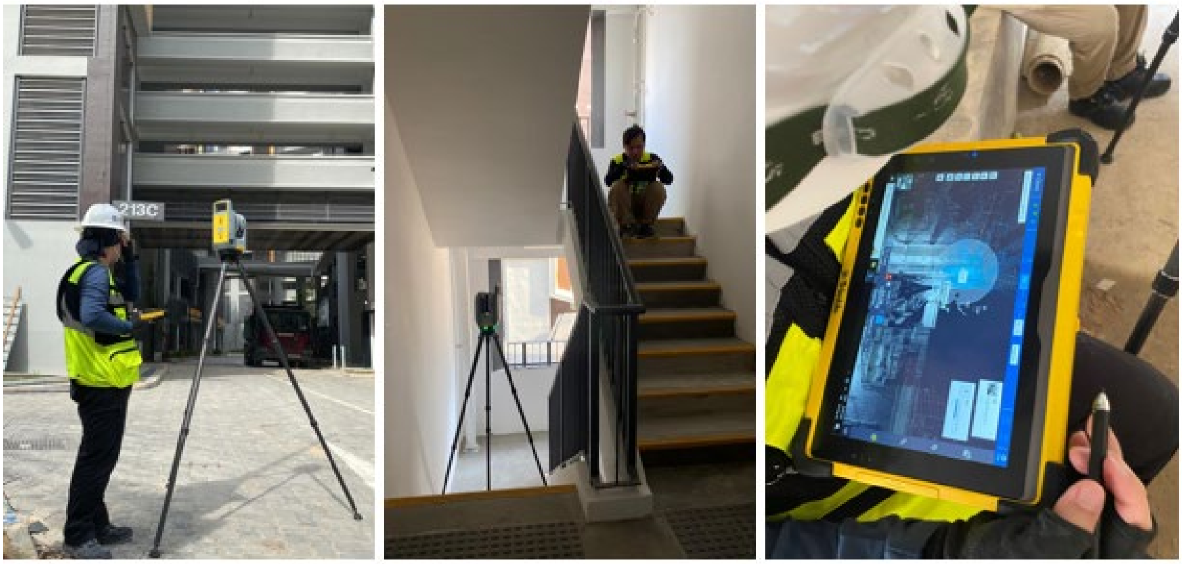

Figure 7. 3D digital strata survey on site

3) **Point cloud registration**

The point cloud captured by Trimble X7 was processed using Trimble Business Centre & Trimble Perspective, while the point cloud captured by Reigl VZ400 was registered by RiscanPro. The point clouds were georeferenced based on the control points that established during the site survey stage. The noise and irrelevant data have been removed from the point clouds. The two datasets were aligned as one single, unified point cloud dataset using Trimble Business Centre, see Figure 8. The combined point cloud was exported to Autodesk Redcap format for next step.
One of the learning points is, that the density of the two point clouds is better to be the same, so that the same feature is easier to identify and take it as reference point for combination. The two datasets from two scanners have differnt density, which cause some extra efforts on the combination.
Another learning point is, a hign-end PC/Laptop is necessary for point cloud processing. In this pilot, the filesize of raw point clouds are up to 1TB. The surveyors' computer is unable to process such massive raw data expeditiously and efficiently. It took a few days to figure out the issue and then the team have to extract the point cloud floor by floor to process, and then merged them into one final point cloud dataset. Also, the Trimble Business Centre was unable to generate the overall point cloud registered report due to such procedure.

Figure 8. Point cloud of the Block 213C

4) **3D Modelling**

3D digital strata information requires two main dimensions, i.e. physical, and legal information. Physical information refers to the shape and geometrical aspects of building elements, such as walls, floors, ceilings etc. Legal information is derived from the strata subdivision process, it refers to ownership information, e.g, the boundaries of strata lots and common properties.

In Singapore, unless otherwise stipulated on the strata certified plan, the common boundary of any strata lot with another lot or with the common property shall be the centre of the floor, wall or ceiling (Chief Surveyor Directive on Cadastral Survey Pratices of Singapore, i.e. CS Directive). In the current 2D strata plan, the strata boundaries were drawn in solid line, and the physical strutures such as walls were drawn in dotted lines, as shown in Figure 9.

