The SmartKADASTER Way – An Approach Towards 3D Geovisualisation Beyond Cadastre Purposes in Malaysia

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SUMMARY

Cadastral maps are a critical cadastral survey product. They contain essential information about the property's spatial dimensions and the owner's rights, restrictions, and responsibilities. Previous research has established that 3D geovisualisation aids in analysing and decision-making when dealing with geospatial data, particularly when land use, the built environment, and people relationships are concerned. A paradigm shift is required to incorporate 3D geovisualisation and cadastral survey data beyond cadastral purposes, which is why the Department of Survey and Mapping Malaysia (JUPEM) developed the SmartKADASTER system with an emphasis on urbanised areas. The first phase of the SmartKADASTER system went live in 2017, and the second phase is currently in development. It is scheduled to go live sometime in 2022. This paper aims to highlight the approach that JUPEM has undergone and discovered throughout its development journey. Section One discusses the motivation for the SmartKADASTER phase 2 (SK2) system development, while Section Two distinguishes the significant differences between the implementation of the first and second phases. Section Three highlights the key features applied during the development period, while Section Four discusses the challenges encountered in SK2, including the effects of the Covid19 pandemic, with its corresponding recommendation. Finally, Section Five summarises the paper and suggests the way forward for better 3D geovisualisation and decision making through SmartKADASTER. It is hoped that this study would contribute to the body of knowledge on incorporating 3D geovisualisation and cadastral data and be used in future plans, particularly those beyond cadastral purposes.

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1. SMARTKADASTER: THE MOTIVATION

Geomatic technology trends have created many opportunities for improving and value-adding the cadastral domain. However, most cadastre applications are designed to serve a single purpose: to act as a delivery system for expediting land registration. As a result, the Department of Survey and Mapping Malaysia (JUPEM) began working on several projects in 2011 to determine the feasibility of implementing the multipurpose and later beyond cadastre concepts in Malaysia. The idea has been advocated by the International Federation of Surveyors (FIG) since Cadastre 2014. Beyond cadastre purposes refers to purposes or applications other than land registration that possess the characteristics highlighted by Bennett (2014) and would benefit from cadastre information depicting the relationships between people, land, and objects. Beyond cadastre applications may consist of cadastre applications that can be expanded to include Disaster Preparedness Management, Building Information Modeling / Management (BIM), Marine Cadastre, Smart City, and the Digital Twin concept. The studies carried out by JUPEM concurred with previous research (Bennett, 2014; Pouliot, 2011; Rahman et al., 2011; Rajabifard, 2014; Stoter et al., 2012) that implementing the concept of a 3D environment or modelling would be the way forward specifically to cater urbanisation issues. Furthermore, technologies for collecting, storing, presenting, and visualising 3D data have advanced sufficiently, thus allowing the concept's realisation and making the relationship between 3D data of the physical world and cadastral properties more visible.

It should be noted that Malaysia's current cadastre application is primarily two-dimensional, with the height of the cadastral parcel (Pantazis et al.) deduced through survey computations. Geomatics tools can generate an abundance of data, particularly point clouds, which can contain data in multiple dimensions, including x, y, and z, as well as time. 2D information, conversely is incapable of serving urban complexed situations. Occasionally, different land use and properties were placed in a complicated 3D scenario. While studies on the 3D representation of cadastre parcels have been widely conducted (Aditya et al., 2020; DÖNer, 2021; Guo et al., 2013; Janecka et al., 2018; Knoth et al., 2020; Larsson et al., 2020; Pouliot et al., 2016; Stoter et al., 2019; van Oosterom, 2013), the actual implementation in Malaysia appears to be underdeveloped. At the same time, researchers (Biljecki et al., 2015; Gupta et al., 2015; Huk, 2006; Zhang, 2017) have also demonstrated that 3D geovisualisation does not stop at point clouds or 3D mesh images but can be further represented as 3D modelling. 3D modelling is a by-product of any BIM-based construction. In contrast, a city model is a digital representation of a city that includes 3D digital models of common urban systems such as buildings, landscapes, streets, and any other relevant object in the urban environment.

A paradigm shift is required to incorporate 3D geovisualisation and cadastral survey data beyond cadastre purposes, which is why the Department of Survey and Mapping Malaysia (JUPEM) developed the SmartKADASTER system with an emphasis on urbanised areas (Halim, Karim, et al., 2022). The SmartKADASTER system's first phase went live in 2017, and the second phase is currently in development and is scheduled to go live sometime in 2022. The goal of SmartKADASTER is to provide its users with a platform that extends beyond cadastre purposes, with a complete 3D geovisualisation, while still maintaining the cadastral survey data as the focal connection for decision-making. Most importantly, the system intends to democratise cadastral survey knowledge among its professional and lay users so that correct data handling and unified reference are used, resulting in more comprehensive and accurate spatial analyses (Sageconsulting, 2020). Additionally, the concept aims to simplify smart city implementation by allowing users to participate in a geospatially enabled community. The SmartKADASTER Phase 1 (SK1) project received support from ten government agencies that unanimously agreed for JUPEM to embark on and spearhead the project. It covers the whole Federal Territory of Kuala Lumpur and Putrajaya. SmartKADASTER Phase 2 (SK2) was initiated in response to the user requirements study, which included a request to expand the project's area of interest beyond Kuala Lumpur to other major cities (Sageconsulting, 2020). As a result, phase 2 encompasses most major cities in Selangor, as well as Nilai and Seremban, which serve as the focal point of area of interest (AOI).

