Design and Development of an LADM-driven 3D Land Administration System: Lessons Learned in Malaysia

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Abstract

Urban infrastructure has been dramatically increasing in Malaysian cities over the last decades. The current 2D-based practices are challenged by the stratified development of urban land in underground and aboveground areas. Currently, in Malaysia, surveying measurements are stored in a 2D-based cadastral database in the form of horizontal coordinates. However, this method is not capable to accommodate ownership complexities in the vertical dimension. The existing methods to capture, compute and adjust cadastral survey data need to be upgraded for the purpose of implementing a 3D land administration system (LAS) in Malaysia. The transformation from 2D to 3D LAS should be in accordance with a standard-based approach. Land Administration Domain Model (LADM): ISO 19152:2012 provides an internationally accepted standard model for recording and managing cadastral data. This study aims to design and develop an LADM-driven 3D LAS for Malaysia by building on existing research carried out for LADM adoption in this country. The proposed approach includes modifications in the existing workflows for capturing 3D survey data, new architecture to support 3D land parcels, and a new database for creating an LADM-based 3D LAS in line with data requirements in Malaysia. The major part of the upgrade from 2D to a 3D environment consists of capturing, processing and management of height of survey points that define parcel boundaries. This study demonstrated and confirmed that the LADM standard plays a significant role in realizing a 3D-enabled system for Malaysian land administration.

Keywords: LADM, 3D land administration, Malaysia, National Digital Cadastral Database

1 Introduction

There have been significant stratified underground and aboveground developments in urban areas of Malaysia due to the scarcity of land and population growth in this country. The implication is that the 2D-based land administration system (LAS) of Malaysia is confronted with difficulties in capturing and mapping land ownership in complex urban areas. One problem is that flat and 2D-based representations may not conclusively show 3D delimitation of spaces inside and outside buildings that have irregular and complex shapes. Another challenge is that multiple pages of strata titles, which are used to show all the spaces of multi-storey buildings, surroundings, would impose a significant amount of cognitive effort for urban planners to establish economic, social, environmental and legal implications of the stratified urban developments.

Currently, Malaysian LAS relies on surveying and cadastral measurements defined as horizontal coordinates (X, Y) and managed within the National Digital Cadastral Database (NDCDB). NDCDB is a 2D spatial database for managing cadastral and survey information. However, the physical dimension of the land parcels in the real world is 3D, which means 2D approaches for capturing and storage of land parcels are not adequate to communicate ownership rights in complex situations (Atazadeh et al., 2016a, 2016b; Stoter et al., 2017; van Oosterom, 2013). In addition, some areas for improvement are identified:

- Data Redundancy: many attributes are repeated in different tables introducing data redundancy.
- Lack of Data integrity: Due to data redundancy, there are many values for the same attribute appearing in various tables.
- Lack of relationships between entities: Relationships between entities are often not defined, which reduces data consistency as well as data quality.

On the other hand, progressing towards 3D LAS in Malaysia should be considered based on standard models in cadastre and land administration (Kalantari et al., 2017; Rajabifard et al., 2018b). A well-known standard model is the international Land Administration Domain Model (LADM) that provides a conceptual model for recording and managing cadastral data (ISO19152, 2012; Lemmen et al., 2015). It provides an extensible basis for the development and refinement of efficient and effective land administration systems based on a Model Driven Architecture (MDA), and enables involved parties, both within one jurisdiction and across different jurisdictions to communicate based on the shared vocabulary (i.e., an ontology), implied by the model (van Oosterom, 2018). The current 2D-NDCBD in Malaysia is not compliant to LADM.

To address the current limitations of 2D cadastral system in Malaysia, a 3D-based approach was developed to capture, compute and adjust 3D cadastral survey data, which would subsequently enable implementing a 3D cadastral database in Malaysia. In a simple term, upgrading 2D-NDCDB to 3D-NDCDB in Malaysia is about adding the height to corner stones of the parcels to improve the use of data in various applications including construction and engineering as well as land administration. However, this impacts a) existing surveying practices in order to capture height component of the land parcel, b) data modelling to be compliant with the LADM standard, and c) application stack to utilize open source technologies and workflow to minimize the overall changes to 2D-NDCBD. The data is captured in the field by surveyors, then it will be processed at the office. The process of data includes height adjustment, modification of new points, insertion of new points into the database and generation of the certified plan. This lifecycle is completed in terms of capturing, processing, managing and visualizing 3D data.

1.1 Aim and Scope

More recently, strategies were proposed for the implementation of 3D-NDCDB, which includes the processes for upgrading the existing datasets and data collection methods to support the 3D digital data and the creation of 3D spatial database based on the elicited user requirements (Rajabifard et al., 2018a). It was also highlighted that the implementation of 3D-NDCBD is an initial step to develop a 3D cadastral system in Malaysia. The major motivation for this upgrade is to introduce an open-source 3D database, which is LADM compliant, to address issues with regards to the existing cadastral practices in Malaysia. The work described in this article provides an expanded version of the paper presented in the LADM workshop in Malaysia (Rajabifard et al., 2019b).

In the next section, current literature relate to LADM-based 3D LAS will be reviewed. Section 3 will introduce a methodology for capturing and adjusting height information in Malaysia. This is followed by designing a new LADM-based 3D-NDCDB for the Malaysian jurisdiction in Section 4. The prototype system is explained in Section 5. Afterwards, Section 6 provides a discussion on the benefits and challenges identified in this study. Finally, the paper concludes with major findings and future research directions.

2 Approach

In the context of Malaysia, there has been significant research on the adoption of LADM for this country. Zulkifli et al. (2015) highlighted the importance of the need for LADM country profile for Malaysia by identifying three arguments to upgrade land administration systems and enable e-Government services: government guarantee of indefeasibility of title to private properties; data integration to support good governance of land administration; and systematic and accurate capturing and curating of land and property taxation purposes as an important source for state revenue. More specifically relevant to 3D LAS, Zulkifli *et al.* (2014b) described modelling and registration of 3D strata objects in line with the conceptual framework of LADM. In another study, Zulkifli *et al.* (2014a) proposed a new country profile of LADM for Malaysia, which provides the required entities to support 2D and 3D cadastral parcels at a conceptual level. To evaluate the developed country profile, Zulkifli *et al.* (2014c) presented an LADM prototype system for Malaysia which used some sample data from the Department of Surveying and Mapping Malaysia (JUPEM) and land office. The database architecture was developed based on Oracle spatial. The prototype frontend development was based on Bentley MicroStation. This prototype had limited functions and only covered small area for the assessment of the Malaysian LADM country profile. Another practical experiment was conducted by Jamil et al. (2017) who investigated the possibility of transforming cadastral data from the current building strata schema to the Malaysian LADM model. The conversion was more specifically about 2D and 3D representation of spatial units (MY_SpatialUnit). The XML syntax was used for creating the building strata schema. This study considered different processes including capturing of strata XML data in the field, converting of the 3D data to a database based on LADM model, and visualising of 3D data.

Previous studies do not provide a practical approach for implementing LADM standard in Malaysia. In This paper proposes a new approach for realising LADM-driven 3D LAS for Malaysia based on a pilot project and highlights the main lessons learned throughout this project. The proposed approach includes modifications of workflows and practices for capturing cadastral survey data, a new architecture to support 3D land parcels, and a new 3D spatial database for supporting LADM-driven 3D LAS in Malaysia. This article provides the major steps for designing and developing an LADM-driven 3D cadastral system in Malaysia. In this study, design and implementation of a 3D-NDCDB comprises four major steps:

- Developing a survey methodology to capture 3D land parcels (see Section 3.1)
- Adjustment computations to process 3D data and ensure height accuracy (see Section 3.2)
- Adoption of an LADM-based 3D-NDCDB to store and manage 3D data for land parcels in Malaysia (see Section 4).