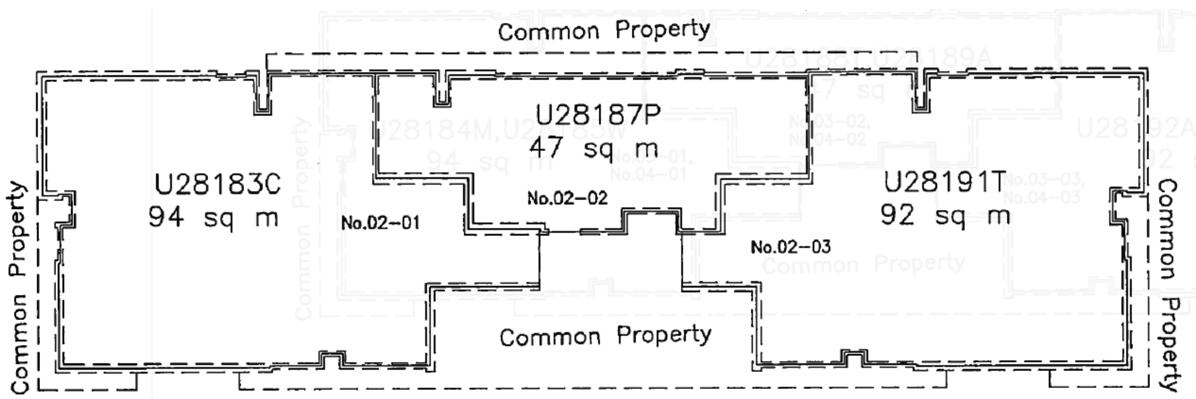

Figure 9. Part of a sample of 2D strata plan

Move to 3D strata, the model should continue not only contain the 3D legal space, but also the necessary 3D physical structures, such as walls, slabs and ceilings. BIM have been adopted for submission in AEC industry in Singapore, and BIM can integrate physical model and legal model with cadastral information, as well as BIM possess the 3D visualizaion capability, hence BIM-based approach was adopted for 3D strata modelling in this pilot.

The unified point cloud in ReCap format has been imported to Autodesk Revit. The physical model was created first based on the point cloud, i.e., the necessary building elements such as walls, slabs, ceilings have been modelled in 3D, see Figure 10.

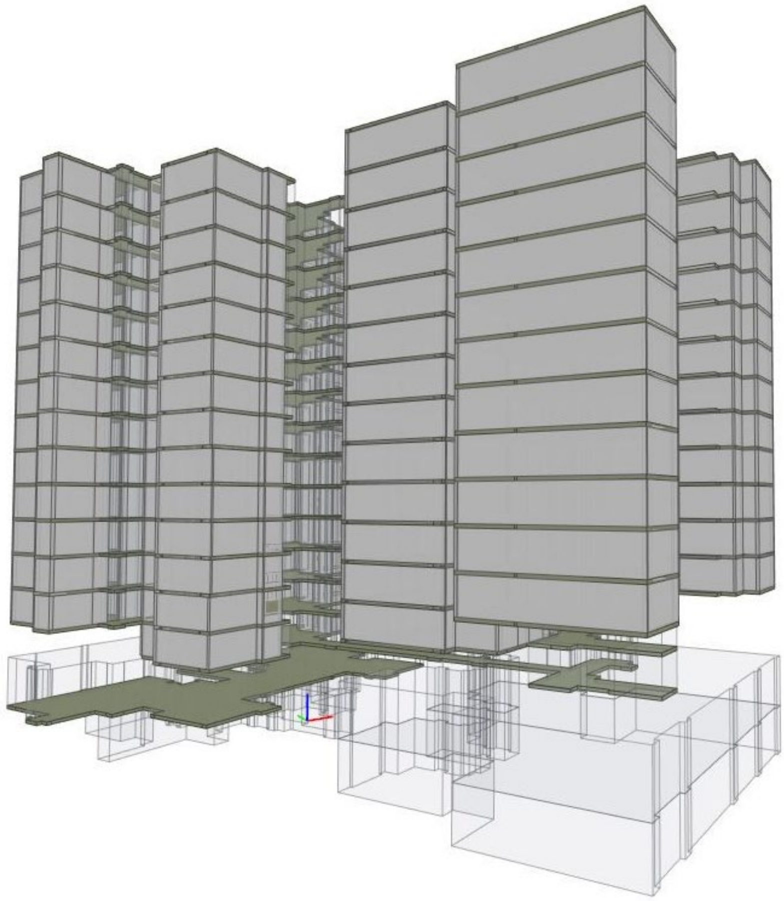

Figure 10. BIM model of Block 213C

The legal model was then created based on physical model manually, with the interpretation by registered surveyor according to the current requirements of strata survey which specified in the CS Directive, e.g, strata boundary determines by the centre of the walls/slabs/ceilings, see Figure 11. At this step, not only the 3D geometries of strata lots were created, but also the cadastral information required by SLA for regulatory approval purpose have been tagged to the individual 3D strata lot. The modelling approach based on existing BIM model using Revit, regardless it is as-built BIM model or as-designed BIM model, has been introduced in Pilot 2 in section 3.2 below.