Therefore, this paper aims to highlight the approach that JUPEM has undergone and discovered during the SmartKADASTER development. This section has explained the motivation for the system development, while Section Two distinguishes the significant differences between the SK1 and SK2 implementation. Section Three highlights the key features that were applied during SK2 development, while Section Four discusses SK2 development challenges encountered with its corresponding recommendation. Finally, Section Five summarises the paper and suggests the way forward for better 3D geovisualisation and decision making through SmartKADASTER.

2. SMARTKADASTER PHASE 1 VS PHASE 2

2.1 Area of Interest

SmartKADASTER Phase II (SK2) is basically similar to SmartKADASTER Phase 1 (SK1) in terms of objective, aims and emphasis on cadastre relationships. So naturally, the basis of SK1 and SK2 is the National Digital Cadastral Database (NDCDB) which has been widely recognised as the foundation for any land-based GIS applications in Malaysia (Halim et al., 2017), while RSO Geocentric (RSO GDM200) is used as the coordinate reference system and the National Geodetic Vertical Datum (NGVD) as the orthometric height reference. The project began in November 2019 and was initially scheduled to conclude in February 2021. However, it was extended due to the COVID-19 pandemic. The coverage is further extended to other major cities from Kuala Lumpur and Putrajaya to Greater Kuala Lumpur, as shown in Figure 1, which includes a part of the state of Selangor and two cities in Negeri Sembilan, namely Nilai and Seremban.

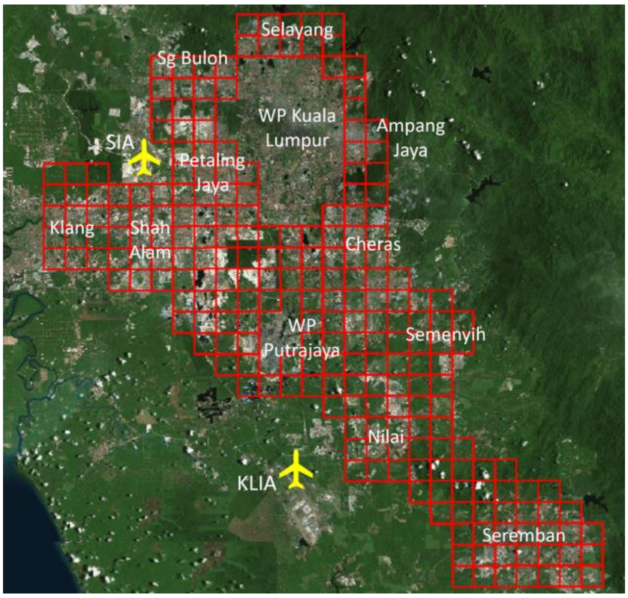

Figure 1: Area of Interest (AOI) for SmartKADASTER Phase 2

2.2 SKiP2 Enhancement

Figure 2 shows the overall system architecture of SK2. Unlike SK1, the SmartKADASTER Interactive Portal (SKiP) of SK2 is designed based on the latest technology framework, inclusive of GPU Processing Technology in combination with the SkylineGlobe Enterprise and Cesium Platform. As with SKiP version 1 (SKiP1) (Halim et al., 2020), SKiP version 2 (SKiP2) is expected to be a fit-for-purpose online platform that provides access to the SK2 environment to its public and registered users via a more familiar and friendly user interface. Users can now access SKiP2 through a mobile application that is made available both on Android and iOS platforms. The 3D visualisation platform's functionalities in SK2 have complied with what previous researchers (Shojaei et al., 2013; Shojaei et al., 2015) have outlined. Other users' requirements highlighted by Sageconsulting (2020), such as integration with eBIZ and eKADASTER, and access from multi-device and internet browsers, were also upgraded in the SK2 environment. Additional spatial analysis functions and features have been added in SKiP2 and the adoption of the CityGML schema for 3D model representations and a cross-scale database. Among the new functions are Spatial Query Tools based on Theme, Property Heatmap, Volumetric-Land Fill, Time Series, 3D Information Tool and StrataXML to CityGML, and other improvements at the 2D, 3D and panoramic spatial analysis tools, including seamless viewing. Simple spatial queries and maps can also be embedded or saved as a workspace. Figure 3 depicts the beta version of SKiP2, which would be gradually upgraded as the go-live date approaches in July 2022. Further details on SKiP2 functions and capabilities shall be highlighted in the upcoming paper.

