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To cite this article: Nur Zurairah Abdul Halim *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **767** 012027





# Developing a 3D City Model Database Beyond Cadastral Purposes

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**Abstract**. SmartKADASTER Interactive Portal (SKiP) is a platform developed by the Department of Survey and Mapping Malaysia (JUPEM), where the cadastral survey information can be visualised in a 3D environment and expanded to satisfy other new-found requirement and beyond cadastral purposes. This paper outlines the approaches used to develop the SKiP phase 2 utilising 3D CityGML database schema. The 3D CityGML Level of Details (LoDs) reconstruction data source is derived primarily from cloud points and images of various airborne and terrestrial geomatic technologies. The 3D building models were constructed with Trimble SketchUp software and later imported into the respective CityGML LoD1, 2, 3 and 4 models (*.gml). The models were then imported into PostgreSQL database based on PostGIS schema and CityGML schema (3DCityDB). A 3D Unique Parcel Identifier (UPI) is introduced to link the respective 3D LoD buildings with their corresponding 2D cadastral lot. Information (attribute) across multiple LoDs is retrievable via UPI ID query, and systematic updating tasks is feasible using the database. Quality assurance and control (QAQC) was applied to the CityGML LoD models and schema using FME workbench, 3DCityDB and CityDoctor. At the end of this paper, discussion and conclusion are outlined, with proposals for future work. Finally, this paper is hoped to help other users and researchers systematically build a 3D city model database and be aware of the possibilities of SmartKADASTER's potential application beyond Malaysia's cadastral purpose.

## 1. SmartKADASTER

### *1.1. How it all started?*

In 2012, the Department of Survey and Mapping Malaysia (JUPEM) carried out a pilot study in WP Putrajaya on the possibilities of implementing the multipurpose cadastre concept. The study found that cadastral data-based analysis could be more comprehensive when value-added with mapping and geospatial information. Similar with other researchers, [1] also concurred visualisation in a 3D environment is significant at describing the relationship of the cadastral parcel with the spaces above, on or below the earth's surface. Consequently, JUPEM decided to expand the concept to WP Kuala Lumpur and Putrajaya and emphasised in developing a 3D-based system. The focus was also broadened to support the SmartCity implementation in Malaysia, so the city's assets and dynamics can be spatially represented in 3D and linked with survey accurate cadastre information. Evidently, SmartKADASTER was the paradigm shift project ensued from the pilot study that went live in 2016. Phase 1 covered the whole WP Kuala Lumpur and Putrajaya intending to provide a web-based platform - SmartKADASTER Interactive Portal (SKiP), where the cadastral survey information can be visualised in a 3D environment and expanded to satisfy other new-found requirement and beyond cadastral purposes [2]. Phase 2 is still ongoing and expected to go live in 2022, covering a larger area of interest (AOI) that included an area of developed regions in Selangor, Nilai and Seremban.

### *1.2. SmartKADASTER 3D representation*

SmartKADASTER city model's full representation was primarily in the 3D mesh model, backed by other 3D geospatial datasets such as Digital Terrain Model and LoD 1 models. The LOD1 models were generated by extruding building footprints (derived from accurate LiDAR point clouds or true orthophoto) to the roof's top, as wireframes. A few buildings of interest were modelled as solid LoD3 and LoD4, in a bid to study the feasibility of having models with multiple semantic classes and determining the model's internal or external relationship with cadastral survey properties. Overall, the city model is mostly represented in 3D mesh and LOD1 3D models in SKiP, as shown in Figure 1.