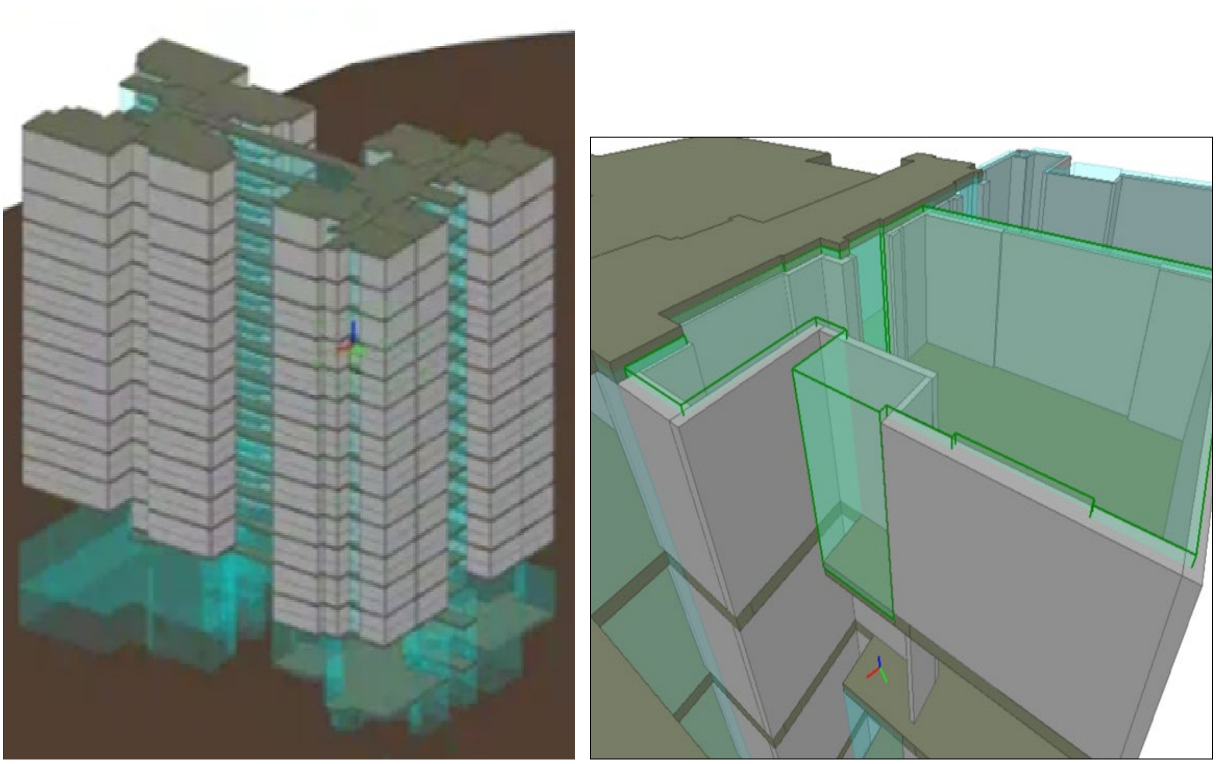

Figure 11. 3D Strata Model contains 3D physical structures and 3D legal space

3.1.3 Findings

This pilot has gone through the as-built digital 3D strata survey techniques and workflow. Some takeaways from this pilot are:

1) 3D laser scanning is a practical solution for implementing the as-built 3D digital strata survey. Surveyor can use the scanned data to create 3D model, and re-measure any dimension without re-visiting the site. Regulatory officers can use it to verify the submitted model. The scanned data is "time stamped" that can be used as survey evident in time of dispute.
2) There is no doubt that the accuracy of the data captured using laser scanning method is more accurate than conventional linear taping especially when the design of a building is a curve or not in right angles.
3) However, the static tripod laser scanner used in this pilot is unable to scan 100% of every part of the building, due to the site conditions and the scanner's range constrains. In such

case, using the conventional measurements or using handheld scanner to capture those difficult parts is a good alternative approach.

4) It is time-consuming to use static tripod 3D laser scanner to scan every single unit and common area of whole building. The pilot suggested to only scan the non-typical floors, and one of the typical floors, as long as the final 3D strata model of the whole building full fill the strata survey accuracy requirements.
5) The pilot also suggested to obtain the georeferenced designed BIM model which had been approved by the regulatory authority prior to conduct the as-built 3D digital strata survey. Such BIM model would be very helpful for the surveyor to understand the strata subdivision and the site conditions better. Also, the approved designed BIM model could be an important supplemental data source for as-built 3D strata modeling in later stage.

3.2 Pilot 2 – 3D Strata Modelling

3.2.1 Objective

The AEC industry is required to make BIM-based submission via Corenet X for regulatory approval for building works in Singapore from Dec 2023. And the Code of Practice (CoP) for BIM submission has been developed for AEC industry use. However, this CoP only emphasizes the construction of 3D physical building objects by architects and professional engineers at design stage. The construction of the 3D legal strata model by registered surveyor at as-built stage has yet covered by the AEC CoP.

This pilot aims to explore the BIM-based as-built 3D strata modelling methodologies. The outcome from this pilot is expected to be incorporated in a BIM-based Cadastral CoP which is under developing for RSs' use.

3.2.2 Data Source for 3D Strata Modelling

For as-built strata subdivision survey in Singapore, the RSs currently use 2D building plan in CAD format approved by the regulatory authorities, which RSs usually received from architects, as the base for creating 2D strata subdivision plans, with the field measurements details which captured on site when the building was built to roof top.