- Implementation of a prototype system for 3D visualization of land parcels (see Section 5).

3 Review of LADM-based 3D LAS

There have been significant investigations on the adoption of LADM to handle registration and maintenance of various types of land data related to legal, administrative, and technical aspects (Atazadeh et al., 2018; Felus et al., 2014; Kalogianni, 2015; Kitsakis et al., 2018; Paulsson and Paasch, 2015; Rajabifard et al., 2018a; Zulkifli et al., 2014b). In this section, 3D LAS studies for adopting LADM in various countries will be reviewed. This will be followed by looking at the relevant 3D LAS investigations conducted for adopting LADM in the national context of Malaysia. The expected outcome of this review is to understand the current efforts for adopting LADM in other jurisdictions.

Investigations related to the LADM standard in the international context can be classified into two categories: general and jurisdiction specific. General LADM studies mainly refer to those studies that investigated the conceptual LADM model and its technical implementation without customising it for a particular jurisdiction. The connection between LADM and other 3D data models, such as CityGML, IndoorGML, and IFC, has been explored in the general LADM studies. These include proposing CityGML application domain extension based on the LADM standard (Rönsdorff et al., 2014), modelling LADM concepts based on the relevant entities in the IFC standard (Atazadeh et al., 2018; Oldfield et al., 2017), and development and implementation of an extension module for IndoorGML based on the LADM standard (Alattas et al., 2017; Zlatanova et al., 2016). Most of these investigations have contributed to one important goal of the proposed revision of LADM (Lemmen et al., 2019), which is the enhancement of the current 3D support in this standard. In this context, a wide range of 3D spatial units based on real-world cases has been identified (Kalogianni et al., 2018a; Thompson et al., 2015). In addition, the user needs and expectations for revising LADM standard in support of 3D LAS have been investigated (Kalogianni et al., 2018b). The user requirements should be updated to support more explicit relationships between LADM and other physical models (CityGML, BIM/IFC, IndoorGML, InfraGML, LandXML). Another suggested update is explicit modelling and semantics of LADM code lists in a more structured way (Kalogianni et al., 2018b; Lemmen et al., 2019).

The local studies investigated the feasibility of LADM adoption at the national/jurisdiction level and its possible extension based on the requirements. To begin, Vučić et al. (2017) raised the importance of legislation in implementation of technological options to realize 3D LAS in the Republic of Croatia. They conducted a research to analyse land-related registers in the Republic of Croatia to evaluate the condition of land-related data such as parcels, buildings, and utilities as well as rights, restrictions, and responsibilities (RRRs) associated with those features and spaces. They aimed to determine the level of redundancy between the registers closely related to the domain of land administration, in which LADM was used for this purpose. In addition, a detailed analysis of the current legislation was conducted. As another example, in Czech Republic, GeoInfoStrategy was developed based on LADM for effective use of the spatial data in public administration to fulfil the government priorities in the fields of environmental protection, cadastre, and protection of cultural heritage (Janečka and Souček, 2017).

Some countries have moved beyond the theoretical research and implemented prototype systems based on LADM for 3D LAS. In Russia, the LADM profile of this country was prototyped by considering five kinds of 3D legal objects, namely land parcels, buildings, structural facilities, premises and incomplete constructions (Elizarova et al., 2012). Polyhedrons are used for visualising 3D legal objects. The technical development of LADM in Russia included a web-based 3D viewer for communicating 3D cadastral data as well as performing search and queries in a mixed 2D/3D data environment (Vandysheva et al., 2012).

In Poland, a CityGML ADE (Application Domain Extension) for LADM was proposed in line with requirements of this country (Gózdz et al., 2014). In this study, the relationships between legal and physical aspects of buildings were defined. To manage 3D legal objects, the proposed ADE considered “PL_3DParcel” and “PL_LegalSpaceBuilding” entities in the Polish country profile of LADM. Physical building elements were modelled using two new classes in CityGML: PL_building and PL_BuildingPart. The proposed ADE was implemented and examined based on 3 test cases: two buildings located on top of other infrastructure developments and a townhouse established on a land parcel. Level of Details (LoD0 and LoD 1) with lower details are considered in this study. Similar to Poland, another CityGML ADE was developed and tested based on LADM in China. Two major hierarchies have been considered in the proposed ADE for LADM of China: legal and physical (Li et al., 2016).

LADM-based profiles for Serbia, Montenegra and Republika Srpska have been developed. (Govedarica et al., 2018; Radulović et al., 2017). It was highlighted that the growing dominance of 3D datasets can provide a significant input for implementing 3D LAS. Furthermore, there are also technical implementation of LADM in Columbia (Guarin et al., 2019; Jenni et al., 2017). A more recent technical implementation of LADM for 3D LAS was conducted in Greece. In this context, a framework was developed based on LADM for crowdsourcing 3D cadastral data (Gkeli et al., 2018). The backend of the developed framework was implemented based on a model driven architecture and LADM. The frontend was responsible for communication between the backend and the 3D cadastral data capturing tool. The frontend was implemented as a mobile application based on open source technologies to capture, model and visualise 3D property units. This study showed that development of crowdsourcing guidelines for 3D LAS based on LADM standard would be considered as a primary step for realising 3D LAS (Gkeli et al., 2019).

4 Survey Methodology and Height Adjustment

The first step for implementing a 3D LAS is to capture accurate and precise 3D survey data. Therefore, this section explains the approach undertaken for collecting the required height information using surveying practices. The data collection method for height component to implement a 3D cadastral system in Malaysia is presented in this section. According to the LADM, in addition to 2D cadastral surveys, survey data required for 3D LAS is the surface information (height information) of the land plots (boundary stone and land surface). Therefore, the main objective of this part of study is to determine the procedure of adding the elevation information to lot boundary marks in the 2-Dimensional National Cadastral Digital Database (2D-NDCDB) to create a 3-Dimensional National Digital Cadastral Database (3D-

NDCDB) that also compliant with LADM. Currently, the Malaysian Department of Surveying and Mapping (JUPEM) has fully digitalized its National Digital Cadastral Database (NDCDB). The current version of NDCDB contains only 2D representation of parcels, which is stored in 2D planimetric coordinates (X, Y). In order to convert those 2D (X, Y) information to 3D (X, Y, Z) for each boundaries mark, the current methods of data collection, calculation and adjustment of traverse survey data need to be modified and changed. Before the establishment of 3D-NDCDB, the achievable total height accuracy of the 3D-NDCDB needs to be determined based on these parameters: accuracy of the Geoid model, calculating the height datum, accuracy of GNSS observations, establishment of control points, transferring the height datum, equipment calibration, accuracy of the Total Station equipment and accuracy of carrying out the field survey.

4.1 Survey method for capturing height data

Based on the current cadastral surveying practice and existing equipment resources in Malaysia, the trigonometric levelling has been chosen for capturing the height information. This method is a particular type of surveying in which slope distances with angular measurements, i.e. zenith and horizontal angles, are precisely determined using surveying instruments such as total stations. According to Figure 1, the differential height between two points can be calculated if the vertical angle (zenith) and the slope distance between two points are measured, given the heights for the instrument and the target points.

