Enhancing SmartKADASTER 3D City Model with Stratified Information in Supporting Smart City Enablement

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Abstract. SmartKADASTER Interactive Portal (SKiP) was developed as a 3D visual and analysis platform for JUPEM clients to better understand the dynamic and spatial relationships between cadastral parcels and their objects surroundings. However, SKiP was incomplete as it lacks strata title parcels information. A study was conducted to determine a suitable conceptual method for incorporating stratified information into the current SmartKADASTER environment. This paper will highlight the related strata survey practice in Malaysia and the advancement of SmartKADASTER 3D city modelling. Considerations and methods for using Strata XML and CityGML datasets are also discussed. Furthermore, some insights into using Strata XML to complement the SmartKADASTER city model with stratified information and 3D models are highlighted. The recommendations proposed at the end of this paper are hoped to contribute to the body of knowledge for 3D city model development and be adopted, particularly in improving the SmartKADASTER system for smart city enablement.

Keywords: Strata XML, SmartKADASTER, City Modelling, CityGML.

1 Introduction

Malaysia is experiencing an increase of 139% of population growth. To date, there are more than 32.7 mil population (including 3mil non-citizens) in Malaysia compared to 13.7 mil in 1980 [1]. By 2050, 68% of Malaysians are expected to live in urban areas. Consequently, systematic and proper handling of space, right and ownership are necessary to provide an equitable relationship between people and their property, providing strong evidence for urban dwellers' tenure security and well-being. These are among the challenges to be handled with smart and sustainable manners for city to expand [2]. This paper aims at sharing the experience of incorporating 3D stratified information into the SmartKADASTER city model developed to support smart city decision making based on 3D geospatial analysis. According to previous researchers [3], 3D city models are being used in the smart city paradigm, typically serving as a framework for the urban environment.

Naturally, location, land-use patterns, distances, and interactions are the essential factors of geospatial approach, as key supporting smart city implementation [3]. The Department of Survey and Mapping of Malaysia (JUPEM) is responsible for Malaysia's land administration's geospatial component, which is the fundamental dataset of Malaysia's Spatial Data Infrastructure (SDI). As of to date, Malaysia has more than 8 million land parcels stored in the National Digital Cadastral Database (NDCDB). While cadastral survey data can be acquired in 3D, it is stored planimetrically (x,y), thus inhibits further 3D-based analysis. 2D information cannot serve urban complexed situations, especially when different types of land use and properties were placed in a complicated 3D scenario. As a result, the SmartKADASTER Interactive Portal (SKiP) was developed as a 3D visual and analysis tool for the clients to better understand the complex and spatial relationships of the land or building parcels with its surroundings [4].

Although the essence of SKiP (Phase 1) was for 3D-based analysis, the cadastral data's foundation was mainly from the 2D survey accurate NDCDB. 3D cadastral information is available in Malaysia but through Strata Title, referring to the building parcels in a strata scheme for aboveground properties. A Strata Title Plan shows an accurate scale model of the strata parcels and their area size and building storey height. It provides the spatial dimensions of assets and properties containing legal interests, legal boundaries, and legal attributes. The Strata Title's legal boundaries are defined as median lines inside physical structures such as walls and ceilings. The management of strata and stratum titles in Malaysia are under the purview of the respective state's JUPEM and Land and Mine Office (PTG). Both authorities differently handle strata title preparations. PTG manages strata ownership and registration with *eTanah* (*eLand*). At the same time, JUPEM handles the spatial component and Strata Title Plan preparation through *eKadaster.* Both systems are still 2D in nature.

To enable 3D spatial analysis in SKiP, other 3D geodata such as building footprints, digital terrain models and meshed city model was applied and incorporated into SKiP. The approach enabled various 3D-based spatial analysis, such as water rising simulation and shadow analysis, for application such as forecasting an area's property market value. Such 3D spatial analysis has directly helped users to democratise SKiP data and was found fit for its purpose at providing ease of doing spatial analysis [4]. However, SKiP is still lacking of 3D cadastral information. A complete 2D and 3D cadastre information in SKiP would enable a holistic spatial analysis result that has linkages to the object's Rights, Restrictions and Responsibility (RRR). Therefore, a study was carried out to determine the conceptual approach to be applied for incorporating stratified 3D cadastral information into SmartKADASTER Phase 2. Another source for 3D cadastral information in Malaysia is the Stratum Title, but it is not included in the study.