Move to 3D era, it is highly likely that RSs would work on the creation of 3D strata model based on the obtained physical model in BIM. There will be two (2) ways for RSs to get the physical models in BIM to work on:

Option 1: As-designed BIM from architects or the regulatory authority

The main issue for this option is, that the BIM model is an as-designed BIM. SLA is looking for as-built 3D digital strata survey and submission. Therefore, RS is required to conduct 3D digital survey, i.e. laser scanning, to obtain the point clouds first. The point cloud will be used as the base to validate the obtained design BIM model. If the offsets between the point cloud and the BIM model are within an acceptable tolerance, RS can create the 3D strata model based on the designed BIM directly.

Using as-designed BIM model to create 3D strata model can save RS's time to create physical BIM model. However, the overall time for the whole process may not reduce. This is because, the as-designed BIM usually is rather complicated with very detailed geometries of walls, slabs, columns, roofs, rooms, indoor furniture, even pipes and cables, as well as the thickness and material information of the structures. Some of the physical elements and information are not important in the context of strata boundaries modelling. Therefore, the BIM model should be generalized to eliminate unnecessary physical information. Such "generalization" works could be time-consuming works due to its complexity and computer's performance. Another issue is that the designed BIM model provided by architect or authority might not be the latest version, and without proper georeferenced. This also required time and cost for RS to verify after the construction of the building.

Option 2: As- built BIM derived from the point cloud

In this option, RS would create the physical model in BIM based on the point cloud which captured from the site survey after the building reach to roof top, and then construct the 3D legal space accordingly, as described in section 3.1.2 above. In such case, the physical structures and legal space would align well with each other in the final as-built 3D strata model, and the 3D model's overall accuracy would be higher than Option 1. SLA is working with the survey industry to implement the as-built 3D digital strata survey submission via Option 2.

3.2.3 3D Data Model and Modelling Methodologies

1) Adopt LADM as the fundation of cadastral database

The Land Administration Domain Model (LADM) is an international standard (ISO 19152) for land administration. It creates a conceptual framework which including Parties, RRRs, Spatial Units and Surveying components for land administration systems worldwide. LADM has been used in many projects, from database design to 3D modelling and 3D visualization, from LandXML-based applications to BIM-based applications (Ying et al., 2011, Soon et al. 2016, Atazadeh et. al.2017, Cemellini et al. 2020). The existing data model implemented in the current national cadastral system in Singapore (CSMS) is based on LADM (2012) (Soon et al. 2016).

2) Adopt IFC as the encoding format for BIM-based 3D strata model

Some international open standards have been developed for data interoperbility and data integration in geospatial and built enviroment domains, wchih inlcuding CityGML, GeoJson, IFC, LandInfra etc (OGC, buildingSMART 2020). IFC (Industry Foundation Classes) is an open BIM format used predominantly for exchange of rich, fine-scale building and infrastructure data in the AEC industry, which has been supported by main BIM modelling software, such as Revit, Archicad, Takla, OpenBuilding etc. In Singapore, the IFC 4 standard has been adopted and localized as IFC-SG standard accoring to Singapore goveryment agencies' requirements of regulatory approval for building works. The IFC-SG standard has been published as the Code of Practice for BIM Submisson with the launch of CORENET X in Singapore. SLA is working on the development of 3D cadastral CoP which is IFC-SG based.

3) Mapping strata elements to IFC entities

Idealy, A BIM-based 3D strata model should include legal, physical and survey information. The application of IFC standard in cadastre has been investigated a lot in different countries (Atazadeh et al. 2021). For example, in Australia, researchers have developed approaches for extending BIM with cadastral information (Atazadeh et al. 2016). For managing legal and physical data requirements, previous studies have identified relevant IFC entities based on the LADM, e.g. "IfcSpace" and "IfcZone" entities are considered for modelling strata boundaries.

In addition, the "IfcSite" entity was also considered for modelling 2D land parcels on a construction site. And IfcGeographicElement was selected as the appropriate entity for managing survey data elements (Atazadeh et al. 2021).
The major knowledge gaps in the integration of building and cadastral information have been addressed by those studies. This paper relies on the outcomes from those studies. Hence, IFC was selected to be the format to integrate the building information and cadastral information in a 3D strata model in SLA's pilot. Particularly, the "IfcSpace" entity was chosen for representing the 3D strata lot, 3D accessary lot, 3D common property and 3D VOID space. To model the 3D space attributes, the "IfcSpace" entity was enriched with different sets of attributes or properties (e.g, SGPset_StrataLot) according to Singapore's context. Table 1 lists the strata elements to be mapped to the IfcSpace with required attributes. Table 2 illustrates the strata lot attributes are mapped to the IFC PropertySet.