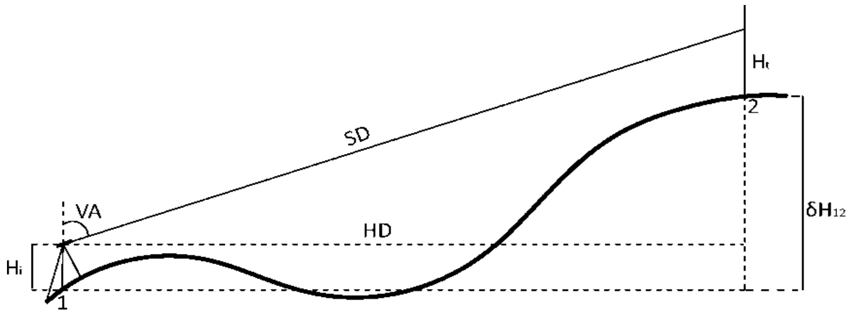

Figure 1, A schematic of Trigonometry

The differential height is obtained as follows:

$$\delta H_{12} = H_i - H_t + SD \times Cos(VA) \quad (1)$$

Where δH is the height difference between two traversed points, H_i is the instrument height, H_t is the height of the target, *SD* is the slope distance and VA is the vertical angle. It is noted that the instrument and target heights must be measured accurately. The zenith and slope distance, in equation (1), are the mean of the direct and reverse readings in an angle set, meaning reading the zenith first in face left position and second, loosen both the horizontal and vertical motions of the instrument, plunge the scope, rotate the alidade half a circle and re-point to the target in the reverse position. The average of vertical angle is calculated from the following equation:

$$VA = \frac{VACL + (360 - VACR)}{2} \tag{2}$$

Where *VACL* and *VACR* are the angular measurements of the zenith in the direct and reverse positions, respectively.

4.2 Accuracy of height measurement

According to Land Act in Malaysia and because of practical application of depth limitation for underground development, it is suggested that the accuracy of height measurement to be 10 centimetres. Experimental results of this study show that an accuracy of less than 5 mm can be achievable by using the height capturing method described in section 3.1. (i.e. trigonometric levelling). However, accuracy of final adjusted height for each point is also depending on the accuracy of transferring benchmark to the site (using levelling or RTK GPS).

4.3 Error propagation

Based on the precision of the instrument and how accurately the instrument and target heights are measured, it is possible to calculate the standard deviation ($\sigma_{\delta H}$) for differential heights (δH) from equation (1):

$$\sigma_{\delta H} = \sqrt{2\sigma^2_{H_{i,t}} + \cos^2(\mathrm{v})\sigma^2_D + SD^2\sin^2(\mathrm{v})\sigma^2_v} \tag{3}$$

In this equation, $\sigma_{H_{i,t}}$ is the standard deviation of the instrument or target height. It is assumed that these heights are measured by a similar tool. For instance, both are measured by a measuring tape. Carefully measuring these heights is of crucial importance, since an erroneous measurement of them could lead to a large error in the traverse. It is recommended that these heights are measured a few times between the stations and the indicators on the measuring instrument or the reflector while especial care should be taken to ensure that the measuring is carried out along the nadir line.

If the height components in equation (1) are measured by an instrument whose precision for angular measurement is 9 seconds, for example, and for distance is 3 mm + 3 ppm, and the instrument/target heights are measured with a precision of 5 mm, the standard deviation of distance and angular measurements for a set of readings (one direct and one reverse) are as follows:

$$\begin{aligned} \sigma_D &= \frac{3\mathrm{mm} + 3\mathrm{ppm}}{\sqrt{2}} = 2.1\mathrm{mm} + 2.1\mathrm{ppm} \\ \sigma_v &= \frac{9}{\sqrt{2}} \approx 6.4'' \end{aligned} \tag{4}$$

Utilizing equation (3), the standard deviation of the differential height for the zenith angle measured as 90º and the distance equal to 100 m is around 8 mm. This example emphasizes the impact of relatively poor measurement of the instrument/target heights on the precision of the differential height. Thus, the more accurately the instrument/target heights are measured, the more accurate the differential heights will be, resulting in a lower misclosure.

4.4 Height measurements check in the field

To guarantee that parameters in equation (1), including the instrument and target heights, are accurately measured and, therefore, the height error is in an acceptable range, we need to either have loops in the height networks, which means starting from one station in a closed traverse and ending the surveying in the same station, or start from one benchmark and end the travers to another benchmark. In a closed traverse, the misclosure, which is calculated by algebraically summing the differential heights in the loop, verified either the faultiness or correctness of the measurements. In an open traverse, the difference between the differential height of the start and end benchmarks ($\mathrm{H_{BMend}} - \mathrm{H_{BMstart}}$) and sum of the differential heights in between from the start benchmark toward the end benchmark indicates the precision of the measurements and blunders/mistakes are recognizable during this process if the error exceeds an acceptable range. Using this technique, although the error can be recognised, and the surveyor learns whether the measurements are correct or not, it cannot locate the error and the surveyor has to repeat the whole measurements.

A possible solution to avoid repeating the entire measurements is that the surveyor repeats the measurements by resetting up the instrument at each station. This way, two independent sets of observations will be collected and after calculation of the differential heights between points, the corresponding differential heights should be equal to a certain precision. An advantage of this method is that due to the remeasurement of the instrument and target heights, the possibility of wrongly measuring of these components will reduce to a considerable extent. In addition, by this technique, the surveyor can be sure of the correctness of the polar measurements on the stations that are neither along with the loop nor between the two benchmarks.

To assist the surveyor to verify the collected measurements in the field, a module has been designed which gets the measurement components as input and automatically creates a graph connecting the stations from which measurements have been carried out. The connectivity of the stations is illustrated in Figure 2. The principal advantage of this graph is that the surveyor can easily look over the loops and simply calculate the misclosures or the differential heights between any successive two stations by selecting the edges. Furthermore, this graph shows the number of observations sets between two stations. For example, there are two edges drawn between nodes 1 and 2 meaning that two independent observation sets have been collected between these stations. Also, the arrow indicates the direction of the measurements. For instance, the direction of the arrow between stations 17 and 20 shows that the instrument was set up on station 17 and it was pointed to station 20. The direction is of importance for total error calculation.

A complete instruction for this module has been prepared in a separate document. The manual gives an introduction on various parts of this module to familiarize the surveyor with the use of the software in the field.

