Opening up 3D Digital Map in Hong Kong: Pilot in Kowloon East

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Key words: Open Data, Open Access, 3D Digital Map, Common Spatial Data Infrastructure

SUMMARY

The Lands Department (LandsD) of the Hong Kong Special Administrative Region (HKSAR) Government provides high-quality geospatial information and spatial data services to the society of HKSAR to facilitate smart city development. The 3D digital map forms a major building block of the Common Spatial Data Infrastructure (CSDI) initiative, which promotes sharing government geospatial data for various digital map applications.

In 2021, LandsD identified Kowloon East, a district of about 24 square kilometres, as a pilot project area to generate a high-quality 3D digital map. With the experience gained from the pilot project, LandsD aimed to complete the 3D digital mapping for the whole territory of Hong Kong by the end of 2023. This paper presents the work completed in the pilot project, including the preparation of the technical specifications, determination of the project implementation approaches, data collection and the generation of the dataset. This paper also discusses the findings and challenges identified from the pilot project.

The results of the 3D digital map obtained in the pilot project will be shared with the public to make greater use of spatial data. The availability of open digital map data will facilitate the development of smart cities, realising the visions of the Smart City Blueprint for Hong Kong 2.0 and bringing benefits to society as a whole.

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1. INTRODUCTION

The Lands Department (LandsD) of the Hong Kong Special Administrative Region (HKSAR) Government provides high-quality geospatial information and spatial data services to the society of HKSAR to facilitate smart city development. The 3D digital map forms a major building block of the Common Spatial Data Infrastructure (CSDI) initiative, which promotes sharing government geospatial data for various digital map applications.

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2. PROJECT SCOPE

An incremental approach was taken to realise a territorial coverage of the 3D digital map for Hong Kong, with the first stage involving the development of a full-fledged 3D visualisation map for Kowloon East (KE), as shown in Figure 1 (the project). KE covers an area of about 27 sq. km, which includes about 24 sq. km land area, 284 km of road length, 47 km of infrastructure (i.e. flyover, footbridge and railway) and over 5,900 buildings.

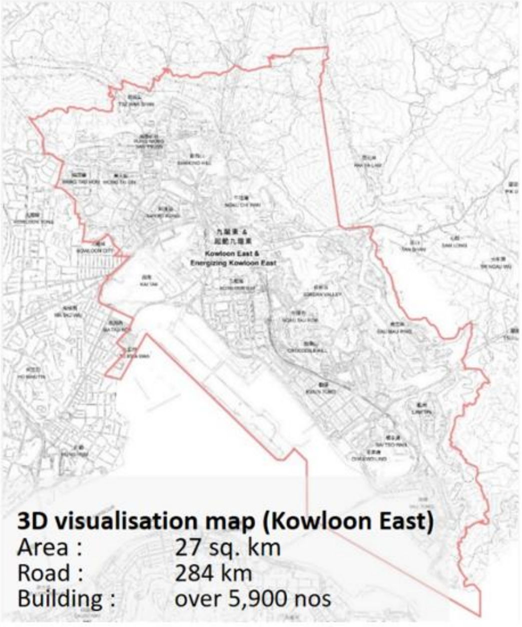


Figure 1: Project Area in Kowloon East

2.1 Global Market Research

Global market research was conducted to stock take the specifications/ standards of companies/ products/ regions for the 3D digital map in different cities. The study also aimed at identifying the state-of-the-art technologies for the 3D digital mapping generation.