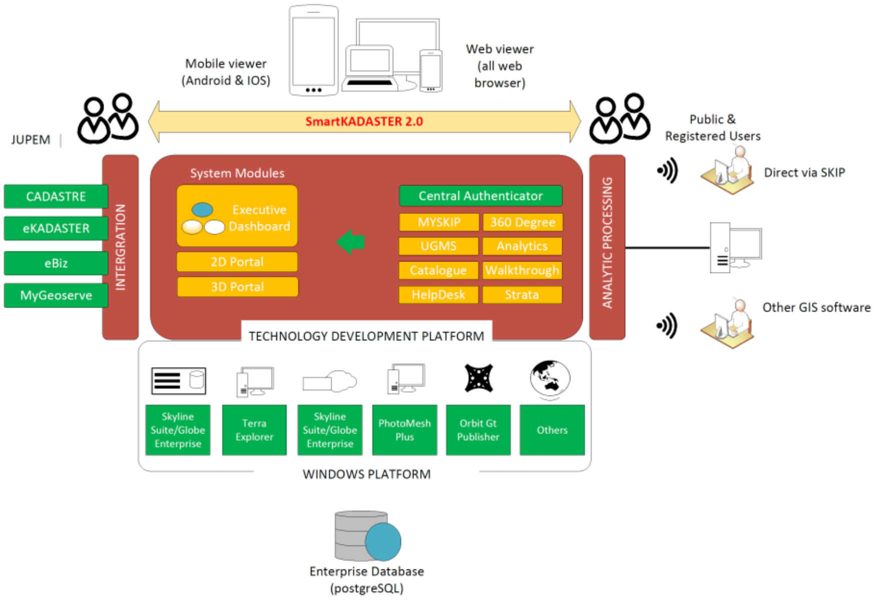

Figure 2: An Overall System Architecture of SmartKADASTER Phase 2

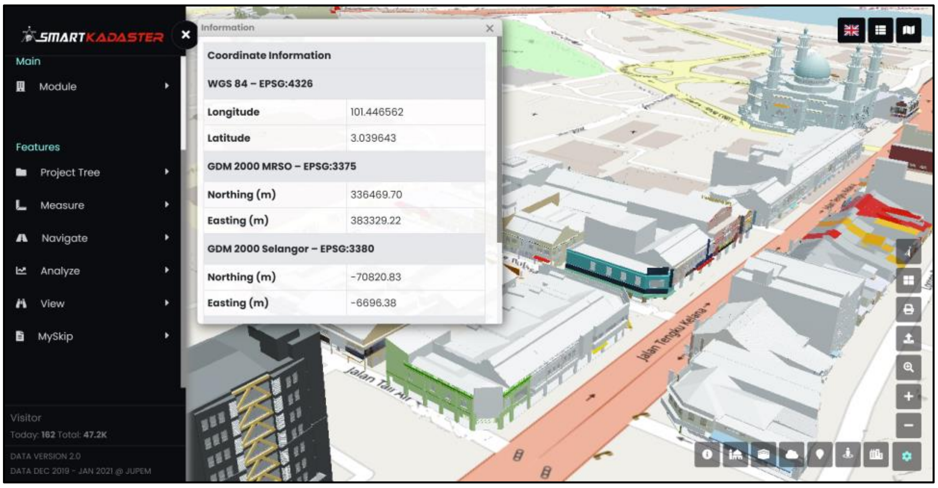

Figure 3: SmartKADASTER Interactive Portal Phase 2 Beta Version

2.3 Incorporation of Stratified Information

Stratified titles typically include high-rise properties such as condominiums, apartments, and landed properties gated and guarded (Hanafi et al., 2019), with underground properties like a basement or bunkers. Despite the availability of stratified information that provides an accurate scale model of strata parcels, their area sizes, and building storey heights, which refers to the parcel's relative height measured from the ceiling to the floor surface (Choon et al., 2008), this information was not incorporated into SK1. Following this, Strata XML was converted into Strata GML and is introduced into the SK2 environment, thus enabling the visualisation of strata information and modelling in a city model setting. Integrating this custom XML schema to the existing standardised CityGML schema requires converting schema, which is allowed by creating ADE for application purposes (Stoter et al., 2019). Siew et al. (2021) and Halim, Karim, et al. (2022) provide additional details on the methodology used to incorporate strata title information and model into SK2 (2022).