The remaining sections of this paper cover the rest of the study, including the related strata survey practice in Malaysia in Section 2. SmartKADASTER 3D City Modelling development is described in Section 3, followed by leveraging Strata XML and SmartKADASTER 3D database. Lastly, Section 5 on recommendations and conclusion.

2 RELATED WORKS ON STRATA SURVEY PRACTICE

Existing cadastre in Malaysia is managed in a 2D environment, except for aboveground stratified properties that are 2D + 1D (Storey Height), which can also be known as the volumetric parcel or 2.5D. Stratified titles typically include high-rise properties such as condominiums, apartments, and landed properties gated and guarded [5], with underground properties like basement or bunkers. Before a strata submission, a Licensed Land Surveyor (LLS) must confirm the subdivided buildings are situated wholly within the boundaries of the cadastral lot, and the subdivision would not contravene any restriction in interest to which the land comprised in that lot is for the time being subject. The LLS is then required to carry out the as-built survey of the strata parcel. The strata parcel's spatial properties are described as 'x',' y' and 'z'. However, the 'z' value does not refer to a specific or established vertical datum or the terrain but rather the strata parcel's geometry. The 'z' refers to the parcel's relative height measured from its ceiling to the floor surface, providing volumetric of the parcel [6].

A strata parcel's legal boundaries are defined in the building elements' median location, most of the time as equal parts of a wall and ceilings or other physical structure. Although 3D data are acquired on-site, the legalistic cadastre system and land law still use 2D geometric description. The legal and land law expression for land and property tenure have not been prepared to register in a 3D situation. The strata title plan is the by-law document prepared and embedded into the paper-based Strata Title to prove ownership. A sample of a Strata Title Plan is shown in Fig. 1.

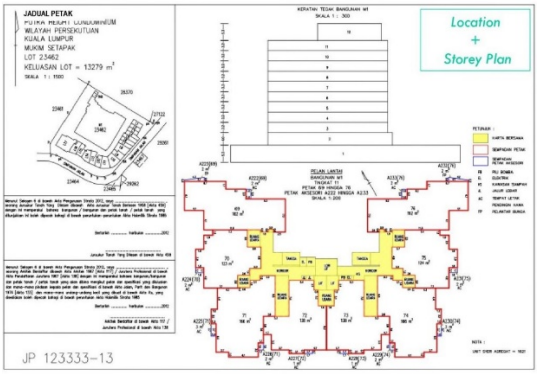

Fig. 1. A sample of a Strata Plan showing the strata unit parcel and its corresponding storey plan.

The Strata Title is a unique title given to parcel units owner of a residential or commercial multi-storey building that shares common facilities such as security, parking, and common governing space [6]. Sometimes it could be owned by more than a person. With the Strata XML data's availability, the strata parcels can now be rendered and visualised in a 3D scene. A 3D model could further illustrate the 'x',' y' and 'z' coordinates of each parcel unit, thus, become more significant as evidence on ownership rights for the vertical space. A strata Unique Parcel Identifier (UPI) is created to help identify

every strata parcel and link it to the corresponding 2D cadastral lot. A detailed explanation of the strata UPI can be referred to [7].

3 SmartKADASTER 3D City Modelling toward Smart City

3.1 The Motivation

One of the unique features of the SmartKADASTER project is the 3D city model. A 3D city model is a mixture of both geometric and non-geometric data. 3D reconstruction and data integration are usually performed to build the city model [8]. The city model of the Phase 1 SmartKADASTER project was constructed and displayed as a 3D mesh with Skyline's proprietary format in SKiP, as shown in Fig 2.

Fig. 2. 3D Mesh Sample of SmartKADASTER Phase 1 City Model

Naturally, NDCDB was the basis for cadastral survey information in SmartKADASTER. However, it was incomplete as it lacks strata title parcels information. Because of this limitation, Phase 2 aims to ensure the city model for a Greater Kuala Lumpur complies (Selangor state and a part of Negeri Sembilan) with a universal exchange standard and database-ready to incorporate cadastre information.