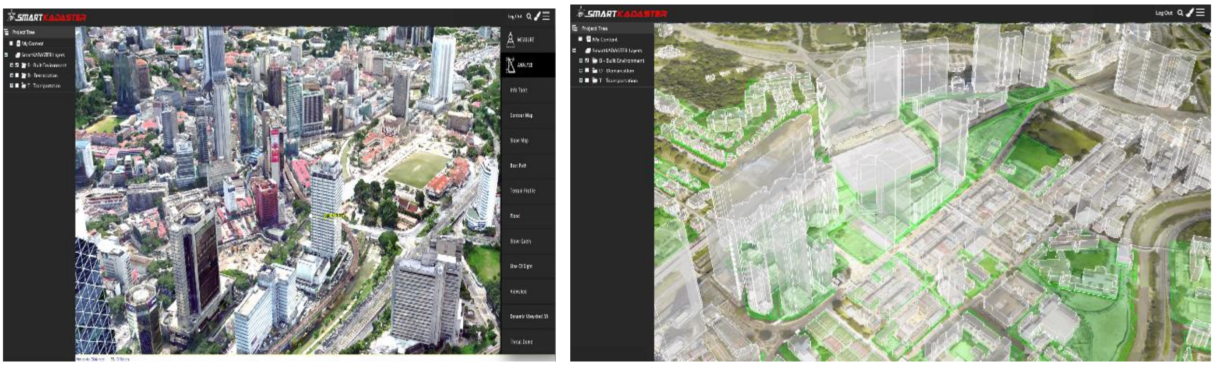

**Figure 1.** (a) Sample of 3D mesh models in SKiP; (b) Sample of LoD1 models in SKiP (wireframe).

### *1.3. The motivation of a 3D SmartKADASTER database*

Generally, the 3D city model in SKiP has enabled a better abstraction of the real world and realistic orientation to users in the form of 3D mesh and 3D LoD1 buildings. A preliminary assessment or insight is possible to users before any comprehensive 3D spatial analysis is conducted in SKiP. An assessment on the usability of SmartKADASTER phase 1 was carried out, and results concluded that SKiP was regarded fit for its purpose of effectiveness, efficiency, and satisfaction in supporting smart decision making, specifically when land and people are concerned [3]. While users benefit from the rich data model in SKiP, there is a high demand to store, manage, and analyse the data in a structured way. However, the SmartKADASTER system does not store the 3D city models in any particular 3D database scheme, format or standard, but instead managed the city model as a file-based system for visualisation purpose. Watt and Eng [4] studied the contrasting features of both database and file-based systems, they and stressed that managing information using a database solution was found more practical, accessible, and cohesive. Realising these setbacks, phase 2 aims to ensure the modelling is based on complying city model standards and encapsulating the 3D city model into a database, targeting beyond cadastre purpose and exchange format. It is noted that most domains have their own LoD definitions and specifications to work with, hence require different abstractions and models of real-world objects [5].

Ensuing this, a standard 3D model schema that covers not only geometry but also its semantic and thematic properties, taxonomies and aggregations as well as addressing cadastre properties, including strata titles, should be considered so more comprehensive users and cases can utilise the 3D data. Evidently, the use of the CityGML 2.0 was deemed fit for developing the SmartKADASTER 3D city model database based on the suggestions and recommendation of previous researchers [6-10] and because academic and business stakeholders broadly accepted it for 3D modelling [6]. Therefore, this paper aims to describe the methodology point of view and give insights into the different components of the method used to develop the SmartKADASTER 3D city model database specifically for buildings. The rest of this paper is structured as follows: Section 2 describes the initial process of incorporating CityGML into SmartKADASTER. Section 3 describes the proposed idea for seamless 3D CityGML modelling, while Section 4 elaborates the 3D model migration spatial database (PostgreSQL). Finally, the discussion and conclusion of the paper will be in Section 5.

## 2. Incorporating CityGML into SmartKADASTER

The CityGML was introduced as a standardised data model and XML format by Open Geospatial Consortium (OGC), which enabled the exchange format of 3D models of city and landscape features from various applications. Applications include but are not limited to, cadastre/mapping, navigation, environment, architecture/urban planning, tourism, training simulation, real estate and urban facility management [7]. Therefore, it would naturally make much sense to extend the usability of SmartKADASTER within these applications as CityGML is being adopted in phase 2.

A revision of CityGML was made in 2012, namely CityGML2.0 - introduced substantial additions and new features to the thirteen thematic extension modules of the CityGML. It can thus characterise 3D city landscape (geometry, semantic, topology and appearance) and is a multifunctional model for geospatial transactions, data storage, database, visualisation, analysis, simulation and exploration tools intended for users [8]. In addition, there are many successful testing, collaboration, and implementation on the CityGML scheme culminating in the scheme being broadly accessible and stable. For example, integration of CityGML-BIM standards, improving data sharing across the life cycle of the urban and environmental process [8]. CityGML also embraces multiple levels of information that can emerge from independent data processing methods that are utilised for effective visualisation and data analysis.