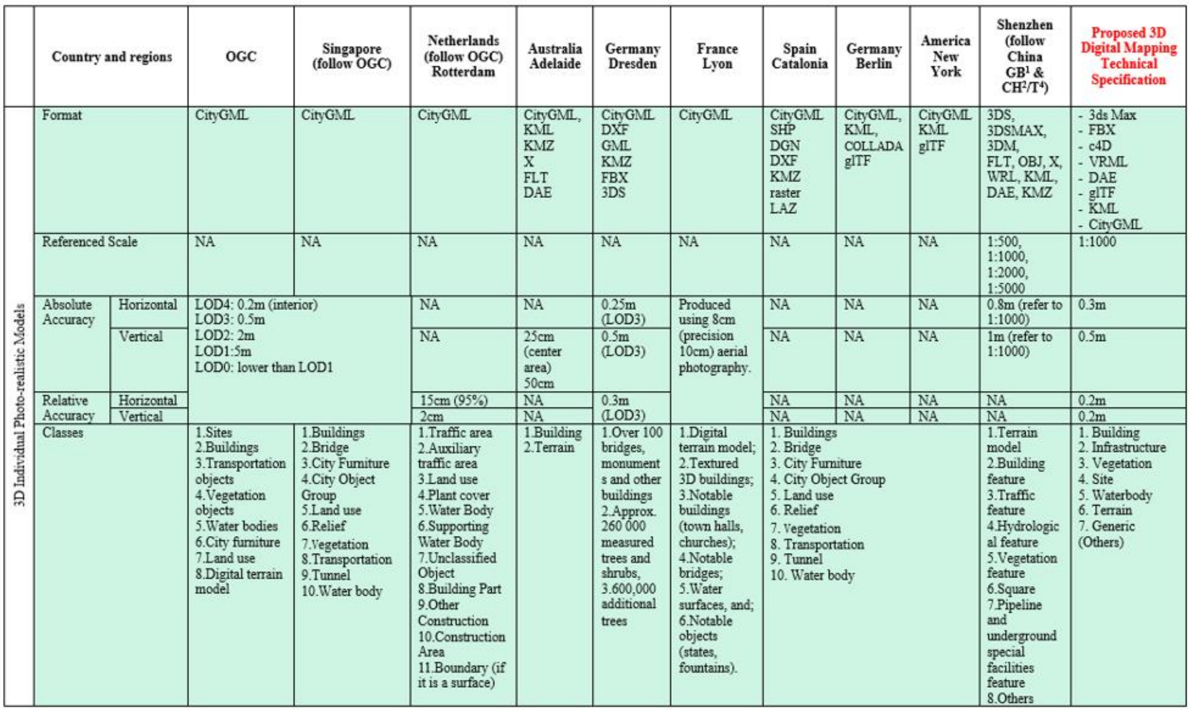
The desktop review was conducted. The Open Geospatial Consortium (OGC) 's CityGML standard was adopted by European cities such as Dresden, Rotterdam, Lyon and Catalonia, and Singapore. Berlin and New York's 3D City Databases also follow CityGML 2.0. On the other hand, cities in China mainly follow the Chinese National Standards or the Standards of 3D Real Scene published by the Bureau of Natural Resources and Planning in 2021. It indicates that European cities and Singapore follow the CityGML focusing on the attributes and relations of the 3D city model. Meanwhile, Chinese cities focus on the visualisation of the 3D city model.

On top of the desktop review, interviews were held with overseas and local vendors and international 3D mapping experts to understand the latest technologies and development of 3D digital mapping. The technologies explored and evaluated cover data capturing technologies (including aerial survey, airborne light detection and ranging (LiDAR), Vehicle-based Mobile Mapping System (VMMS) and Portable Mobile Mapping System (PMMS)); and data processing/integration technologies.

Data capturing for the 3D digital map can be classified into the aerial survey, VMMS survey and PMMS survey. Currently, the most precise and accurate method for creating 3D models is using LiDAR point cloud data taken at aerial and ground-level, where high-resolution 360° panoramic images are used to supplement the details (texture and geometry) of the 3D model.

2.2 Preparation of Technical Specifications

When developing the 3D digital mapping specifications for Hong Kong, our proposed mapping standards/specifications were compared with OGC's CityGML and standards adopted by cities from nine countries to identify potential gaps and opportunities for enhancement based on current technological trends and capabilities. European cities, such as Berlin, Munich, Helsinki, Rotterdam, and Singapore, commonly adopted CityGML as a standard, focusing on the semantics and relations of the 3D model. In contrast, most cities in China emphasise the facade quality on 3D photo-realistic modelling, except the Shenzhen government, which has produced semantic 3D models but does not yet comply with OGC's CityGML standard. The project team also interviewed Prof. Lutz Plumer and Prof. Christian Heipke, international experts on 3D mapping, to seek their advice on current trends and the development of the 3D digital map. Both experts commented that while Hong Kong's project is ambitious, it tallies with the international trend for 3D mapping development. Therefore, our proposed 3D Digital Mapping Technical Specifications are comparable to the prevailing standards in other cities.