Table 1. 3D Strata Elements to be mapped to the IFC entities

Strata Elements to be modelled	**Mapping to existing entity (IFC4 Entities)**	**New Subtypes (IFC4 Userdefined Object Type)**	**IFC-SG_PropertySet (IFC4 Userdefined Property Set)**
Strata Lot	ifcSpace	STRATALOT	SGPset_StrataLot
Accessory Lot	ifcSpace	ACCESSORYLOT	SGPset_AccessoryLot
Common Property	ifcSpace	COMMONPROPERTY	SGPset_CommonProperty
Void	ifcSpace	VOID	SGPset_Void

Table 2. Mapping strata attributes to IFC-SG PropertySet_

IFC4 (USERDEFINED) IFC-SG_PropertySet	**IFC4 (USERDEFINED) IFC-SG PropertyName**	**Property Type**	**Sample Values**
SGPset_StrataLot	StrataLotNumber	Label	MK03-U017049L
	StrataLotArea	Area	120
	LotStatus	Label	Live
	ParcelType	Label	Strata
	ResidingOnLandLot	Label	MK03-01847M
	SVYFileNumber	Label	0226-1985
	TypicalFloor	Boolean	TRUE
	UnitNumber	Label	05-02

4) Modelling methodologies

In this pilot, the 3D strata modelling in Revit is based on the physical model of Block 213C which have been created in Pilot 1. As the strata boundary in Singapore is defined as from the middle of the walls, slabs and ceilings, with different treatments at balcony, aircon ledge, curtain walls and walls with different thickness, RSs' interpretations are required during the modelling process. Mass family in Revit was selected to create 3D strata boundaries, due to Mass objects can easily create complex, irregular geometries that are often required for strata boundaries. Mass object provides flexibility in modifying intricate shapes, which might not be as straightforward with other Revit families. Figure 12 illustrates the strata boundary was created using Mass family.

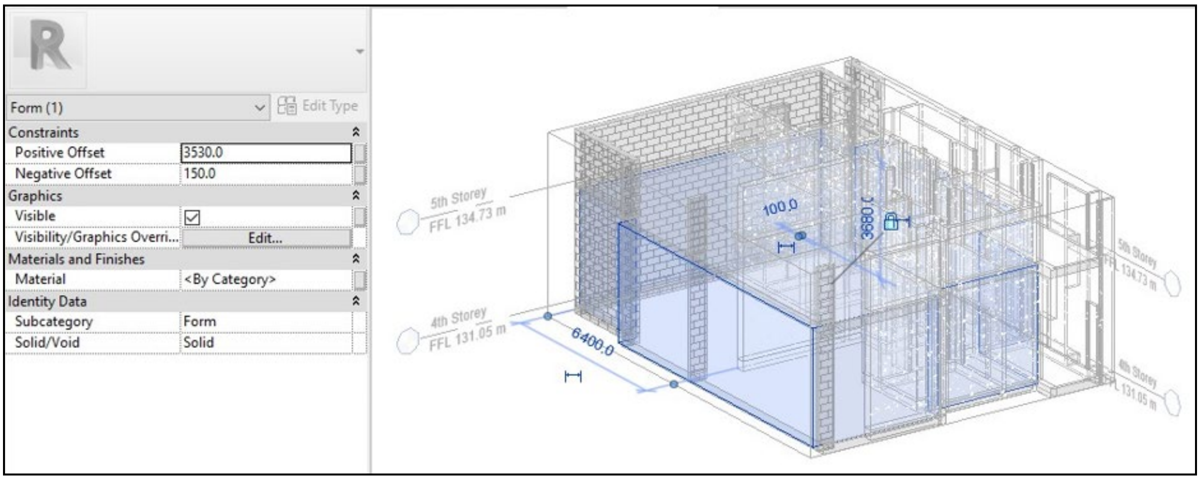

Figure 12. Using Mass family to create 3D strata boundary

In this pilot, the 5th storey is typical floor. Hence, the 3D strata boundaries of 5th storey were duplicated for the rest of typical storeys (6th -16th storey) after it was modelled. For those lower storeys (1st- 4th) which are not typical floors, the non- relevant units were removed, and some strata boundaries were adjusted accordingly. The attributes associated to individual strata lot were modified according to the actual information as well. The accuracy of the duplicated strata boundaries was verified against to the point cloud, and it was within the acceptable tolerance (3cm). And the rounded up as-built strata areas aligned with the approved strata areas too. This presented that the overall accuracy of the as-built 3D strata model is acceptable. The completed 3D strata model was exported from Revit to IFC-SG format. Figure 13 shows the final 3D strata model with attributes of Block 213C in a free IFC viewer called BIMVision.