CityGML is available in five different standardised LoDs, which are illustrated in Figure 2. While Figure 3 shows the examples of standard input datasets in constructing a 3D model. LoD0 is a building footprint with 2.5D Digital Terrain Model. LoD1 is the common block model, while LoD2 is the extension of LoD1, including the roof structures. The object's vegetation may also be represented in LoD2. LoD3 is similar to an architectural model with openings such as windows and doors, while the walls, roof structures and bays can be included with textures. Lastly, LoD4 completes a LoD3 model by adding interior structures like rooms, interior doors, stairs, and furniture.

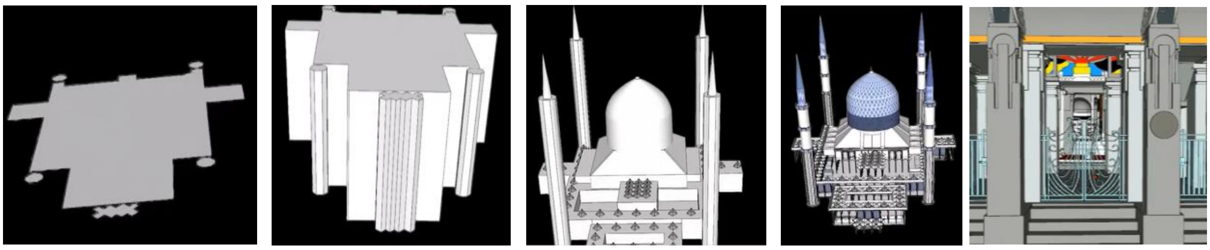

**Figure 2.** Five LoDs in CityGML[9] (e.g. Sultan Salahuddin Abdul Aziz Mosque).

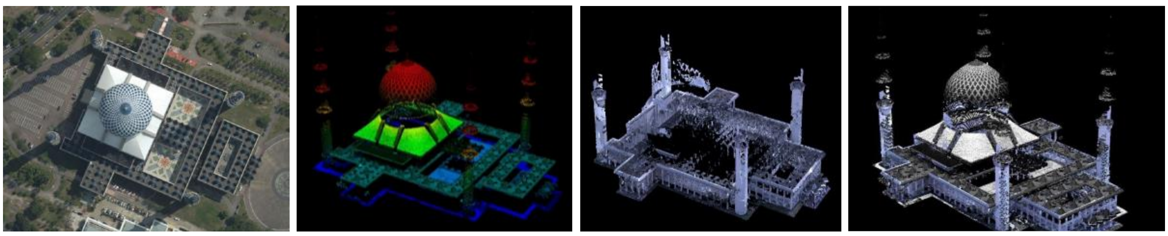

**Figure 3.** (a) True Orthophoto; (b) ALS point clouds; (c) MTLS point clouds; (d) Combination ALS and MTLS point cloud data of the mosque building structure.

## 3. Conceptual Framework for Connecting Multi-LoD In A Single Viewer

Systematically designed and organised large multi-scale models would provide advantages in minimising data storage redundancy and updating workload [4]. General project/research and implementation workflow on the multi-scale supported 3D model database is shown in Figure 4.

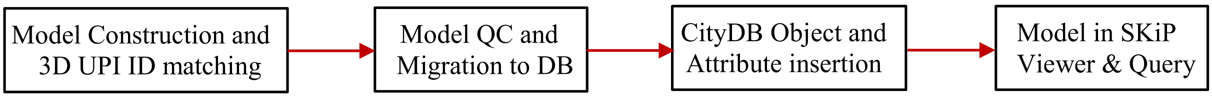


**Figure 4.** General research implementation workflow.

In general, there are two options for constructing a linkage/network for accessing information (attribute) from the respective 3D building LoDs. Either defining a schematic connection in the CityGML schema (currently not accessible from OGC) or introducing a mutual unique ID database. The later is applied in phase 2, where 2D cadastre lots are already available with UPI. Next, a supported spatial database is required to migrate CityGML LoD models. Database implementation makes it easy for end-user/application query to retrieve related information from respective LoD and compared them with the CityGML-based file. For example, the current view is LoD2, but attributes in LoD0, 1, 3 and 4 can be retrieved via 3D UPI and database implementation as illustrated in Figure 5. CityEditor tool is used to defined respective 3D UPI LoDs of imported SketchUp model toward CityGML schema.