	Country and regions		OGC	Singapore (follow OGC)	Netherlands (follow OGC) Rotterdam	Australia Adelaide	Germany Dresden	France Lyon	Spain Catalonia	Germany Berlin	America New York	Shenzhen (follow China GB^1 & CH^2/T^4)	Proposed 3D Digital Mapping Technical Specification
3D Individual Photo-realistic Models	Format		CityGML	CityGML	CityGML	CityGML, KML KMZ X FLT DAE	CityGML DXF GML KMZ FBX 3DS	CityGML	CityGML SHP DGN DXF KMZ raster LAZ	CityGML, KML, COLLADA glTF	CityGML KML glTF	3DS, 3DSMAX, 3DM, FLT, OBJ, X, WRL, KML, DAE, KMZ	- 3ds Max - FBX - c4D - VRML - DAE - glTF - KML - CityGML
	Referenced Scale		NA	NA	NA	NA	NA	NA	NA	NA	NA	1:500, 1:1000, 1:2000, 1:5000	1:1000
	Absolute Accuracy	Horizontal	LOD4: 0.2m (interior) LOD3: 0.5m LOD2: 2m LOD1:5m LOD0: lower than LOD1		NA	NA	0.25m (LOD3)	Produced using 8cm (precision 10cm) aerial photography.	NA	NA	NA	0.8m (refer to 1:1000)	0.3m
		Vertical			NA	25cm (center area) 50cm	0.5m (LOD3)		NA	NA	NA	1m (refer to 1:1000)	0.5m
	Relative Accuracy	Horizontal			15cm (95%)	NA	0.3m (LOD3)		NA	NA	NA	NA	0.2m
		Vertical			2cm	NA			NA	NA	NA	NA	0.2m
	Classes		1.Sites 2.Buildings 3.Transportation objects 4.Vegetation objects 5.Water bodies 6.City furniture 7.Land use 8.Digital terrain model	1.Buildings 2.Bridge 3.City Furniture 4.City Object Group 5.Land use 6.Relief 7.Vegetation 8.Transportation 9.Tunnel 10.Water body	1.Traffic area 2.Auxiliary traffic area 3.Land use 4.Plant cover 5.Water Body 6.Supporting Water Body 7.Unclassified Object 8.Building Part 9.Other Construction 10.Construction Area 11.Boundary (if it is a surface)	1.Building 2.Terrain	1.Over 100 bridges, monuments and other buildings 2.Approx. 260 000 measured trees and shrubs, 3.600,000 additional trees	1.Digital terrain model; 2.Textured 3D buildings; 3.Notable buildings (town halls, churches); 4.Notable bridges; 5.Water surfaces, and; 6.Notable objects (states, fountains).	1. Buildings 2. Bridge 3. City Furniture 4. City Object Group 5. Land use 6. Relief 7. Vegetation 8. Transportation 9. Tunnel 10. Water body			1.Terrain model 2.Building feature 3.Traffic feature 4.Hydrological feature 5.Vegetation feature 6.Square 7.Pipeline and underground special facilities feature 8.Others	1. Building 2. Infrastructure 3. Vegetation 4. Site 5. Waterbody 6. Terrain 7. Generic (Others)

Table 1: Comparison of 3D Mapping Standards/Specifications of Different Regions

2.3 Project Implementation

The project was conducted progressively in two stages. Stage 1 would enhance the mesh model by separating features into seven classes (Building, Infrastructure, Vegetation, Site, Waterbody, Terrain, Generic) with individualised objects in seven non-CityGML formats. This stage also produced the tile-based mesh model in OBJ, OSGB and Cesium 3D Tiles formats. Stage 2 takes up a full-scale production of CityGML to cover all buildings and infrastructure of KE with detailed attributes and semantics information [5].

Data was captured by different survey methods in the project, including aerial survey, VMMS survey, PMMS survey, and control survey.