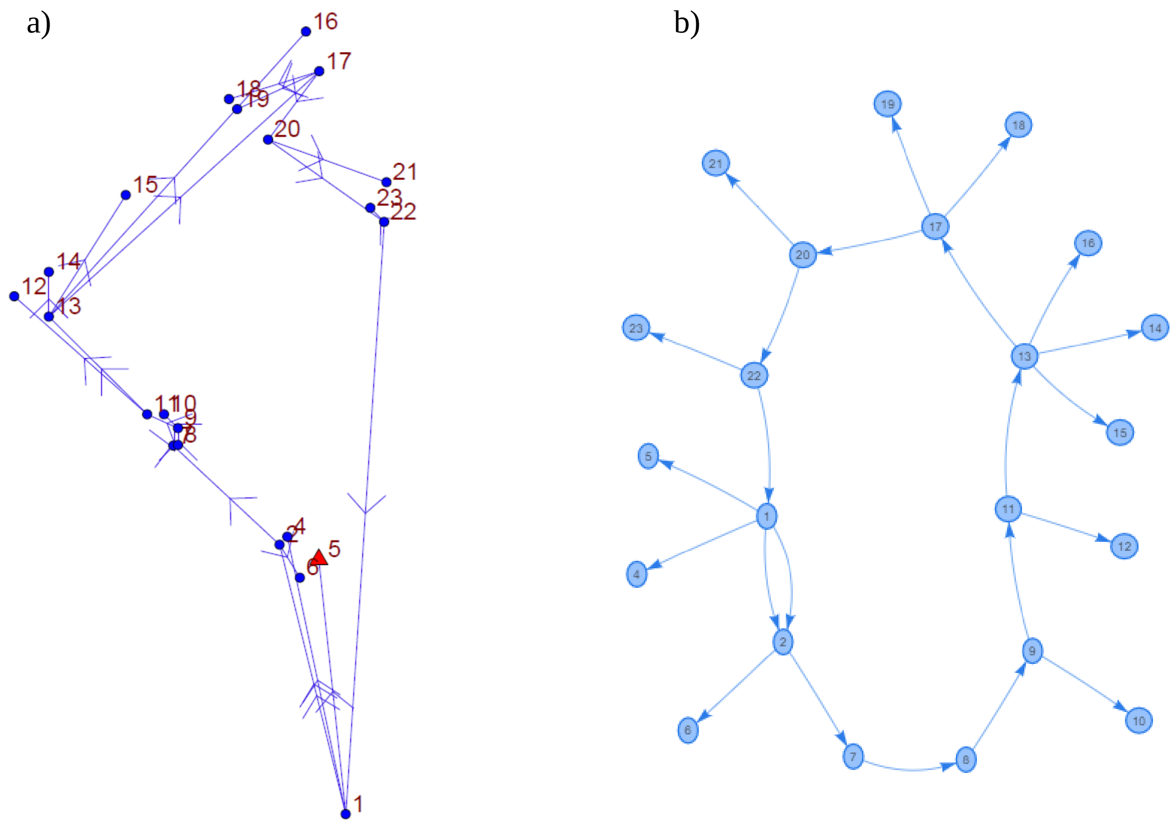

Figure 2, a) A height network, b) Graph of loops in the height network

4.5 Height Adjustment

Having collected trigonometric data and assessed the misclosures in the field, measurements can be used in a height network adjustment to simultaneously estimate the height of all the points. Along with the plot, the StarNet software generates a report including the adjusted heights, the uncertainty of the heights and the result of Chi-square test. Having adjusted the height network, StarNet calculates the standard deviation of all the heights. Table 1 summarizes the number of points, the estimated height as well as the uncertainties. As seen, there are two columns allocated for the uncertainties. Column 3 shows the standard deviation of the estimated heights which represents the confidence level of 68%, whereas Column 4 shows the uncertainties with the level of confidence 95% (3σ). This level of confidence conveys that the height of point number 16, for instance, is between 38.572 (lower bound) and 39.34 (upper bound) with 95% probability if there is no systematic error included in measurements. The average of the standard deviations for the presented network is 0.057 m and the maximum error belongs to point 21 with the value of 0.088 m.

Table 1, The standard deviation of the adjusted height

Station	**Elevation (m)**	**Standard Deviation (m)**	**95%**
5	38.948	0.000007	0.000014
16	38.642	0.072175	0.141461
1	39.082	0.014764	0.028936
2	38.933	0.028255	0.055379
4	40.292	0.024858	0.048720

6	39.170	0.030391	0.059566
7	38.474	0.050919	0.099799
8	38.201	0.056041	0.109839
9	38.430	0.059273	0.116174
10	38.540	0.059831	0.117267
11	38.460	0.068377	0.134017
12	38.487	0.071711	0.140551
13	39.092	0.071345	0.139834
14	38.748	0.072409	0.141919
15	39.231	0.077186	0.151283
17	38.395	0.076454	0.149848
18	38.836	0.079776	0.156358
19	38.680	0.080670	0.158110
20	38.710	0.073908	0.144856
21	38.431	0.087918	0.172316
22	39.535	0.049560	0.097136
23	39.540	0.053683	0.105217

The values of uncertainties in the confidence levels of 68% and 95% are illustrated in Figure 3. To better show the uncertainties of heights visually, we drew a circle around each point whose radius is equal to the value of the corresponding uncertainty. The blue circles show the standard deviation of heights, whereas the red circles represent the uncertainty with the confidence level of 95% (3σ). As seen, by increasing the number of intervals between the benchmark (indicated by a red triangle) and the other points/stations whose heights were estimated, the uncertainty enlarges. A solution for bounding the expansion of uncertainty can be the exploitation of two benchmarks, one at the start of traverse and another somewhere in the traverse very close to the points that are relatively far from the start point. For example, in the presented network, point 16 can be a desirable choice as the second benchmark. However, care should be taken that these points should be benchmark, meaning their relative accuracy should be quite high otherwise network will suffer from another error source affecting the standard deviation of the other points/stations across the network.

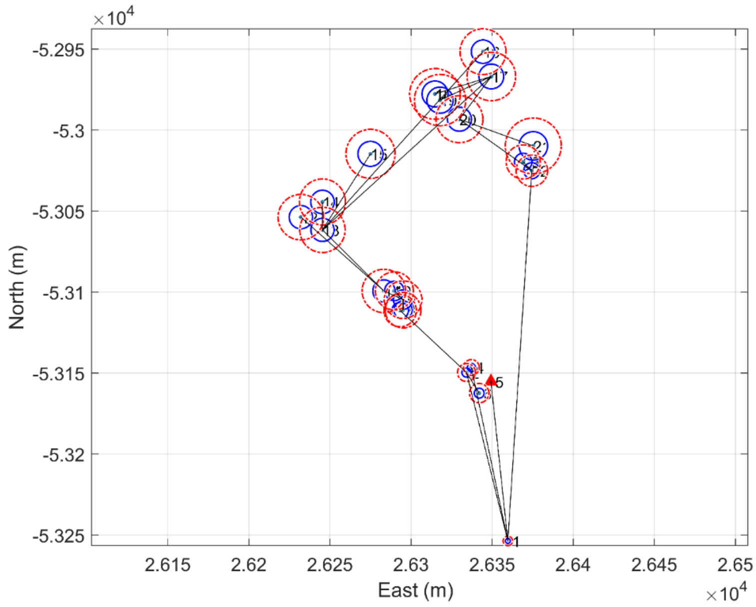

Figure 3, Illustration of uncertainties: Blue circles show the standard deviations, while red circles represent the uncertainties in the confidence level 95%

A valuable part of the generated report, which provides us with quality control of the network adjustment, is "Adjustment Statistical Summary". This part summarises the number of observations, unknowns and redundant measurements. From statistical point of view, the greater redundancy, the better the network adjustment. In the presented network, this value is 2, which is not quite sufficient for a good adjustment. The other valuable information is about Chi-square test. STAR*NET utilizes this test to evaluate the quality of resulting residuals and determine whether they are likely due to random errors or not by performing Chi-square statistical test at the 5% significance level.

In statistics, a χ^2 variable, which is derived from a statistical process consisting of random errors, will have a positive distribution that is a function of the number of degrees of freedom. For instance, considering a significance level of 5%, the lower and upper bounds of Chi-square test checks whether a χ^2 variable falls in the range of the middle 95% area of all possible c^2 values in the distribution. If it is the case, then the χ^2 value will be accepted, and the Chi-square test will pass. In this case, it can be said that the measurements are affected by only random errors. If the χ^2 value falls outside the 95% region, then the Chi-square test will not pass indicating the presence of another type of error influenced the measurements. These errors could be systematic errors, blunders, incorrect standard errors, etc.

The Chi-square test of the adjustment of the height network demonstrated in this report, fails by exceeding the upper bound. This indicates of the probability of having excessive residuals and/or misstating the measurement standard errors by setting them too small. It is of importance to find out the reason of failure of this test and make further corrections.

In another adjustment process, the initial standard deviation of the all differential heights was set 2 cm. In this attempt, the Chi-square test passes, and the error factor has not exceeded the upper bound. Although this test passes for this adjustment and it seems the standard deviation of the estimated heights are smaller compared to their correspondences in the first adjustment, setting the standard deviation of differential heights as 2 cm is unrealistic indicating the presence of systematic errors or blunders in the measurements. It can be verified by looking at the differential heights calculated from trigonometric measurements. The differential heights calculated between points 1 and 2 at two separate times vary by almost 5 cm verifying the presence of a mistake in measurements. The evaluation of measurements in the surveying filed decreases these issues in post processing to a considerable extent.