In phase 2, 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. Editing tools like QGIS and ESRI ArcMap were used to amend, update and delete feature/object in the database. The assignment of the 3D UPI ID and the respective LoD model was based on the following characteristic; i) LoD0 CityGML (3D UPI LoD0) = Cadastre lot (UPI); ii) LoD1 CityGML (3D UPI LoD1); iii) LoD2 CityGML (3D UPI LoD2); iv) LoD3 CityGML (3D UPI LoD3); and v) LoD4 CityGML (3D UPI LoD4).

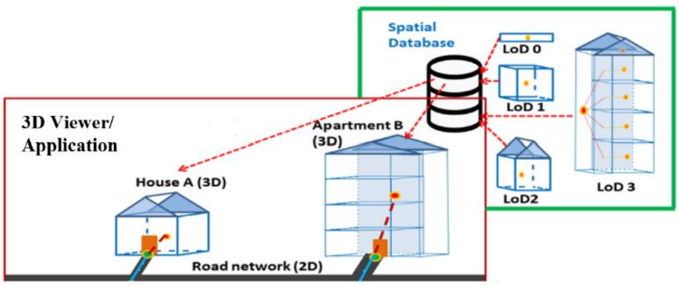


**Figure 5.** Illustration of a single viewer with database integration supporting multi 3D LoD models [10].

## 4. 3D Model Migration Process

### *4.1. QAQC According to CityGML Schema*

Figure 6 illustrated the methodology applied in phase 2 to ensure a valid 3D CityGML LoD model was migrated and linked into the PostgreSQL database.

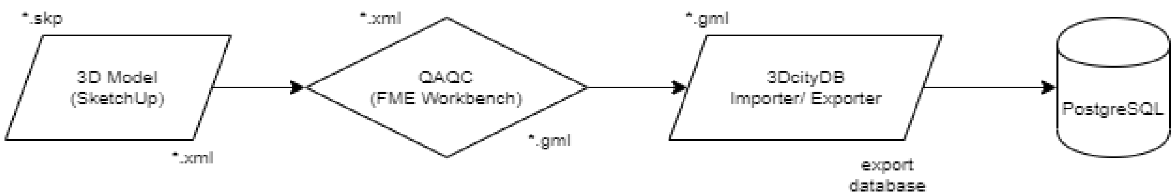


**Figure 6.** 3D model migration workflow from model construction in SketchUp to PostgreSQL database.

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The LoD model must comply with CityGML LoDs schema prior to the migration PostgreSQL database. Quality assurance and control (QAQC) was conducted using the FME workbench. Each LoD is tested in compliance with the proper classification and in accordance with the respective CityGML LoD schema group layer mentioned earlier. Apart from that, the consistency of the model's accuracy was also rechecked by using point clouds. If errors are found, correction is made in SketchUp, before converting them into CityGML format. A sample of a corrected 3D LoD4 model is shown in Figure 7.

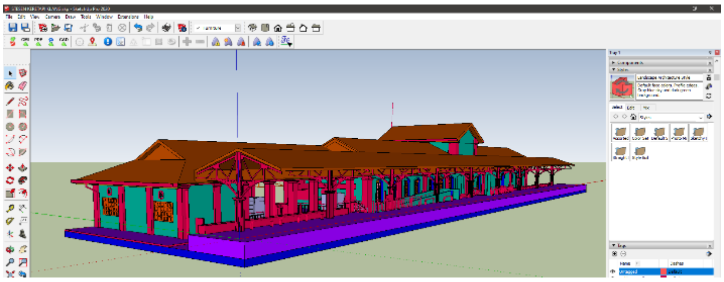

**Figure 7.** Corrected 3D model LoD4 CityGML, ready to be exported into the database.

*4.2. 3D UPI (LoD Connector)*
As described earlier, the 3D UPI is the unique ID linking LoD0 to LoD4 of the same model on the cadastre lot. This 3D UPI also works as the primary key to update building information in each respective building, minimising duplication and redundancy during insert/update attribute. In a 2D environment, each cadastre lot of the NDCDB has a 2D UPI (Figure 8) with 16 characters, that consisted the state, district, mukim, section and lot number information. Therefore, for the 3D environment, it was decided that the 3D UPI is the extension of the 2D UPI of the cadastre lot. For example, 1601400141393(S)x(B)x**D1**, …**D2**, …**D3**, …**D4** (with **D** representing the LoD type) for the respective LoDs. The 3D UPI of LoD0 (building footprint) is the existing NDCDB 2D UPI, and the process of connecting them both was with Spatial Join tool in the ArcGIS or QGIS software.