3.2 CityGML Schema

CityGML is an open data model and XML-based format for storing and exchanging common 3D features in virtual 3D city and landscape models [9]. The development of CityGML is to reach a standard definition of the basic entities (such as buildings, roads, rivers, bridges, vegetation and city furniture), attributes, and relations of a 3D city model. It also defines different standard levels of detail (LoDs) for the 3D objects, which allows the representation of objects for various applications and purposes, such as simulations, urban data mining, facility management, and thematic inquiries. Thus, the schema is a crucial feature of 3D city modelling in terms of cost-effective, long-term model maintenance, enabling the reuse of the same data in multiple application areas, such as the 3D model of Helsinki, which supports more than ten applications as

of 2017. Consequently, CityGML2.0 is utilised in SmartKADASTER to support existing strata XML files (converted into Strata-CityGML compliences) and for the same purpose of visualisation and management within SKiP environment.

3.3 3D Database

In Phase 2 SmartKADASTER, PostgreSQL is used to handle the attribute table for 2D and 3D data, while PostGIS is the spatial extender to serve geometry and coordinate system of vector data. The 3D CityGML schema in PostgreSQL database is based on the CityObject relationship – 3DCityDB class (one of the elements supported in Object-based Spatial Database, OSD). An OSD is a spatial database that stores the location as objects (e.g. cities, rivers), which exist independently of their locations. While CityObject in this case capable of representing an object in several predefined details (LoDs) and linking with respective LoD attributes. The attributes storing with objects within an OSD provide better presentation result, improved security, searching query, manipulation (update/add/delete) capabilities in a more efficient way.

3DCityDB is used to provide SQL functions to create a CityGML (CityObject) schema for PostgreSQL. The selection is based on previous researchers' recommendations, such as [11], where 3DCityDB offers more compact and allows fewer tables to automatically create a spatial relational database schema. The database is essentially supporting the CityGML version 2.0 and other tools such as the Data Publishing Web Feature Service and the Importer/Exporter tool. With CityGML Importer/Exporter, CityGML features and geometries are the first to be read and imported, neglecting all XLink reference information, but temporarily stored in the database. To complete the entire CityGML import process, the XLink relationship information stored in the database are being re-resolved and written to the respective CityGML data tables. At the same time, CityGML datasets are validated for 3DCityDB syntax error and geometric-topological accuracy with CityDoctor. Apart from software, information and communication technology (ICT) also plays important roles in measuring smartness level of smart city indication [10]. As a consequence, for the SmartKADASTER 3D citymodel, a database approach is preferred over file-based management to allow functions such as ease of queries and data or model updating.

3.4 3D UPI Supporting Multiple Representation Details (LoDs)

As the study focuses on the Building Module of CityGML and the migration process has completed, CityObject generates the Building Table. The minimum attributes of the 3D CityGML LoD and 3D UPI models are shown in Fig. 3. User queries (SKiP) are performed in this database for LoD information and its geometry. The 3D UPI allows users to quickly access a list of CityObjects by querying the selected geometry and attributes. For the SmartKADASTER 3D model, it was decided that the 3D UPI is the extension of the 2D UPI of the cadastre lot too, but "D" is introduced to represent the respective LoD type. For example, 1601400141393(S)x(B)xD1 for LoD1, …D2 for LoD2, …D3 for LoD3, …D4 for LoD4. Attributes can be managed directly using the PostgreSQL database. However, the geometry for each 3D CityGML LoD still

demands manual intervention. Nevertheless, PostgreSQL allows any obsolete model to be replaced with a new model based on the 3D UPI while preserving attributes.

The LoDs model was constructed using SketchUp software from the various sources of surveyed point clouds tied up to the ground control points (GCP) and 2D cadastre marks. Fig 4 show a building sample of LoD1-3 according to CityGML version 2.0 schema. For Phase 2, the minimum number of building in LoD2 and LoD3 is 1500 buildings, while LoD1 is for the whole project area, 1,430km^2. All these models will be tied up using 3D UPI ID with D extension, stored in Postgres database and visualise/query using SKiP.