In summary, the Chi-square test, often called the "goodness-of-fit test", statistically tests whether your residuals are due to normal random errors. If the adjustment fails the test, first check the standard error values assigned to the observations. If the Chi-square test failed by exceeding the upper bound, then it is crucial to check for mistakes which can include blunders in the trigonometric measurements, fieldbook recording errors, or data preparation errors such as incorrectly entered measurements or misnamed stations in the input data file.

4.6 Accuracy for Survey Methodology

Two independent sets of observations between every two successive points are required to improve the height accuracy measurement. The key advantage of these two independent measurements is recognizing any mistakes/blunders that may occur during the measurements for any reason. To have two independent measurements, it is suggested that the measurement components in equation (1) are collected twice by setting up the instrument once on the head of the edge and pointing to the target on the tail and vice versa. Figure 4 compares a height network whose edges for the major loop were collected as suggested with a network whose edges were conventionally measured. In this figure (right), one wrong measurement is added to show the benefit of having two independent sets between two vertices for the recognition of local blunders and thus remeasurement of that edge.

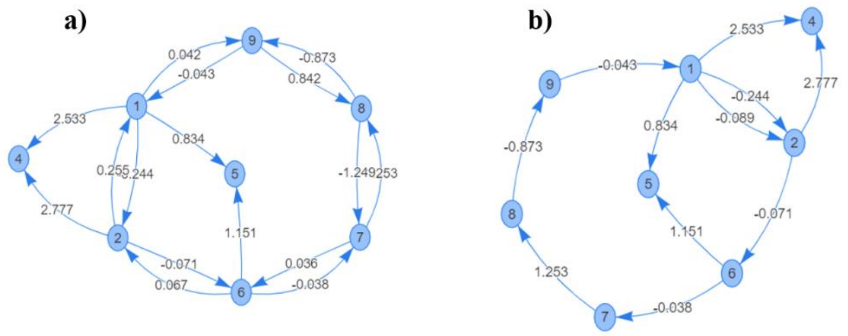

Figure 4, a) A height network including 2 independent sets of measurements on each edge of the major loop. b) A height network without independent measurements on each edge (the independent set of observation between node 1-2 is only added to show the values)

Comparing the average standard deviation of these two networks, the network with two independent sets of observations achieved better accuracy due to more observations across the network and therefore higher redundancy. Although the overall accuracy improves about 1 mm, this method guarantees that the network does not suffer from any mistakes or erroneous measurements to a certain degree.

5 LADM-based 3D-NDCDB

The 3D data captured and adjusted by the proposed survey methodology, which is described in Section 3, should be stored in 3D-NDCDB. In this study, the design of 3D-NDCDB is compliant with the LADM standard and follows the standard practices of relational database design. Both spatial and non-spatial classes in Malaysian LADM country profile have been transformed into an object-relational database. To make sure that this database is LADM-compliant, we transformed the data elements (entities, attributes, and relationships) from the object-oriented model to the object-relational database. In the following subsections, we will describe the details of 3D-NDCDB designed in this study.

5.1 Spatial and survey elements

Spatial elements (spatial unit, 2D lot, 3D lot, boundary, point and spatial source) were mapped to the 3D NDCDB (see Figure 5). This package mainly represents the features that are related to parcels. Based on LADM, a parcel can be represented based on ‘LA_SpatialUnit’ Class. However, Malaysian country profile suggests that a parcel should be presented based on four different classes. The 2D parcel is presented in ‘MY_lot2D’ subclass and 3D parcel in ‘MY_lot3D’ subclass. ‘MY_GenericLot’ is a superclass of ‘MY_Lot2D’ and ‘MY_Lot3D’ which does not have any geometric attribute and is a subclass to ‘MY_ SpatialUnit’. To map the observations and survey data elements acquired from Malaysian land surveying practices, the MY_SpatialSource entity from Malaysian LADM country profile is considered as the appropriate one. Therefore, to make sure that observation elements are LADM-compliant, we defined them as MY_SpatialSource.

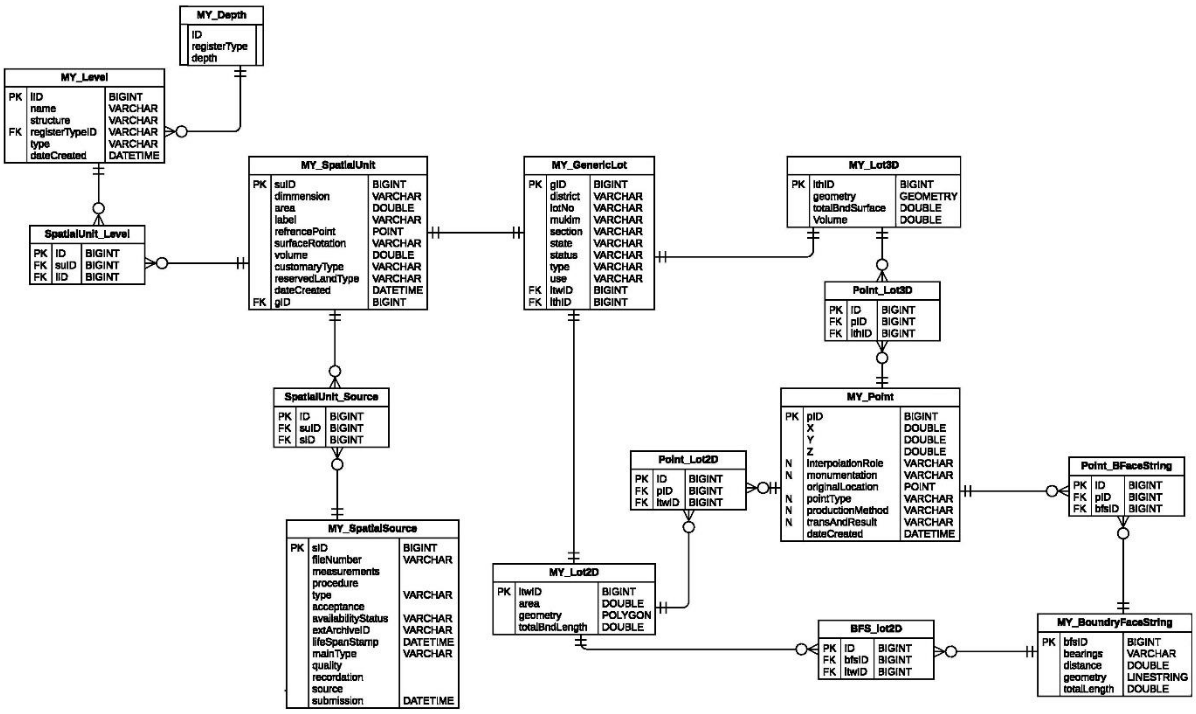

Figure 5, Spatial and survey elements in 3D-NDCDB

5.2 Non-spatial elements

Figure 6 shows all the non-spatial elements (party, party member, group party, basic administrative unit, administrative source, right, restriction, responsibility, and mortgage) that are defined based on the LADM standard in the object-relational database. Due to the need for normalisation in the database and avoiding redundancy of data, some entities inside the LADM standard merged into one object-relational class in the 3D database. For instance, MY_RRR and its subclasses (MY_Right, MY_Restriction, and MY_Responsibilities) are defined as one class (MY_RRR) inside the 3D database.