2.4 3D Modelling and Database

In SK2, 3D models of buildings are constructed based on point clouds from airborne, mobile, and terrestrial laser scanning, with level of detail 3 (LoD3) models having an accuracy of +/-0.3meters for each axis. In SK1, 3D representations of Kuala Lumpur and Putrajaya city models are displayed as 3D Mesh and 3D wireframes, with the building height derived by extruding from the building footprint to the highest point cloud of the building's construction. In SK2, 3D reconstruction of buildings and their installation in various LoDs emphasises cadastre linkages and semantical aspects of 3D city models that allow users for a more advanced spatial analysis. 3D building blocks are now split into a single model to cater to every LoD's geometric topology. Each LoD is given a unique 3D UPI linked to the corresponding NDCDB lots, as shown in Figure 4. Naturally, CityGML 2.0 was chosen to develop the SK2 3D city model database for the purpose of data sharing and management. It was selected considering previous researchers' suggestions and recommendations (Jovanović et al., 2020) and generally because academic and business stakeholders widely accept it for 3D modelling (Tang et al., 2020). Further explanation of the methodology applied for developing the 3D models, and its corresponding database in SK2 can be found in Halim et al. (2021).

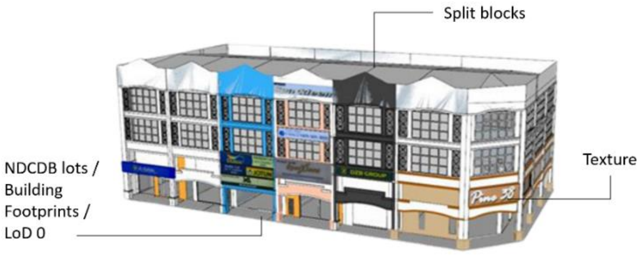

Figure 4: A 3D Model of a Shop House Block Segmented According to NDCDB Lots

3. SMARTKADASTER PHASE 2 DEVELOPMENT

This section focuses on some of the most critical aspects of SK2's development, such as data collection, processing, and deliverables. This section also describes the accuracy achieved for each data collection, allowing SK2 to be a survey accurate 3D geovisualisation platform.

3.1 Data Collection, Processing and Deliverables

The SK2 data content is retrieved from various geomatic tools that provide 2D data, 3D point clouds and images (oblique and orthophoto), and external APIs. The techniques of airborne, mobile, and terrestrial laser scanners and mapping were integrated to ensure all angles and views of the city environment are covered for the 3D city model constructions. The airborne technique was chosen for SK2 because, while 3D models of large buildings with few geometric details can be easily constructed using high-resolution satellite data, finer details require datasets with a resolution greater than 1m (Gupta et al., 2015).

Each data acquisition is controlled to any of the 64 ground control points that were established across the AOI using survey-grade GNSS equipment (Trimble R10 GNSS) and are also tied up to the nearest three good NDCDB marks and relevant Standard Benchmarks (SBM) for height transfer, image matching, network control adjustment and ensuring spatially correct linkages to the respective cadastre lots. Orthometric height value was obtained by reducing the ellipsoidal height to Mean Sea Level (MSL) using MyGeoid and connected to the nearest SBM value. Procedures of equipment calibration, GNSS survey, ground proofing, and cadastral tie-up survey were conducted in accordance with JUPEM's standard practices. Redundant observations were conducted to minimise the possibility of systematic errors.

The aerial data and images were acquired with a hybrid sensor (LiDAR, oblique and nadir images), the Leica City Mapper, with a ground sampling distance (GSD) of 10cm and frame overlaps of 80% along track and 60% across the track. To supplement aerial mapping in urban areas that are inaccessible by air, the Leica Pegasus Two mobile mapping solution was used to capture panoramic street view images and 3D point clouds at the street view level. In order to avoid privacy concerns with street view images, an additional bulk and a manual editing process of blurring pedestrians and vehicles were performed. Additionally, 3D data of ten identified buildings are captured using a RIEGL VZ-400i 3D Terrestrial Laser Scanner integrated with a Nikon D8000 camera. These buildings were chosen for their intricate and aesthetic features and their potential for 3D-based spatial analysis in terms of heritage-cadastre management, which can be spatially analysed via SKiP2 Walkthrough.

Aside from that, hydro flattened water bodies within the AOI are required to deliver elevation models. The process was conducted to avoid an unwanted spike in water bodies that could compromise hydraulic analysis. Furthermore, hydro-flattening allows water bodies like streams, rivers, and reservoirs to show elevation change along their length, while ponds, lakes, and other cartographically polygonal water surfaces show a static surface. The criteria of hydro flattening in SK2 include any water bodies more significant than 10m river width, greater than $400m^2$ lake and pond and greater than $400m^2$ swamp.

The feature extraction process was carried out based on the Features and Attribute Codes MS1759:2015, to deliver 68 feature layers that included Built Environment, Transportation, Utility, Hydrography, Hypsography and Vegetation. In addition, the overall SK2 digitising method is performed by adapting the JUPEM's Peta Bandar feature extraction standard procedure with slight exceptional rules, such as building types that share the exact wall boundaries must be split/cut according to their units, and the boundaries must intersect. Consequently, the classification of the building feature layers and transportation digitising are customised to SK2 requirements to enable navigation analysis, cadastre-based spatial queries and SKiP1 integration into the SKiP2 environment. The attributes of the feature extraction, specifically *Name*, are labelled with standard proper nouns and are determined according to the hierarchy of data references, starting with MyGeonames, followed by other official local government services, and finally by visualisation via Google Maps or Street Maps. If none are available, site verification is performed. Additionally, the process was also used to finalise the polygon shapes of inaccessible features.