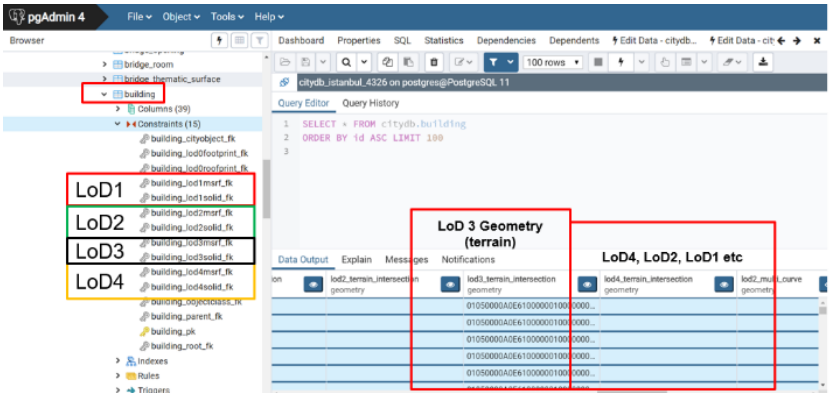

Fig. 3. Building table for respective LoD in Building module of CityObject Table.

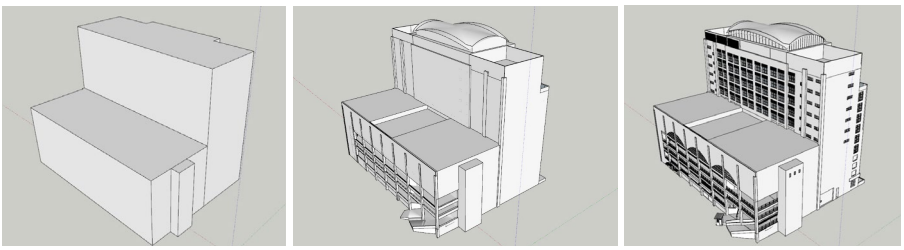

Fig. 4. L-R: Samples of LoD 1, 2 and 3 of *Wisma Perbadanan Kemajuan Pertanian Selangor*.

4 Leveraging Strata XML in 3D SmartKADASTER Databases

4.1 Differences Between Strata XML and City Modelling

During the project implementation, it was found that there are some significant differences in comparing the dataset schema of strata and the new SmartKADASTER city model using CityGML. Six main differences are highlighted; details information, 3D UPI, geometry, attributes, focus users and storage management.

Level of Details. Strata XML only have a single schema for a building. The schema includes metadata, UPI ID, geometry, classes (e.g. owners, shared facilities etc),

attributes (e.g. name of unit) and others whereas CityGML with 5 LoDs (4 of them are for 3D).

Geometry. The geometry of the strata file focuses on the middle wall of the building structure (boundary). However, CityGML is based on each wall's surface coordinates (exterior in general and interior for LoD4). In other words, the Strata concept is defined by boundary and rights (hidden) while CityGMLis based on actual representation by eyes.

3D UPI Strata vs 3D UPI City Model. Both strata and city models have UPI 3D depicting each other's characteristics. For example, "*Tingkat*" and Accessories are available in Strata XML and LoD categories are presented for city models. However, both UPIs have a continuation of the 2D UPI, which refers to the cadastral lots as found in the NDCDB. The 2D UPI in NDCDB is equivalent to 3D UPI for LoD 0 City Model, while for Strata XML refers to the UPI codes set by JUPEM on strata properties.

Attributes. In terms of attributes, existing Strata XML have rich information linked with the RRR information available in PTG (*eTanah*). While in CityGML LoD, most of the attributes incorporated and linked in the database are in fact shared with other datasets. There are very minimum attributes migrated during the construction of the 3D model and database migration since model extractions are from point clouds.

Focus Users and Professional Domains. Strata is a file data with specific purposes and may interest users where linkage of geometry and RRR ownership is their primary concern. Meanwhile, CityGML is introduced to offer different standard LoDs and cost-effectiveness, so more comprehensive users and cases can utilise the 3D data.

Storage Management (File-based and database). The main differences of both schema implementation lie on storage management; strata in file-based XML format and CityGML in the PostgreSQL database. In general, file-based data provides less security, less efficient in updating and searching and multi-user viewing/updating data. In Strata XML format, all strata files refer to a specific development area with plenty of files, IDs, and information of the 3D space. Accessing a specific file in multi-user mode without secure account security will be a devastating drawback compared to database query. Similarly, proprietary CityGML format is also in XML type file-based but more specialised as in Geographic Markup Language (.gml format). However, with advanced and recent development in import/export tool such as 3DCityDB, has allowed migration of CityGML file-based into PostgreSQL database. Accessing 3D city model from database gives any 3D online platform a booster in supporting massive datasets, especially city level and even a country. Fast information retrieval, updating work and security could be enhanced drastically using database environment.