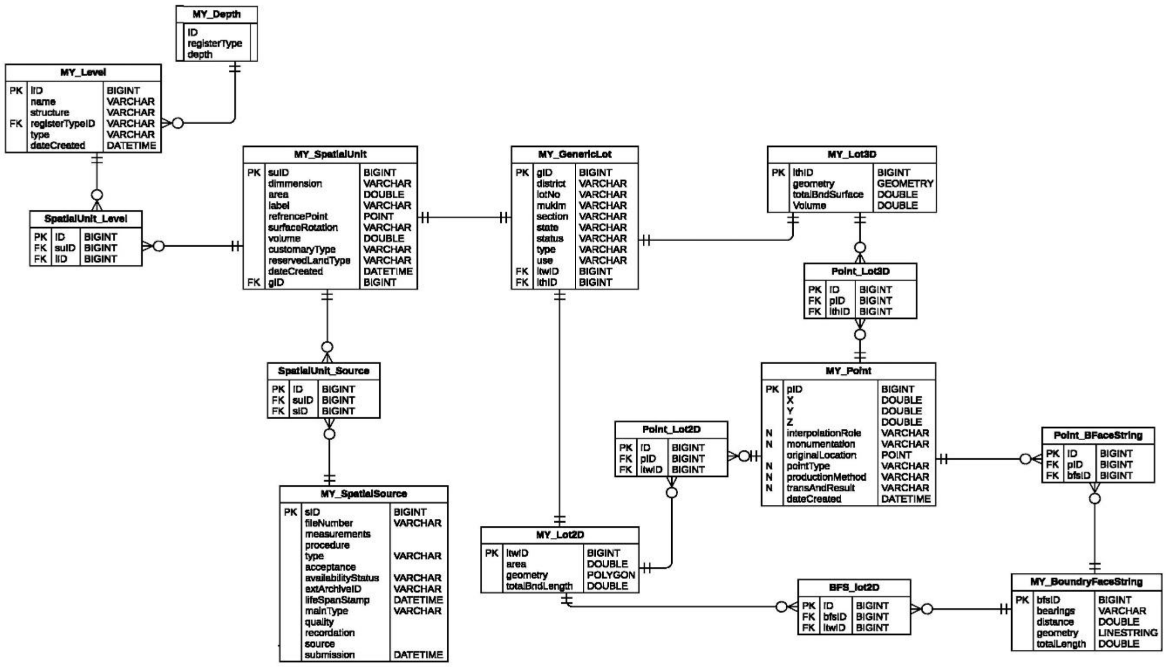

Figure 6, Non-spatial elements in 3D-NDCDB

5.3 Relationships Between LADM Classes in 3D-NDCDB

We considered three types of relationships between two entities (each entity represents one class of LADM) in the relational database: one-to-one, one-to-many and many-to-many.

Some classes in LADM are subclasses of a superclass. This can be represented as a one-to-one relationship in a relational database. However, it is more efficient for the database to combine them in one entity to reduce number of relationships between tables and maintain the data integrity without using foreign key. For example, both 'my_lot2d' and 'my_lot3d' are subclasses of 'MY_GenericLot' superclass in Malaysia country profile. 'MY_genericlot' is a subclass of 'MY_SpatialUnit' which is based on LADM 'LA_SpatialUnit' class. In this case 'gid' has been used as a foreign key to connect 'MY_genericlot' to other two entities.

If two entities have a one-to-many relationship, this would result in a new table that keeps track of this relationship using the primary key of both entities as a foreign key in a new 'link' table. For example, 'point_lot2D' table indicates which boundary points belong to which 2D parcel. This kind of table (link table) is a major concept in relational databases and is mandatory for efficient data management.

6 Implementation of a prototype system

Based on the developed relational 3D-NDCDB, a prototype system was implemented with these features (see Figure 7):

- Modular design: Every module can be used independently. This enables JUPEM to use any of these applications based on their future direction for development of 3D-NDCDB.
- Modern application framework: The system architecture follows the modern application design
- Platform Independent: System can be used on various operating systems and devices.
- Open Source Software and libraries: Except for StartNet (height adjustment software), the rest of system is developed using open source software and libraries.
- Parallel process to 2D-NDCDB: 3D process does not interrupt the existing system and is parallel to existing practices.

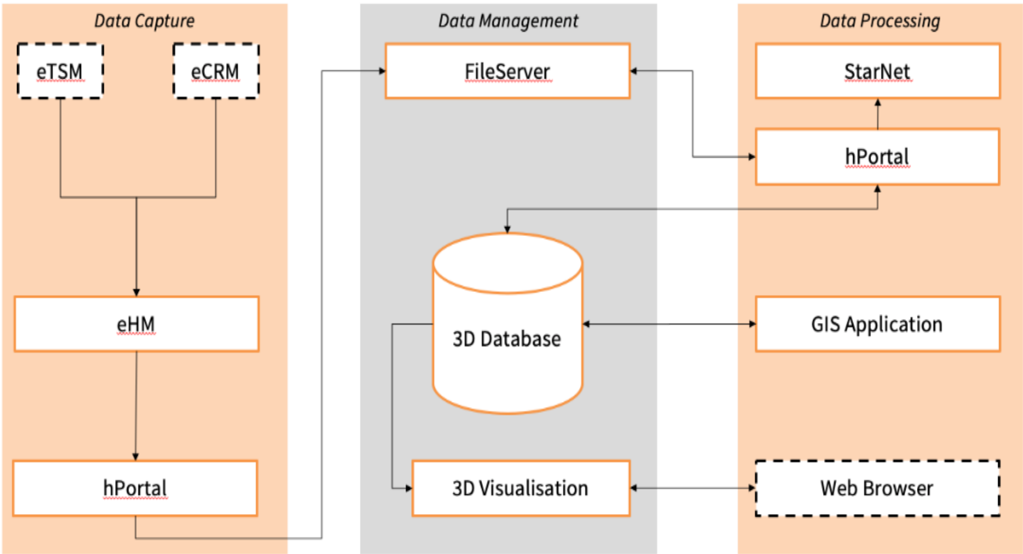

Figure 7, Architecture of prototype system

Important modules of the prototype system are explained in the following subsections.

6.1 Electronic Height Measurement (eHM)

This module has been developed using Electron library. Electron is an open source library developed by GitHub for building cross-platform desktop applications with HTML, CSS, and JavaScript. Electron accomplishes this by combining Chromium and Node.js into a single runtime and apps can be packaged for Mac, Windows, and Linux.

eHM produces these ASCII files to capture various data:

- hbk: data related to equipment precision
- hms: instrument and target height that surveyor captures in the field
- fht: calculation of height differences based on hms and hbk
- hdc: input to the STAR*NET for height adjustment
- f3d: 3D field book with additional information about height

eHM also produces two html files:

- Misclosure report: contains all the misclosures that the surveyor has done on the filed
- 3D field book: information related to captured data in tabular format

6.2 StarNet

StarNet software is used for 3D adjustment in the prototype system. One of the limitations of StarNet is the number of stations it can adjust at the same time. According to provider of the software, StarNet Ultimate can adjust networks containing up to 65,000 stations, an increase from the previous maximum of 10,000 stations. However, StarNet Pro/Plus/Standard/Lev all still support a maximum of 10,000 stations.

6.3 GIS application

One of the main applications in 3D prototype system is the GIS application. QGIS supports shapefiles, coverages, personal geodatabases, DXF, MapInfo, PostGIS, and other formats. Web services, including Web Map Service and Web Feature Service, are also supported to allow use of data from external sources. QGIS integrates with other open-source GIS packages, including PostGIS, GRASS GIS, and MapServer. Plugins written in Python or C++ extend QGIS's capabilities. Plugins can geocode using the Google Geocoding API, perform geoprocessing functions and interface with PostgreSQL/PostGIS database.

In this study, we connected QGIS to the 3D database to support all various functions for visualizing and editing spatial data. One of the important functions of this prototype was generating certified plans (see Figure 8).