The Leica City Mapper generates single nadir, oblique, and LiDAR point clouds, which can be processed and rendered into a 3D mesh. Complete coverage of the cityscape was ensured by collecting data from the Leica Pegasus Two, which was also used to augment the 3D Mesh rendering. Additional editing was required and completed in SK2, including the removal of floating objects such as trees and signboards, the removal of moving cars at a main road's traffic light, and the hollowing out of the road, rail, or river networks that ran beneath paths, flyovers, and bridges. A sample of the hollowing out editing process in SKiP2 compared to SKiP1 and Google Earth is shown in Figure 5. The general flow of the SK2 development and deliverables published into SKiP2 is shown in Figure 6.

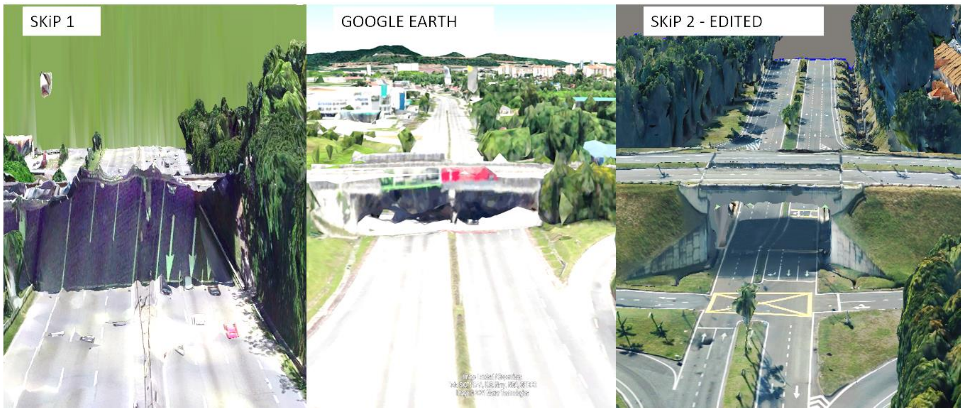

Figure 5: A comparison of the hollowing out editing process between SKiP1, Google Earth and SKiP2

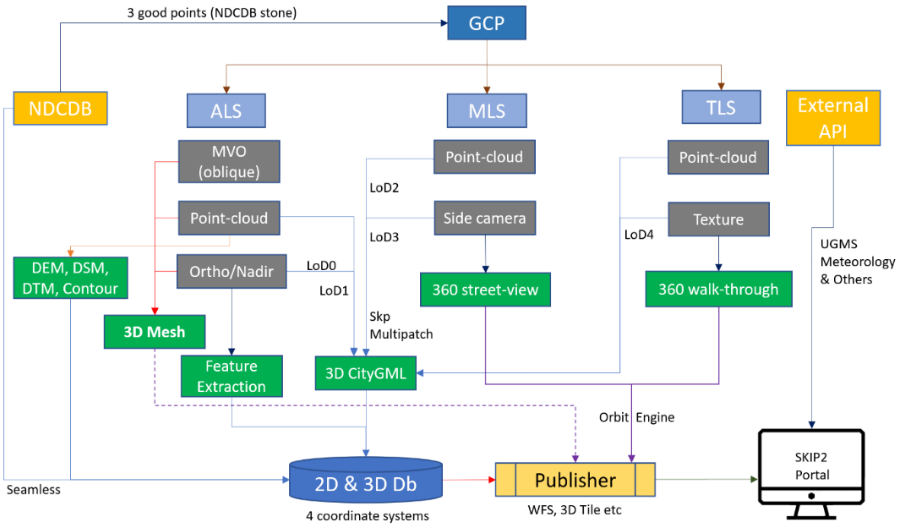

Figure 6: Overall SmartKADASTER Phase 2 Development and Deliverables Published in SKiP2

The final deliverables that are being incorporated into SKiP2 are the Digital Elevation Model (DEM), Digital Surface Model (DSM), Digital Terrain Model (DTM), the contour of various intervals (1m, 5m, 10m, 20m and 25m), 3D Mesh, 68 feature layers, 3D city models, 3D StrataGML, 3D panoramic street views, 3D walk-through, and 2D and 3D databases of the specified AOI. Further reading on the 3D model reconstruction and database development, as well as the Strata GML conversion process in SK2, are available from (Halim, Karim, et al., 2022), (Siew et al., 2021), and (Halim et al., 2021).