| OGC_FID | NEGERI | DAERAH | MUKIM | SEKSYEN | LOT | UPI | KELUASAN | PA |
|---|---|---|---|---|---|---|---|---|
| 12 | 16 | 01 | 40 | 014 | 1164 | 1601400141164 | Refer to JUPEM | PA806 |
| 12 | 16 | 01 | 40 | 014 | 1164 | 1601400141164 | Refer to JUPEM | PA806 |
| 13 | 16 | 01 | 40 | 014 | 1165 | 1601400141165 | Refer to JUPEM | PA806 |
| 13 | 16 | 01 | 40 | 014 | 1165 | 1601400141165 | Refer to JUPEM | PA806 |
| 14 | 16 | 01 | 40 | 014 | 1392 | 1601400141392 | Refer to JUPEM | PA1248 |
| 14 | 16 | 01 | 40 | 014 | 1392 | 1601400141392 | Refer to JUPEM | PA1248 |
| 15 | 16 | 01 | 40 | 014 | 1393 | 1601400141393 | Refer to JUPEM | PA1248 |
| 15 | 16 | 01 | 40 | 014 | 1393 | 1601400141393 | Refer to JUPEM | PA1248 |

**Figure 8.** Existing 2D UPI for Malaysian cadastre lot.

*4.3. 3D UPI for buildings with different cadastre cases*
A cadastral survey is conducted to demarcate the boundary of a land parcel, and naturally, buildings within the boundary are owned by the respective land or parcel owners. However, to model and store the built environment is challenging and not straightforward. There at least five scenarios that need to be to catered particularly in phase 2; i) single building within NDCDB lot; ii) multi-building within single NDCDB lot, iii) multi-level buildings (strata title) within NDCDB lot; iv) party wall buildings, i.e. terrace house or shop lots within NDCDB lot; and v) buildings but with no available NDCDB. Even though the reconstruction process of LoD models remains the same, the assignment of the 3D UPI, however, differs for each case as illustrates in Figure 9 and further described in following sub-sections.

*4.3.1. Single building within NDCDB lot.* This is the ideal and straightforward 3D cadastre, where the object on the land parcel can be displayed and linked directly with RRR. For the case of (A) in Figure 9, the 3D UPI is identified as 1601400141166(S)0B(M1)D(x); where (S)0 is identified as without strata information and B is the block/building with model 1(M1) and D is the representation of the LoD type.

*4.3.2. Multi-buildings within single NDCDB lot.* Based on (B) in Figure 9; the 3D UPI are 1601400141164(S)0B(M1)D(x), 1601400141164(S)0B(M2)D(x) and 1601400141164(S)0B(M3)D(x); where B is the block/building with model 1(M1), model 2(M2) and model 3 (M3). The building models are registered according to the clockwise pattern.

*4.3.3. Party wall buildings.* Instead, as a long block, the LoD models for party wall buildings are reconstructed into individual models and is based on the exact building footprints (refer to (C) in Figure 12). Therefore, the 3D UPI for case (D) in Figure 9 is assigned as 1601400141118(S)0B(M1)(D1), 1601400141119(S)0B(M1)(D2), 1601400141120(S)0B(M1)(D3), and so on, separately.

*4.3.4. Multi-level building (strata title) within NDCDB lot.* For a building that has strata titles, the strata information is incorporated into the 3D model. An Application Domain Extension (ADE) for CityGML Strata datasets is required to enable interoperability between existing in-house JUPEM strata dataset and CityGML dataset. The detail incorporation of the strata title information with the city model shall be further explained in a separate study and paper. Nonetheless, based on (E) in Figure 9, the 3D UPI for the strata-based building is 1601400141165(S)1B(M1)(Dx), where (S)1 indicates the LoD model has strata information.