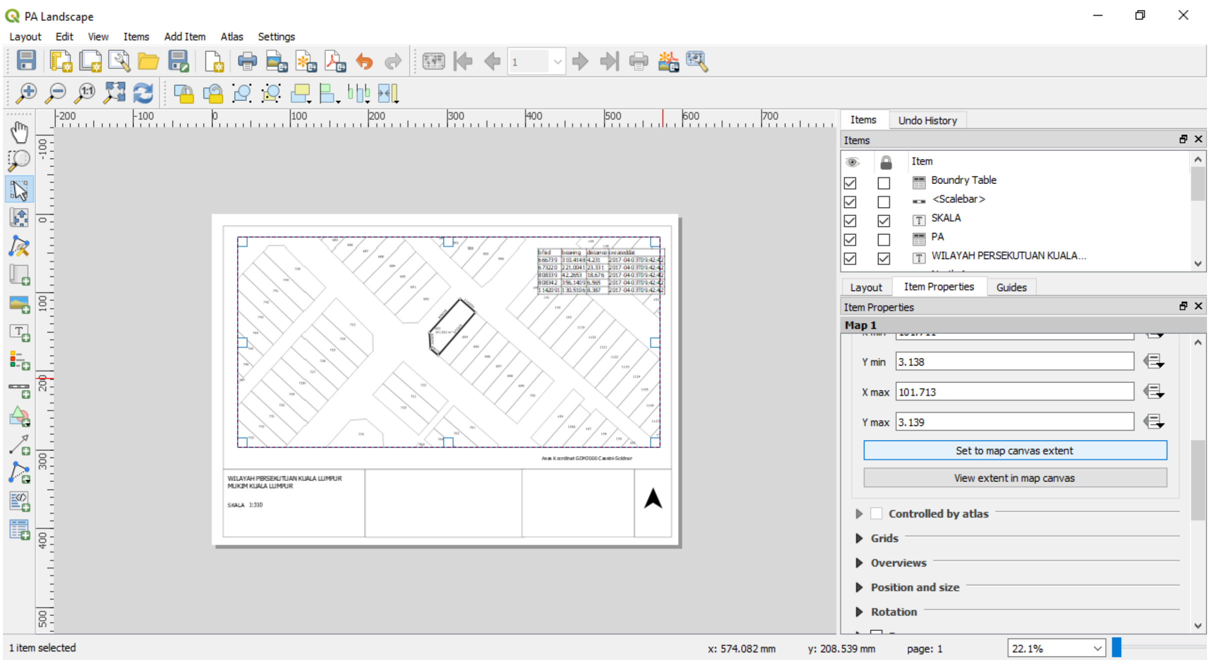

Figure 8, Generating certified plans in QGIS

6.4 3D Database

The 3D database in this prototype is one of the first relational databases designed based on the LADM standard which was implemented in PostgreSQL. PostgreSQL is an object-relational database management system (ORDBMS) with an emphasis on extensibility and standards compliance. PostgreSQL has updatable views and materialized views, triggers, foreign keys, support functions and stored procedures, and other expandability. 3D-NDCDB utilizes PostGIS which is an open source software program that adds support for spatial objects to the PostgreSQL object-relational database (see Figure 9). PostGIS follows SQL specification from the Open Geospatial Consortium (OGC). It also supports GIS functionality for various analyses and geometric calculations.

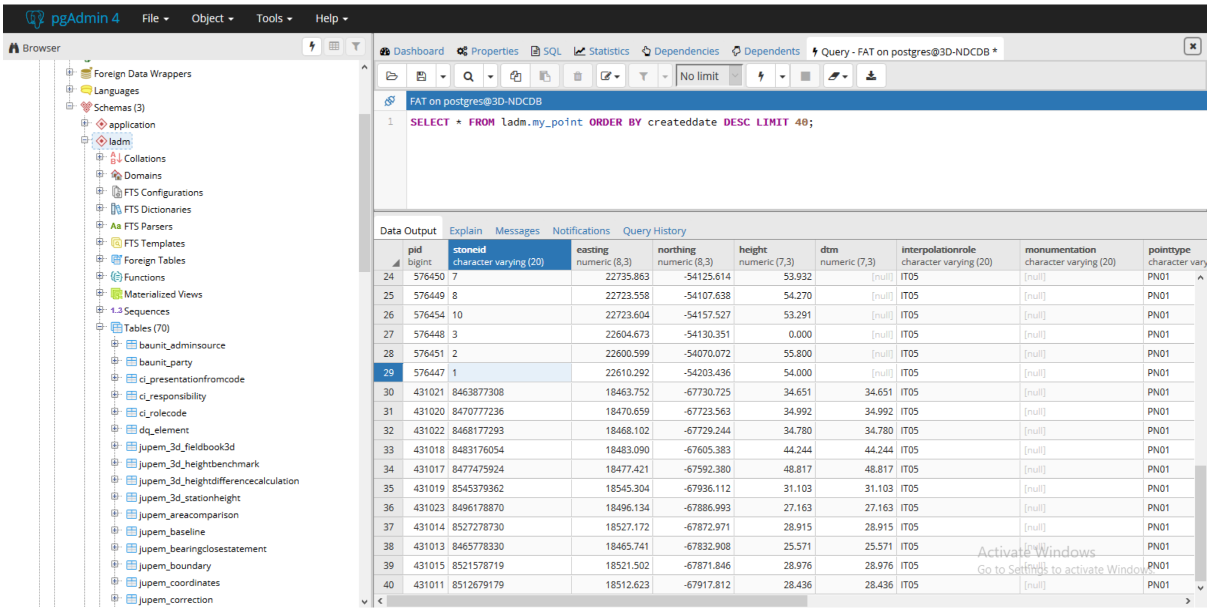

Figure 9, 3D database implemented in PostgreSQL/PostGIS environment

6.5 3D Visualization

This part of prototype system (LADM viewer) visualizes the 3D parcels, parcel boundaries and point boundaries on a customized Digital Elevation Model (DEM) for Malaysia (see Figure 10). This DEM is based on authoritative data received from JUPEM. The LADM viewer is only implemented for JUPEM and it is only custom-made for the prototype implementation of the LADM-based Malaysian profile. The LADM viewer also provides capabilities for querying land parcels based on attributes in the 3D database (see Figure 11). It is an open platform to provide information to other users since it is a web-based application which can be accessed using any modern web browser. This application provides various functions including searching, querying and identifying 3D land parcels. LADM viewer was developed based on 2 main open-source projects:

- CesiumJS: It is a JavaScript library for creating 3D globes and 2D maps in a web browser without a plugin. It uses WebGL for hardware-accelerated graphics, and is cross-platform, cross-browser, and tuned for dynamic-data visualization. CesiumJS can stream 3D content such as terrain, imagery and 3D Tiles.
- GeoServer: It is an open-source server that allows users to share, process and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. GeoServer has evolved to become an easy method of connecting existing information to virtual globes as well as to web-based maps. GeoServer functions as the reference implementation of the OGC Web Feature Service standard and implements the Web Map Service, Web Coverage Service and Web Processing Service specifications.