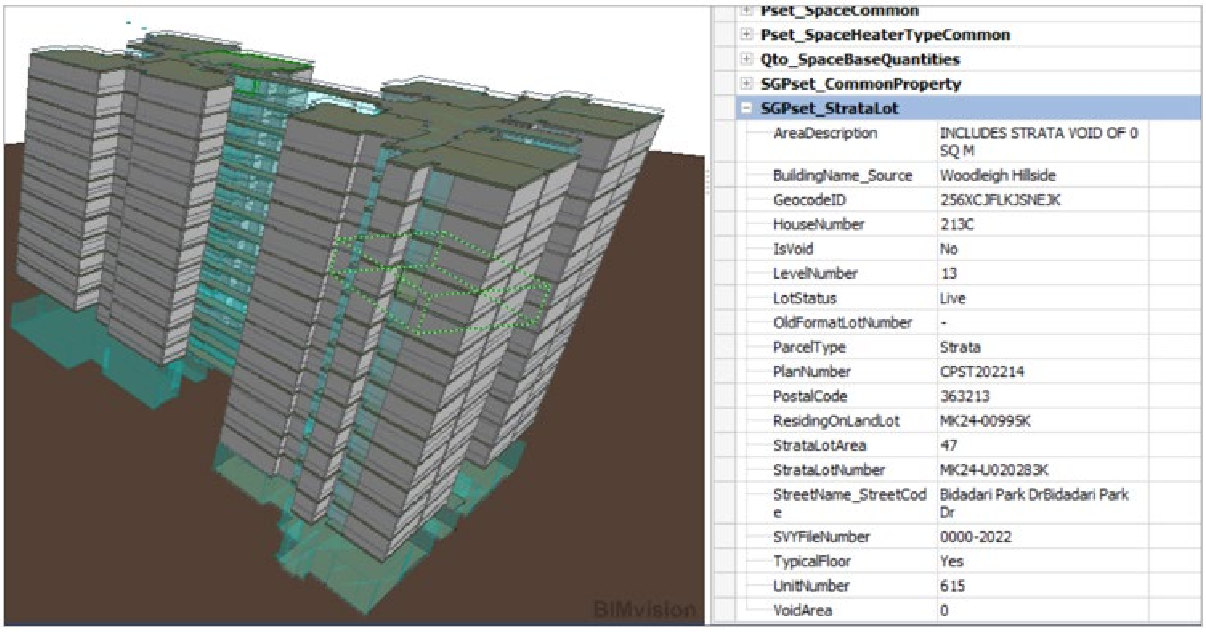

Figure 13. As-built 3D strata model of Block 213C

3.2.4 Findings

This pilot has explored the BIM-based as-built 3D strata modelling methodologies. Some takeaways are:

1) The adoption of LADM as data model which consistent with the existing cadastral system in Singapore, and leveraging on other jurisdictions' research outcome on IFC standard, built the technical foundation of this pilot.
2) Technically, the creation of 3D Strata Model based on existing BIM model using Mass object in Revit, associated the strata property sets to individual strata unit, and then exported the model as IFC format, where the 3D geometries were mapped to IfcSpace entity and attributes were mapped to IFC-SG Property Set, have been demonstrated that the methodologies are workable.
3) Most BIM modeling software focus on the physical structures' modelling. There is no BM-based tool for 3D strata modelling available fit for Singapore's strata submission context. It is time-consuming for as-built 3D strata modelling manually, especially surveyor's inputs are required for strata boundaries determination for different scenarios.
4) There is a need to develop a more intelligent 3D strata modelling tool to facilitate the modeler to generate the middle line of the walls/slabs/ceilings, and key-in the attributes automatically or semi-automatically.

3.3 Pilot 3 – Regulatory Validation and Visualization for 3D Strata Models

3.3.1 Objective

This pilot is more focusing on regulatory process using IT system in SLA. It aims to figure out the technical solution to enable the current CSMS system for digital 3D strata submission. This pilot is at initial design stage. It mainly covers two key components: regulatory validation and visualization.

3.3.2 Regulatory Validation

The integrity of any cadastral survey system is dependent on the quality of the data. Prevention of ambiguity in survey data is fundamental to safeguard the land title registration. The process of validating cadastral data prior to it entering into a cadastral database is an essential quality assurance process (Karki et al. 2013).

In Singapore, the CSMS has implemented the regulatory validation for 2D land submisions since it was launch in 2018. A set of complex validation rules has been applied to the validation process, from surveyor's license to the encoding file schema (SGLandXML), to single object geometric and textual information of the survey data, and to the relationship of objects on the certified plan. The digital format SGLandXML enables the pre-validation is an automated workflow at the front-end portal (RS Portal) of CSMS (Soon, et al. 2016).

Move to 3D, the same RRR apply to 2D strata unit also apply to 3D strata unit, though the surveying and creation requirements would be different between 2D plans and 3D models. As current 2D submission pratice, a registered surveyor carries out a 3D digital strata survey and produces the 3D model accordingly. The 3D model will be submitted to SLA and then will be examined for completeness and correctness against the validation rules.