4.2 3D Model Presentation of Strata + CityGML for SmartKADASTER

Essentially, the purpose of modelling 3D cadastre objects highlighted by [11] is intended to provide boundary certainty for 3D cadastre objects. Therefore, with the notion that a 3D visualisation is a form of geovisualisation, the 3D model presentation is the key to disseminating, visualising and utilising the 3D model to support decision-making especially as part of smart city module. Ideally, the rich Strata XML information should be retained. However, because of the differences between the strata and city model schema, the presentation of the 3D model may require a different grouping of data. Nevertheless, both strata and city model models can still be integrated with 3D UPI. An actual 3D model of shop lots reconstructed using SketchUp is shown in Fig. 5. Instead, as a long block, the LoD models for party wall buildings are reconstructed into individual models based on exact building footprints with 3D UPI with respective 2D Cadastral lot (2D UPI). The 3D UPI ID later shall be linked to Strata UPI ID for any information on space ownership and RRR without opening a new 3D viewer for the visualise Strata model. The overall concept of integrating CityGML model in SmartKADASTER Phase 2 with existing Strata XML, database and single viewer (SKiP) is illustrated in Fig. 6. Previous researchers [12] had successfully integrated PostgreSQL database to support the smart city concept in their work with 4D web application.

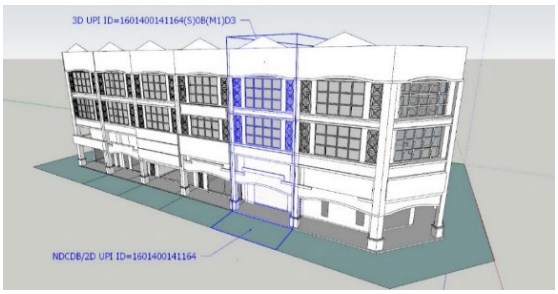

Fig. 5. Example of proposed 3D UPI (LoD3, D3) based on NDCDB 2D UPI.

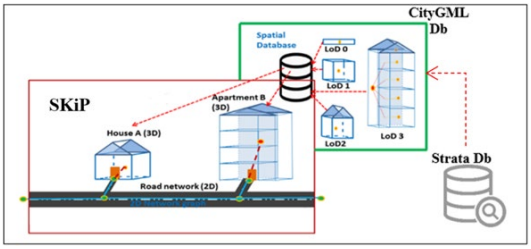

Fig.6. 3D visualisation concept and data workflow (edited from [12]).

4.3 Development of Strata XML to CityGML Converter

Strata XML as part of the legalised data and primary output of Malaysia strata legal framework, comprises information but not limited to attribute information such as types of building usage, types of parcels, strata project information, the height and altitude of

the parcel; as well as spatial information such as surveying information that includes bearing and distances of the corner of the associated parcel. The XML has a customised schema that explains how elements represent the real-world entity, e.g. *Petak* is equivalent to Building Parcel. The underlying concept that pushes the idea of future-cadastre in 3D smart city management is to enable customised schema in the city modelling domain, a subset of Smart City Management. Enabling customised schema in city modelling requires the use of Application Domain Extension (ADE) in CityGML. On the one hand, the application is city modelling, while on the other hand, it comprises specific strata information beyond the CityGML standard scope. Fig. 7 depicted how strata XML data be utilised for a city model that contains cadastre information.

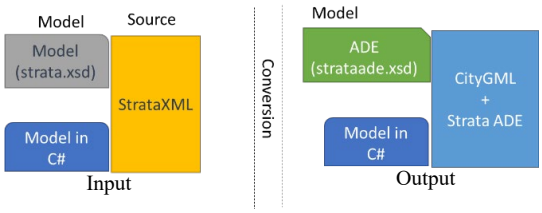

Fig. 7. The logical model of both input and output to enable cadastre information in smart city.

The conceptual workflow is then further realised into a physical workflow where each input and output model is created in C#, complied to the formatting of Schema Definition (XSD). The XSD (strata.xsd) was used to develop the model, while the new XSD (strataade.xsd) was developed and further developed into C# model. Fig. 8 also shows the workflow that is physicalised using C#. The program was then developed using C#, whereby it converts StrataXML to CityGML with custom attributes and naming using the ADE. The ADE was validated using XML validator. With the ADE the CityGML was produced and further visualised in FME Safe software. The CityGML is additionally imported into database as required on the application side.