3.2 SK2 Geospatial Data Accuracy

It should be noted that this paper does not intend to go into detail about the data processing and verification process. Nonetheless, all collected data is processed and verified appropriately to ensure that the deliverables meet the accuracy and specification established for SK2. ASPRS Accuracy Standards for Digital Geospatial Data is used as a reference to benchmark the quality of the accuracy achieved for data collection. Horizontal accuracy is assessed compared to the ground control points value using root-mean-square-error (RMSE) statistics in the horizontal plane, i.e., RMSEx, RMSEy, and RMSEr. In contrast, vertical accuracy is assessed in the z dimension only.

3.2.1 Vertical Accuracy

The tolerance for the vertical accuracy of the elevation dataset was set to 15cm RMSEz Vertical Accuracy Class. The airborne Non-Vegetated Vertical Accuracy (NVA) of SK2 was determined to be RMSEz = 6.5 cm, which equates to +/- 12.8 cm at the 95th percentile, while the airborne Vegetated Vertical Accuracy (VVA) was determined to be +/- 19.2 cm at the 95th percentile. (12.8 cm x 1.5 (ref. value = 17.05 cm). SK2's mobile NVA accuracy was found to be RMSEz = 2.4 cm, equating to +/- 4.8 cm at a 95% confidence level.

3.2.2 Positional (Horizontal) Accuracy

The tolerance Positional Accuracy was set for a 30 (cm) RMSEx / RMSEy. SK2's airborned positional accuracy was found to be RMSEx = 4 (cm) and RMSEy = 4.1 (cm) which equates to airborne Positional Horizontal Accuracy = +/- 5.7 cm at 95% confidence level. SK2's mobile positional accuracy was found to be RMSEx = 2.4 (cm) and RMSEy = 3.5 cm which equates to mobile Positional Horizontal Accuracy = +/- 7.4 cm at 95% confidence level.

3.2.3 Relative Accuracy

Additional relative accuracy was evaluated for data collected along the Leica Pegasus Two tracks, where each mission in the tracks includes on-site verification of at least three squarish fixed features. Signboards, power boxes, and walls are examples of features used for data verification. There were a total of 220 features verified, with the RME_{length}, $RMSE_{width}$, and $RMSE_{height}$ all being 0.011m. The result concurs with the statement highlighted by Gröger et al. (2008) that relative accuracy is typically much higher than absolute or positional accuracy.

3.2.4 3D Model Accuracy

The 3D models of buildings reconstructed in SK2 basically adopt the CityGML Version 2.0 multi-scale-representations and accuracy of different Level of Details (Gourbesville et al.), ranging from LoD 0 to LoD 4 (Gröger et al., 2008). LoD1 is considered accurate with a positional and height accuracy of 5m or less and a 6m by 6m or more footprint. The positional and height accuracy of LOD2 is 2m if the footprint is 4m x 4m or larger. 0.5m is the accepted accuracy for a 2mx2m footprint LoD3. Finally, LOD4 must have a positional and height accuracy of not more than 0.2m. In SK2, the acceptable tolerance of each axis geometry of LoD 3 and 4 was set to +-0.3 m to be useful for cadastre purposes. Other values may be regarded as gross errors or mistakes (RICS, 2014).

4. CHALLENGES AND RECOMMENDATIONS

Unsurprisingly, the Covid-19 pandemic was the primary impediment to the SK2 development, given that the majority of the project's timeline was impacted by not one but three Movement Control Order (MCO) events imposed by the Malaysian government to contain the outbreak. Therefore, aside from the pandemic challenges, this section discusses some other major challenges encountered during the development of SK2 and the recommendations made in response to them.

4.1 Flight Altitude Restriction

While the GSD set for SK2 is 15cm or greater and the actual implementation is 10cm, SK2's goal is to produce a GSD value equal to the capabilities of the Leica City Mapper specification, which is 8cm. In achieving the value, the calculated flying altitude should be within a range of 3,000 feet above the ground. However, the approved flying altitude was 4,500 to 5,000 feet above the ground due to the AOI's overlap with two major airports in Malaysia with heavy airbus traffic, namely Kuala Lumpur International Airport and Subang International Airport (refer to Figure 1), as well as their taxiways. Another issue that has arisen due to this approved flying altitude is the limited amount of clear sky available within the flying altitude and windows. Malaysia is a tropical country with high humidity. Low clouds, particularly cumulonimbus with anvil, were almost completely covered in the AOI area. The observed height of the base of any clouds present during the approved flying window was around 2,900 feet above the Kuala Lumpur and Subang stations (Meteologix, 2021), thus limiting the airborne mapping visibility unless the minimum 3,000 feet above ground flying altitude was granted. 75% of the airborne data from SK2 had to be re-flown multiple times due to this and unpredictable weather caused by climate change. As a result, extensive editing of the produced aerial images or LiDAR points is required to remove clouds, shadows, noise, spikes, and colour balancing when applicable. It is recommended that the flying time be between 8 and 11 a.m., during the dry season of May to September, when the sky is ideally clear. However, it is contingent upon the AOI's air traffic's sensitivity, which may allow for a lower flying altitude. Alternatively, unmanned aerial vehicles may be used in the future for the purpose of airborne

LiDAR and mapping. Still, other factors such as the time span and speed required to cover a large AOI area should be considered.