The validation rules for 3D strata submission will be proposed and tested in CSMS in this pilot. The challenges that demand attention including:

1) validation rules on the field data, e.g. control points, leveling, traverse, point cloud;

2) validation rules on the 3D geometries, e.g. 3D geometry must be closed and watertight, no gap and no overlap between two 3D ownership boundaries;
3) validation rules on the textual information associated with the 3D model, e.g. the lot number consistency between submitted data and SLA cadastral database records;
4) further development and refinement of the validation rules even they have been implemented initially in CSMS;
5) develop the intelegent process for validation (e.g, automated valiation), to maintain the integrity and quality of 3D cadastral databases

3.3.3 3D Visualization

Beside the automated validation process to the 3D strata submission, it is important for the regulatory processing officers to further inspect the submission in a 3D environment and raise any query to registered surveyor, to ensure the whole process is reliable, consistent and justifiable before granting approval. The current absence of a fully 3D viewer for 3D strata submission in Singapore is another challenge for 3D cadastre implementation.
Various prototypes have been developed for 3D cadastre visualization, including using 3D PDF in The Netherlands, 3D ePlan in Australia (Shojaei et al. 2018), and the web-based 3D cadastral system in China. This pilot will explore the technical solution on developing an IFC-based 3D viewer with the functionalities of integrating BIM and the surrounding GIS data, viewing 2D plan and 3D model for cross checking, generate 2D plan from 3D model, as well as detect/verify encroachment etc. Figure 14 below illustrates the concept on how the 3D strata models (different color represent different physical and legal parts of the building) integrating with various geospatial data such as 2D land lots, terrain data, basemap etc. in the desired 3D Viewer. Some 3D platform including ArcGIS, Bentley, even opensource platform like Cesium, BIMVision etc, will be further assessed in this pilot.

Figure 14. Illustration of BIM/IFC + GIS data integration

The development of 3D validation rules and process, and the 3D viewer, to support the 3D strata submission is progressing at this initial stage. The current CSMS architecture has been discussed in detail by Soon et al. 2016. Figure 15 illustrates an enhanced architecture of CSMS for 3D strata submission, where the enhancements are indicated in red fonts. The proposals will be tested based on the CSMS in this pilot. The authors keen to further share once there is significant milestone reached in near future.

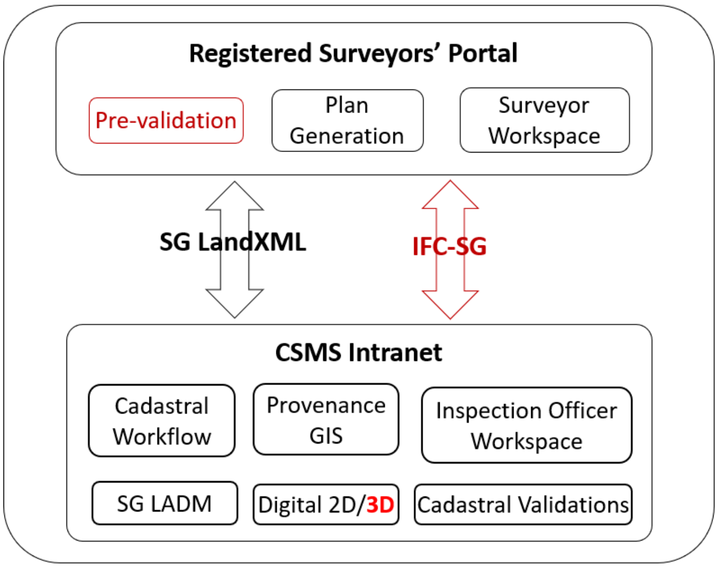

Figure 15. Enhanced architecture of CSMS

4. CONCLUDING REMARKS

3D cadastre development has been studied with significant milestones in legal and technical research, including standards and prototyping in different jurisdictions in the past decades. Particularly, the BIM-based solution for 3D strata implementation received significant attentions with the advancement of BIM and GIS development in the last decade. However, there is no nation-wide operational 3D cadastral system being used in the world up to date. The reasons are various, probably partially due to the desire on the 3rd dimension (vertical) of cadastre has different priorities in different jurisdictions.

Singapore pursues full digitalization for cadastral survey submission since the last decade of 20th century. After the digitalization for land survey submission using SG LandXML in 2018, SLA has been urged on 3D digital strata survey submission. This paper mainly discussed the current 3D strata pilots in Singapore, including 3D digital survey workflow, 3D modelling methodologies and 3D data validation and visualization. Through the piloting works which are progressing, some main remarks could be summarized as below:

1) Laser scanning is workable technology for as-built 3D digital strata survey. Generally, handheld laser scanner is more effective and economical than terrestrial laser scanner.
2) Georeferenced designed BIM is a good reference for surveying onsite, and a good data source for 3D strata modelling.
3) Modelling the typical floor and then duplicate it to the rest typical floors can fulfill the accuracy requirements in Singapore, which reduce modelling time and cost significantly.
4) IFC-based encoding and mapping for 3D strata model submission demonstrated that it is a workable solution in Singapore.
5) The CoP for 3D strata survey submission should be developed with maximum clarity on the regulatory requirements, e.g, the 3D strata survey and modelling specification.
6) The 3D enabling for CSMS, the development of a 3D strata modelling tool according to Singapore context, and the change management for the transition from 2D to 3D, are the main challenges for 3D cadastre implementation in Singapore in the next few years. The

overall productivity and data quality for 3D digital strata survey submission will be improved by overcoming these challenges.