4.4 Visualisation Platform

Some potential web-based visualisation platforms such as Skyline (commercial) and Cesium (open source) are in the exploration stage. [13] managed in integrating 2D (current land registration systems) and 3D geospatial data (3D properties) via utilising Cesium JS as a 3D geospatial platform. Nevertheless, the project aim is to utilise strata information in the same visualisation platform as the SmartKADASTER city model in SKiP. The 3D visualisation platform's functionalities should at least meet what previous researchers [14, 15] have outlined. It is unnecessary to have the same database as CityGML; it could be a different database name/schema but supported in the same PostgreSQL database and schema to link via the same 3D UPI standard. Fig. 8 shows an example of the strata model (3D) converted from Strata XML, while Fig. 9 shows another converted sample with existing 2D NDCDB cadastre system.

To enable smart, on-demand and online purchasing, JUPEM's eBIZ application is being integrated with the visualisation platform of SKiP. Primary Users can enjoy SKiP

services and make online payments by prepaid or e-wallets and instantly download their purchased digital data.

Fig.8. Example of strata model (3D) in a web-based imagery application.

Fig.9. Example of strata model (3D) with CityGML schema overlaid with 2D NDCDB lot.

4.5 3D UPI Linkages Between both Models

The schema structure and differences are "not connected" to one another based on geometrical details (LoD). Otherwise, another new schema of data structure is required to incorporate both geometric features. However, there is a way to connect them, that is by using 3D UPI ID. Basically, all strata parcels are associated with every LoD type. Although it can be from different database sources, it can be linked and displayed in a single viewer in SKiP. This relationship between tables was made using the specific 3D UPI in each object class as a connection continuity in the 3D database.

5 Concluding Remarks

5.1 Recommendations and Future Plans

Several recommendations based on the findings of the study are highlighted for future work consideration, particularly incorporating stratified information into city database:

i. 2D cadastre data should still be employed for 3D visualisation in a 2D/3D hybrid cadastre approach.
ii. 3D models are typically resulting in higher storage when converting into CityGML.
iii. Traditionally, strata's value is based on parcel area (length x wide) without volume (height) calculation. This new information should be added into Strata GML database, and help owners understand their parcel's vertical dimensions.
iv. Seamless 3D visualisation between Strata GML and the CityModel is crucial to increase user experience. Generally, a strata parcel usually consists of several utilities like column, beam, and sewerage pipe that can be considered unusable areas; could be updated. These exclusive use areas cannot be determined in the Sale and Purchase Agreement, Property Valuation Report and Cadastral Map.
v. Concerning the above, combination of LoD and stratified information, has potential, including indoor navigation.
vi. The 3D buildings can be seamlessly integrated with other datasets such as terrain, roads, traffic, sewerage, sensors, landscapes, and others to complete and understand the city with a common reference datum.
vii. The 3D city model of SmartKADASTER comprises all spectrums of LoDs (from LoD 0 to 4). Under the new CityGML 3.0, the LODs 0/1/2/3 remain, and the interior of objects that are typically modelled and described as LoD 4 is removed. Instead, they are expressed and integrated with the LODs 0/1/2/3.
viii. Underground legal object (utilities etc) is best represented in city model CityGML and integrated with owner's information and RRR from cadastral law.
ix. The developed Strata converter can act as a new medium for validating Strata XML provided by LLS to improve as-built document for strata title reference.

5.2 Conclusion

This paper has highlighted the background, the aim and motivation to have a 3D city model database for SmartKADASTER (CityGML) and 3D Strata for smart city-based 3D model. The description on CityGML, Strata file, and database were also explained in this paper for a better understanding and idea of integration. A strata-to-CityGML converter is developed from strata information into CityGML-based schema for standardisation of information retrieval in SKiP. These two data sources will provide significant improvement in spatial analysis and smart city data management, especially for Phase 2 area of interest. Thus, issues related to the land or building's RRR can be verified seamlessly. In addition, several insights on leveraging the Strata XML to complete the stratified information within the SmartKADASTER environment were also touched in this paper that can be further studied in the future. Recommendations proposed in this paper is hoped to contribute to the 3D city model development body of knowledge and be adopted especially for smart city management in Malaysia.

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