4.2 Time Gaps Between Data Acquisition During MCO

MCOs were imposed into three stages by the government, and some SK2 data acquisition occurred within the MCOs. Several airborne LiDAR and mapping blocks within the AOI were completed earlier than the rest, as most of the data used to develop SK2 is derived from airborne data by-products. The four- to seven-month intervals between airborne missions resulted in data incoherence due to significant site changes, such as new land development or terrain change. Figure 7 illustrates a sample of the dramatic differences between the earlier (old) and latest (new) data processed, where the elevation between the old and new is found to be significant. Several GCPs also required site re-establishment due to new construction or being missing on-site. While the situation is unprecedented and time is of the essence, it is recommended that areas where significant changes occurred be redone to avoid visualisation and analysis inconsistency.

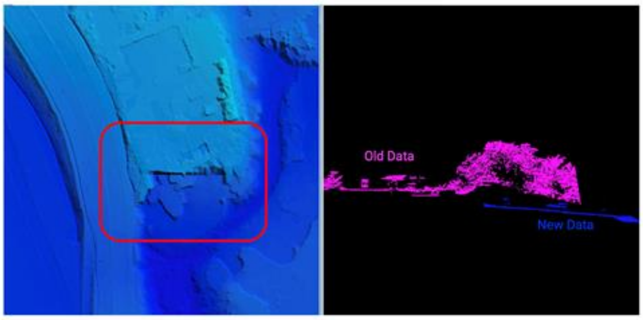

Figure 7: A drastic elevation change between the old and new data processing

4.3 Unavoidable Multiple Reprocessing Process

As a result of those mentioned above, the reprocessing process is unavoidable due to the multiple frequencies of data acquisition and its domino effects. These tasks include readjusting network controls, reprocessing extracted features, remodelling elevation models, remodelling city models, recompiling databases, re-rendering 3D Mesh, and republishing SKiP2. Furthermore, unlike any simple process, the enormous size of the geomatic, image, models and geospatial data acquired within the 1,475 km^2 AOI, precludes bulk or automated processing or publishing. Moreover, speed is also hampered by software and hardware limitations. Consequently, the processing process had to be deduced into a smaller workspace, prioritising only the affected areas. However, more robust and higher-spec hardware is still required to ensure the seamless end-product of SK2 and publishing into SKiP2, specifically for 3D Mesh models. The recommended minimum hardware specification to render 3D Mesh in SK2 is 512Gb RAM, 12 Gb GPU, 80 Cores CPU with 2.0 GHz speed or better, 2TB SSD NVMe and 100TB size of storage data.

4.4 Capture Once, Used by Many

It is the aim of SK2 that, aside from realising the SmartKADASTER concept, all of the data captured and delivered for SK2 can be used for other purposes, whether internally or externally. Hence, the concept *captured once, used by many*. In addition, the spatial accuracies, as detailed in the previous section, are better than that of other GIS-based platforms offered in Malaysia (Halim et al., 2018), and are basically relevant for land-based spatial decision making (Halim et al., 2020). However, the contrasting requirement between spatial and navigation analysis in SKiP2 and map publishing, where the cartographic and aesthetic elements are the concern, hinders direct data sharing or adoption of SK2 data for JUPEM's map publishing. The only linkages between the two are the standard features and attribute codes (MS1759). Nevertheless, data matching, masking and generalising (even though painstaking) can still be applied to adapt all SK2 feature categories, except for the *Vegetation* layer, for map publishing purposes of 1:5000 scale map or higher (up to 1:500). To permit seamless integration for GIS purpose, it is recommended that JUPEM value-add the existing geospatial database (PDGN) structure so that SK2 data, specifically its feature layers and city models, can be interrelated into the relevant databases. Each SK2 city model already includes a unique 3D UPI that connects to the NDCDB and stratified data, where applicable and is explained in detail by Halim et al. (2021). Additional connections to PDGN would broaden its potential for other applications.

4.5 Insufficient Data For 3D Modelling or Mesh

As stated in the previous sections, street view images and a mobile laser scanner supplement ground-level cityscape for LoD 3 modelling and 3D mesh generation. However, it was discovered that some sites are still inaccessible due to roadblocks or extremely narrow roads, resulting in incomplete building view sides. Figure 8 depicts error data and image samples related to driving methods and narrow streets. Aside from that, there are issues with bumpy roads and driving methods that resulted in tilted data and images and buildings located far away from the mapping vehicle. It is recommended that the operator repeat the scanning by slowing down the vehicle at each corner and bumpy road to compensate for these shortcomings. For buildings that lack side views or point clouds, the 3D model can be reconstructed using the same pattern as its neighbouring buildings as a reference. Its texture can be patched using any editing software and other alternative image sources, such as Google Street View. If the building footprint is still undetermined, site verification is required for these situations.