*4.3.5. Buildings with no available NDCDB.* If the LoD is reconstructed, but with no NDCDB available, the lot number field in the LoD0 UPI is given a new set of coding as TM (*tiada maklumat*). As a result, the 3D UPI as shown in (F), Figure 9 shall be 160140014TM00001(S)0B(M1)D(x); where TM00001 is a running number for the polygon where the buildings are located. Similar to the abovementioned multi-building concept, B(M1), B(M2) and so forth are the building models numbered in clockwise.

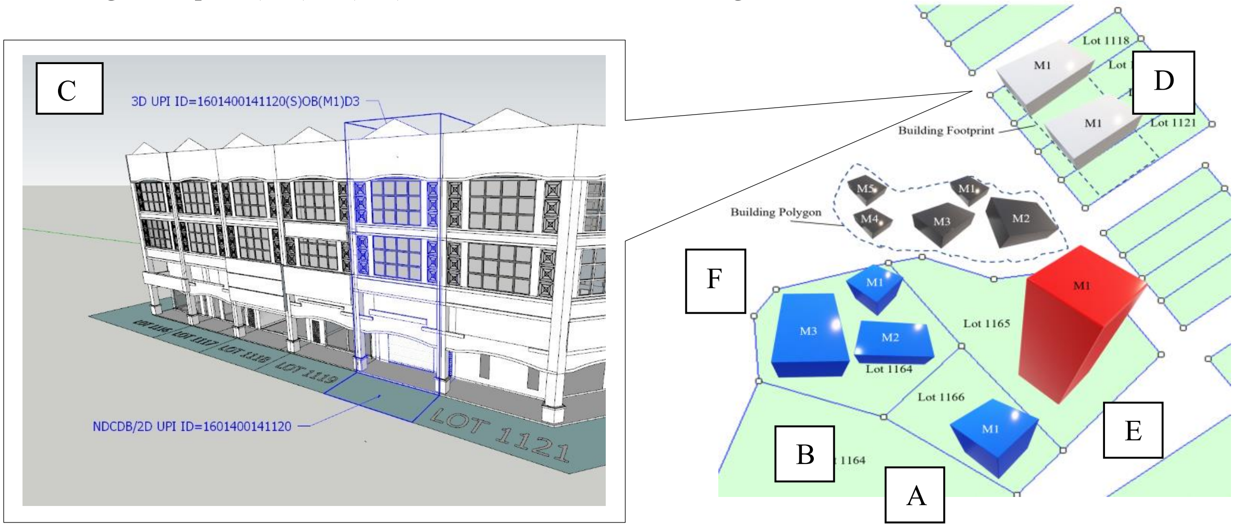


**Figure 9.** 3D UPI scenarios in the cadastre environment

## *4.4. 3D LoD CityGML in Postgres Database*

The 3D City Database or 3DCityDB is used to provide SQL functions to construct a CityGML schema for PostgreSQL. It is chosen based on previous researchers' suggestions [11] that it is more compact and requires fewer tables to generate the spatial relational database schema automatically. Another factor is that it can be easily accessed with external GIS and ETL (Extract, Transform and Load) software applications that enable enriching the 3D city model with additional information to the corresponding database tables. The database deployed basically supports the CityGML version 2.0 and other tools such as Web Feature Service for data publishing, and importer/exporter tool. The database store procedures are organised into six packages, namely c. With the CityGML Importer/Exporter, CityGML features and geometries are the first to be read and imported, neglecting all XLink reference information, but temporarily retained in the database. In order to complete the entire CityGML import process, the XLink relationship information stored in the database is resolved again and written into the respective CityGML data tables. Concurrently, the CityGML datasets are validated for syntax error with 3DCityDB and also geometric-topological consistency with CityDoctor.

As highlighted earlier, phase 2 focusses on *Building* module. When the import process is completed, CityObject table will appear containing the *Building* table where attributes of 3D CityGML LoD models and 3D UPI are available as in Figure 10. SKiP user queries are performed in this database, particularly for LoD information and geometry. The 3D UPI allows a list of CityObjects to be easily obtained via a query on their attributes, and the database returns much faster than using GML file or other built-in software. Attributes can be handled directly by using the PostgreSQL database. However, to update the geometry for each 3D CityGML LoD, manual intervention is still required. Using PostgreSQL, the obsolete model is replaced with the new reconstructed model based on the 3D UPI, but the attributes can be retained or changed if necessary.