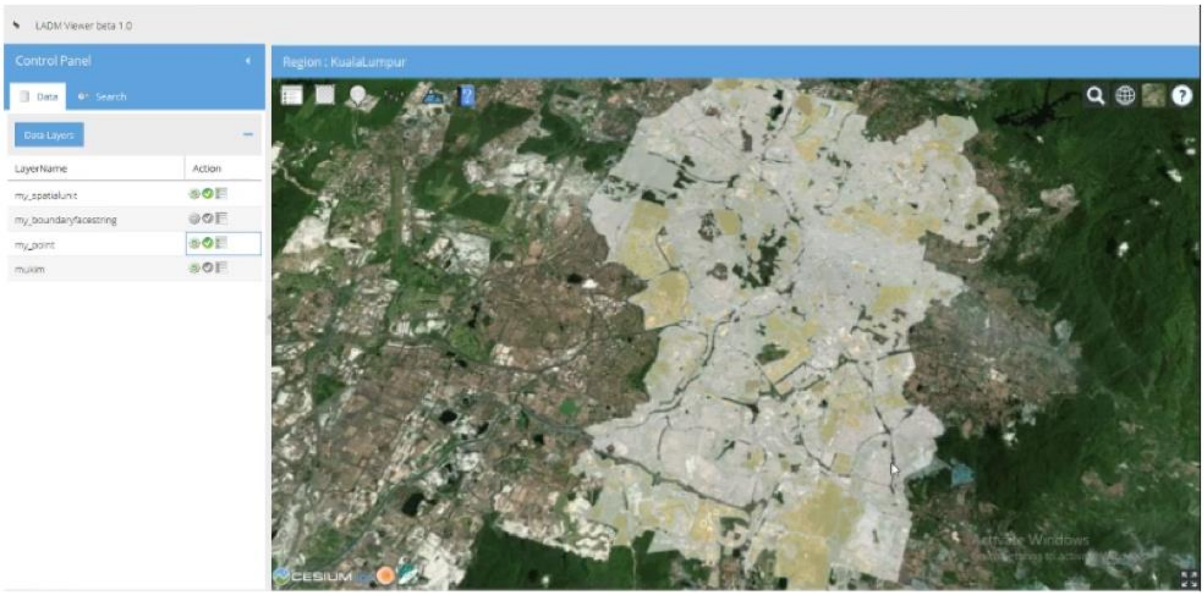

Figure 10, Visualization of land parcels in LADM viewer

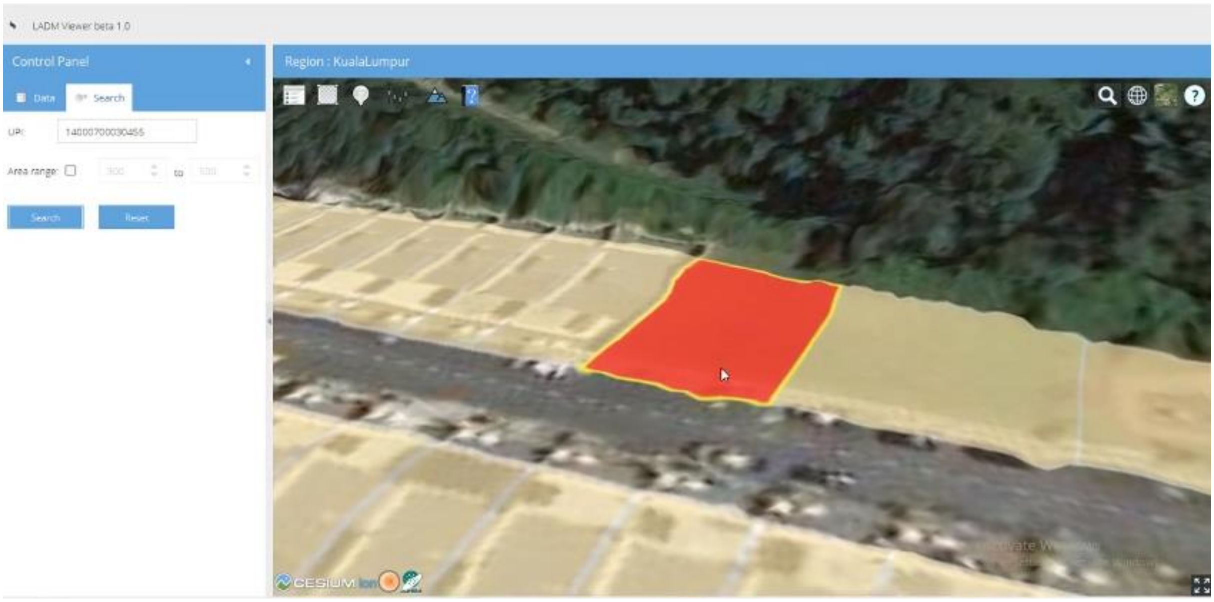

Figure 11, User Interface of LADM viewer, in which 3D parcels are visualized and queried based on their 'Lot Number'.

7 Discussion

The motivation for this study was to identify a practical pathway towards realizing an LADM-driven 3D cadastral system by considering current cadastral surveying practices in Malaysia. This study focused on data migration from existing database and development of various application modules for implementation of a 3D LAS. In developing the prototype system, this research investigated how the current 2D-NDCDB should be upgraded to 3D-NDCDB and how the current workflows and associated data to be modified to support the realization of LADM-based 3D LAS in Malaysia.

As the third dimension, height information is a critical piece of data in many government businesses including infrastructure development, urban planning, public safety and many more activities. Already some of the government activities in Malaysia benefit from the use of 3D data and its potential is well acknowledged in the Malaysian government agencies. Unless a country-wide systematic approach is adopted, the potential of 3D digital data will not be fully realized. Upgrading the current cadastral information system from 2D (horizontal) data to a new system based on LADM-driven 3D digital data will lay the groundwork for Malaysia to become among the first nations in the world to have a 3D-enabled national spatial data infrastructure based on LADM.

Adopting an LADM-based approach in Malaysia would facilitate 3D cadastral registration in complex ownership situations. Benefits of an LADM-driven 3D cadastral system in Malaysia are:

- An LADM-based approach can provide 3D digital representation of land parcels in complex urban developments. This would help easily communicate legal ownership of complex land parcels with inexpert stakeholders, particularly owners and facility managers, involved in property and building management.
- LADM would support standard management of 2D and 3D cadastral data from different jurisdictions. This standard provides a shared language among different states in Malaysia, which can help with sharing and using cadastral information at a semantic level.
- As current strata and stratum subdivision practices in Malaysian jurisdictions are based on 2D-based analogue plans, adopting an LADM-based approach could potentially advance current subdivision practices into 3D digital, intelligent and dynamic data environments.
- Re-using cadastral information from current proprietary 2D-NDCDB is quite cumbersome since the data environment is not open. However, the 3D-NDCDB, which is designed based on LADM and open source database packages, can facilitate re-using and sharing 3D cadastral data. For instance, when a land parcel is being subdivided or consolidated, the surveyors can access to the relevant dataset related to 3D land parcels and use it for 3D subdivision purposes.

The adopted approach for capturing survey data is based on the current practice used by JUPEM Malaysia; however, implementation of LADM for 3D LAS in Malaysia can support other height determination methods such as GNSS. It is important that the height information is accurately and precisely captured with any survey method. This information can be then stored and managed in the proposed LADM-based database.

Despite the significant benefits of an LADM-based for 3D LAS implementation in Malaysia, we observed some technical challenges when adopting LADM in the context of this jurisdiction. One important challenge was development of a clear workflow for implementation of the Malaysian LADM country profile based on the existing real-world surveying practices. Current version of the LADM standard does not provide specific guidelines for implementing LADM in practical situations. We suggest that the revised version of LADM provides some general implementation guidelines for adopting LADM in the existing cadastral surveying practices. This would help various jurisdictions to understand the requirements for upgrading their cadastral systems based on LADM specifications.

8 Conclusions and future work

This study demonstrated and confirmed that the Malaysian cadastral infrastructure is ready for an upgrade to include 3D digital data that follows the standard approach adopted by the LADM standard. It identified that the workflow of field surveying could be modified without significant overhead. The integration of vertical data with existing horizontal data will require a careful consideration due to varying degree of uncertainty that results from the different methods of data collection. The significant change in the upgrade is the change in the basic building block of the land administration from the land parcel to the cornerstone.

Based on the outcomes of the study, it is recommended that the Government of Malaysia lay the groundwork for a 3D cadastral system by investigating legislative requirements for the introduction of 3D data collection into the current workflows, trialling the current prototype system in selected land development and infrastructure projects, conducting a pilot project to investigate the integration of the strata development into the current prototype system, developing a roadmap for a full 3D LAS in Malaysia considering developments in Spatially Enabled Government (SEG) including artificial intelligence for visual communications and analysis as well as integrating BIM into land administration (Atazadeh et al., 2018, 2016a; Rajabifard et al., 2019a) and querying 3D cadastral information.

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