Figure 8: (L): Titled Point Clouds Due to Sharp Turn Vehicle; (R): Incomplete Building Side Views

4.6 LoD 1 Building Height Reference

There are some challenges in the reconstruction and use of LoD1 models since automatically generated LoD1 models for the same area can differ in their reference heights (Biljecki et al., 2014) and geometric references (Biljecki, Ledoux, et al., 2016). Biljecki et al. (2014) discovered that using the reference H3 (half the roof height) as the top surface height for LoD1 models generates the least number of volume computation errors and is thus the most suitable approach for LoD1 generation. Initially, the height reference was used to create LoD1, but it was later determined to be incompatible with the SK2 application and aim. Unlike buildings in other countries, those in SK2's AOI are condominiums or multi-story commercial buildings with functional spaces or ownership, such as duplexes, penthouses, attics, and rooftop halls, as well as other types of cultural multilevel roof houses or commercial buildings, as illustrated in Figure 9. The strata relationship associated with that specific building model would be unavailable. As a result, SK2 generated LoD1 using H6 (Height at the top of the building's construction). In the absence of superstructures extending beyond the roof's top, the height value corresponds to H5 (Height at the top of the roof). While volume analysis may not be accurate for LoD1 in SK2, other analyses such as shadows, line of sight, and viewshed can still provide useful decision-making information. When performing spatial analysis on LoD1 models, it is recommended to refer to the 3D Mesh in SK2 for verification. The implications of LoD 1 automated building height extrusion and the choice of height reference in SK2 is explained in detail in Halim, Abdullah, et al. (2022).

Figure 9: Top Left: A multilevel roof commercial building inspired by *Rumah Minangkabau*; Top Right: Sultan Abdul Samad Mosque with tall pillars; Down Left: A *kampung* house in the city with usable attics; Down Right: A semidetached house with usable attic

5. CONCLUSION AND WAY FORWARD

This paper has highlighted JUPEM's approach in the SK2 development process. According to Halim et al. (2020), SKiP was found suitable for its purpose as an online platform and the first of its kind to provide previously unavailable cadastral-based information and analysis to the Malaysian public with spatially accurate data sources. Additionally, Sageconsulting (2020) discovered that 79% of SKiP users used the application at least once a month, while 10.5 percent used it weekly or daily for work analysis tasks or to obtain information to aid in decision making. All respondents agreed that they always prefer SKiP over other commonly available applications when planning or making decisions that require cadastral-based information and further geospatial analysis applications, which has aided them significantly in their daily tasks. Therefore, the enhancements to SK2 are expected to expand the number of potential applications that can benefit its users and stakeholders via on-screen site analysis. A potential house buyer, for example, can determine the *feng shui* elements of the house (Hassan et al., 2021), its shadows to yield photovoltaic panels (Biljecki et al., 2017), as well as emergency planning such as identifying the safest high grounds to park their vehicles in the event of a flood and the height of their house that the flood could potentially submerge. A local authority can estimate population estimation (Biljecki, Arroyo Ohori, et al., 2016), the potential property casualties of disaster victims or development compensation due to land acquisition, while an insurance company can accurately estimate the premium of the house located on the riskier ground.

Given these potential applications, the following are the way forward and suggestions to ensure that the purpose of SK2 is met and can be expanded beyond cadastre purpose:

i. Continuous promotion and awareness program of the usage and benefits of SKiP2 to its existing users and potential new users;
ii. It is widely assumed that 3D environments use more machine resources as well as internet data. As a result, SKiP2 performance should be continuously improved using appropriate performance tests until an acceptable baseline is established to enhance users' experience with SKiP2;
iii. A broader assessment study should be performed to determine the socioeconomic and sustainability impact of SKiP that have yet to be conducted;
iv. It should be noted that the NDCDB only stores Final Title and Request for Survey cadastral lots. A 3D model of a building block that lacks an NDCDB is not necessarily a squatter house or has no ownership. Integration with Land Offices for Qualified Titles information is necessary for a comprehensive cadastre analysis;
v. Because visualisation is a key feature of SKiP, the aesthetic quality of the published data is unavoidably as crucial as its spatial accuracy quality. Future AOI should consider the time for aesthetic quality checking and editing during the development timeline;
vi. Further research into the integration of SK2 CityGML and IFC or BIM formats should be considered in order to broaden the application of SmartKADASTER's 3D city model database for the architecture, engineering, and construction (AEC) industry use; and
vii. Policies governing SK2, such as its business architecture and data sharing, should be considered and planned, as SK2 may create opportunities for spatial use-cases in eccentric business analyses and a spatial-information-as-a-service model.

Finally, it is hoped that this study will add to the body of knowledge regarding the development of 3D geovisualisation and cadastral data, particularly those that can be used in applications beyond cadastre purposes. The emplaced lessons learned, recommendations, and suggestions in this paper are also hoped to guide others in any future work of venturing beyond cadastre purpose or similar to the SmartKADASTER concept and system.

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