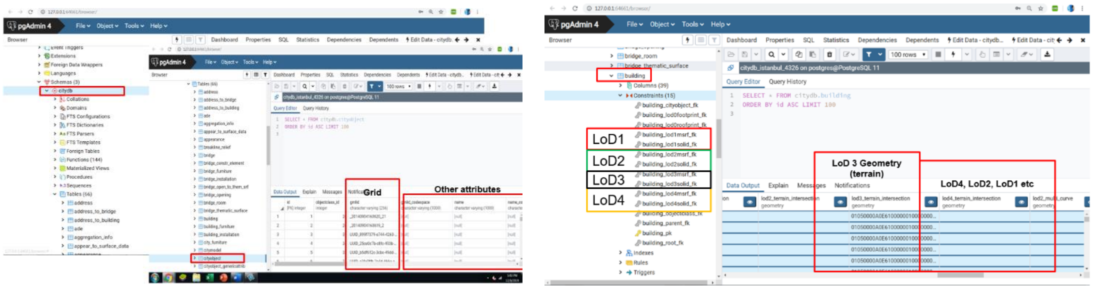


**Figure 10.** (a) CityDB and CityObject tables in PostgreSQL; (b) Building table for respective LoD.

## 5. Discussion and Conclusion

This paper has highlighted the background, the aim and purpose of having a 3D city model database for SmartKADASTER phase 2. Unlike phase 1, which was predominantly geometrical and mesh models, CityGML focusses on the semantical aspects of 3D city models that allow users for a more advanced spatial analysis. Therefore, 3D model construction, migration to CityGML schema, and PostgreSQL database implementation using 3D UPI in phase 2 are highlighted in this paper. In addition, several insights of developing the 3D city model database were also highlighted in this paper.

A good example that needs to be addressed is that even though NDCDB is not available to certain building polygons, it does not imply the land parcel has no ownership. This is because NDCDB only stores the spatial information of Final Title lots. Additional spatial information, such as Qualified Title lots or Temporary Occupied Land (TOL) should be incorporated into the 3D city model database later. Therefore, application on Land Administration Domain Model (LADM) may also need to be adapted and integrated into the 3D database, hence will provide a complete relation between spatial objects from the legal and physical world. Concerning this, instead of as an external reference, NDCDB is linked to the 3D city model database by applying 3D UPI. However, the means to update the 3D UPI for building polygons without NDCDB, particularly the Lot field, needs to be considered and investigated further when a Final Title has been granted to the new landowners.

The potentials of 3D models been extensively studied since the past ten years and was explained in detail by [11]. Given this, around 1,500 buildings within phase 2 AOI will be modelled as LoD3, while ten building models will be reconstructed up to LoD4. The spatial structure of the CityGML LoD3 and LoD4 models and attributes in phase 2 can be useful and integrated with already existing relevant information systems or technical models such as Industry Foundation Classes (IFC) and Building Information Model (BIM). Thus, consideration is to expand the application of SmartKADASTER's 3D city model database for architecture, engineering, and construction (AEC) industry use.

In geovisualisation context, the 3D city database can be a basis for an improved version of plans or maps, such as a 3D Certified Plan or a 3D-extra-large-scale topographical map (i.e. MY701T/A), all of which are JUPEM's published products. The 3D visualisation from the certified plan or topographical map could facilitate the realistic representation of the scene's spatial arrangement, making it easier for laypersons to interpret the scene without any help of symbolism [12]. The proposed enhanced plan and map can be further detailed for future works. All applications highlighted by previous researchers [7] could be integrated, easing the way we do business, especially when the results require the cadastre linkage for city management. For example, identifying the building, space or land encroachment and tax calculation based on building or land built-up area could aid the local municipality.

In conclusion, many potentials can be realised with SmartKADASTER's 3D city model database, beyond the cadastre purpose. This paper has contributed to the existing body of knowledge in developing a 3D city model database, specifically when the cadastral information is the champion. The outcome of this paper will aid users to understand the capabilities of the 3D city model offered through SmartKADASTER. With recommendations emplaced, future work on SmartKADASTER 3D city database can be implemented in the future to increase interoperability of models with other applications or systems.

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