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REFERENCES

Atazadeh, B., M. Kalantari, A. Rajabifard, S. Ho and T. Ngo (2017). Building Information Modelling for High-rise Land Administration. Transactions in GIS, 2017, 21(1): 91–113

Atazadeh, B., M. Kalantari, A. Rajabifard, S. Ho, T. Champion. Extending a BIM-based data model to support 3D digital management of complex ownership spaces. International Journal of Geographical Information Science 31 (3), 499-522, 2016

Atazadeh, B., L.H. Mirkalaei, H. Olfat, A. Rajabifard & D. Shojaei (2021). Integration of cadastral survey data into building information models, Geospatial Information Science, 24 (3), 387-402

Atazadeh, B., H. Olfat, A. Rajabifard, M. Kalantari, D. Shojaei, AM. Marjani. Linking Land Administration Domain Model and BIM environment for 3D digital cadastre in multi-storey buildings. Land Use Policy 104, 105367

Atazadeh, B., H. Olfat, A. Rajabifard (2021). 3D Cadastre in Australian and New Zealand Jurisdictions: Similarities and Differences 7th International FIG 3D Cadastre Workshop 11-13 October 2021, New York, USA

Cemellini, B., P. van Oosterom, R.Thompson, M. de Vries.Design, development and usability testing of an LADM compliant 3D Cadastral prototype system. Land Use Policy, Volume 98, November 2020, 104418

CS Directive of Singapore. https://www.sla.gov.sg/newsroom/circulars

Jeong, D.H., B.B. Jang, J.Y. Lee, S.I. Hong, P. van Oosterom, K.D. Zeeuw, J. Stoter, C. Lemmen and J. Zevenbergen (2012). Initial Design of an LADM-based 3D Cadastre – Case study from Korea. 3rd International Workshop on 3D Cadastres: Developments and Practices 25-26 October 2012, Shenzhen, China.

Karki, S., R. Thompson, K. McDougall (2013). Development of validation rules to support digital lodgement of 3D cadastral plans. Computers, Environment and Urban Systems, 2013

Khoo, V. (2011). 3D Cadastre in Singapore. 2nd International Workshop on 3D Cadastres, 16-18 November 2011, Delft, the Netherlands.

Khoo, V. (2012). Towards "Smart Cadastre" that Supports 3D Parcels. Proceedings of 3rd International Workshop on 3D Cadastres: Developments and Practices. Shenzhen, China. 25-26 October 2012. FIG.

OGC, buildingSMART (2020). Built environment data standards and their integration: an analysis of IFC, CityGML and LandInfra. Version 1.0 • 02 March 2020, OGC Document 19-091r1 bSI TR1012.

Olfat, H., D. Shojaei, M. Briffa. The Victorian digital cadastre: challenges and investigations. Proceedings of the 3rd Annual Conference of Research@ Locate, 2016
Olfat, H., B. Atazadeh,F. Badiee,Y. Chen,D. Shojaei, A. Rajabifard. A Proposal for Streamlining 3D Digital Cadastral Data Lifecycle. Land 2021, 10(6), 642; https://doi.org/10.3390/land10060642
van Oosterom, P. Research and development in 3D cadastres. Computers, Environment and Urban Systems (2013), http://dx.doi.org/10.1016/j.compenvurbsys.2013.01.002
van Oosterom, P. (2018). FIG publication Best Practices 3D Cadastres. https://www.fig.net/resources/publications/figpub/FIG_3DCad/figpub_3DCad.asp
Shojaei, D., H Olfat, A Rajabifard, M Briffa. Design and development of a 3D digital cadastre visualization prototype. ISPRS International Journal of Geo-Information 7 (10), 384, 2018
Soon, K.H., Tan, D. and Khoo, V. (2016). Initial Design to Develop a Cadastral System that Supports Digital Cadastre, 3D and Provenance for Singapore. 5th International FIG Workshop on 3D Cadastre 18-20 October 2016, Athens, Greece
Stoter, J., H. Ploeger, R. Roes, E. van der Riet, F. Biljecki, H. Ledoux. First 3D cadastral registration of multi-level ownerships rights in the Netherlands. Proceedings of the 5th International FIG 3D Cadastre Workshop, Athens, Greece,2016
Sun, J., Mi, S., Olsson, P., Paulsson, J., Harrie, L. (2019). Utilizing BIM and GIS for Representation and Visualization of 3D Cadastre. ISPRS International Journal of Geo-Information.
Sun J., and J. Paulsson (2020). A BIM-based Approach for Swedish 3D Cadastral Management. FIG Working Week 2020, Smart surveyors for land and water management, Amsterdam, the Netherlands, 10–14 May 2020
Tekavec, J., M. Ferlan, A. Lisec (2018). A review of research on 3D real property cadastre. https://www.researchgate.net/publication/326840886
Ying, S., L. Li & R. Guo (2012). Building 3D cadastral system based on 2D survey plans with SketchUp. Geo-spatial Information Science 14(2):129-136, Volume 14, Issue 2
Ying, S., R. Guo, L. Li and B. He (2012). Application of 3D GIS to 3D Cadastre in Urban Environment. 3rd International Workshop on 3D Cadastres: Developments and Practices, 25-26 October 2012, Shenzhen, China

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