Figure 2: Data Capturing by Different Survey Methods

The categories and types of the

3D digital map datasets include the 3D Individual Photo-realistic Models, Tile-based 3D Photo-realistic Models, Oblique Aerial Images, True Orthophoto, Digital Surface Models (DSM), Colorized Dense Point Cloud (including both VMMS and PMMS), 360° Panoramic Images (including both VMMS and PMMS) and Individual Images (with the blurring of human faces and car plate numbers on the images), Ground Control Point (GCP) and Check Point (CP) and CityGML Models (for building and infrastructure only).

Item	**Category**
F1	3D Individual Photo-realistic Models (Data types include building, infrastructure, vegetation, waterbody, site, terrain and generic(others))
F2	Tile-based 3D Photo-realistic Models
F3	Oblique Aerial Images
F4	True Orthophoto
F5	Digital Surface Models (DSM)
F6	Geo-referenced Point Cloud Data
F7	Geo-referenced 360° Panoramic Images
F8	Individual Images
F9	Ground Control Point (GCP) and Check Point (CP)
F10	CityGML Models (Data types include building and infrastructure)

Table 2: Categories and Types of 3D Digital Map Datasets

In the project, all buildings were modelled individually in a high level of detail (LOD) which are LOD3, except CityGML models in LOD2, with photo-realistic textures. As a result, the building models in LOD3 represented a higher degree of resemblance to the buildings' geometry and appearance than the building block models in LOD1, a uniform prismatic column representing the footprint and the overall height without texture.


Building Block Models in LOD1
Building Photorealistic Models in LOD3

Figure 3: Comparison of Building Block Models in LOD 1 and Building Pohotrealistic Models in LOD 3

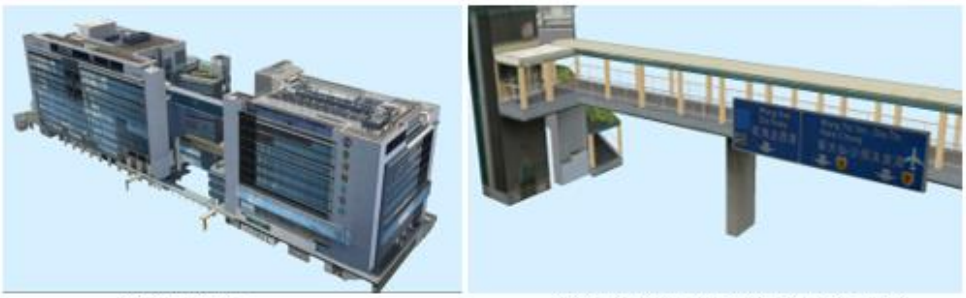
Infrastructure models were classified into two sub-types (Road and Others). Road features were individualised and grouped in tiles, and other infrastructure features such as overpasses, tunnels, bridges, footbridges and subways were individualised.

Site features were classified into different sub-categories according to their types and functions. The sub-categories of site features included Farm, Accommodation, Commerce, Education & Training, Health & Medical Service, Leisure, Culture & Sports, Organisation, Public & Social Service, Religion, Military, Industry, Works Area, Transportation and Utilities. The site models were delineated on the mesh models by referring to the outline of site features in the 2D digital topographic map and the up-to-date geometry of the mesh models.

The sub-categories of waterbody features included Breakwater, Catchwater, Culvert, Dam, Moat, Nullah, Pond, Reservoir, River/Stream, Rocky Streambed, Shaft, Sluice and Weir. Each waterbody model was created by referring to its footprint from the 2D digital topographic map to ensure that the water surface was presented uniformly. If the features were occluded by vegetation, ground-level data such as MMS data would be used for enhancing texture and edge lines modification to secure the accuracy of the waterbody model. For areas where the texture cannot be obtained in the field, these areas would be filled with the colour of the surrounding water surface to ensure the consistency of the texture of the waterbody model.

Since the vegetation and generic models were created based on the mesh model, the number of vertices and polygons of each model would be relatively large, which might hinder the viewing performance in the 3D platform. Therefore, optimisation was applied to the models to reduce vertices according to the angle value between the set surface and the surface, ensuring that each model's shape was maintained.

With the preparation of individualised models for different features, the final tile-based photo-realistic model combines individualised/ tile-based models. Compared with the original raw mesh models, the file size and vertices were optimised; the quality of the models was maintained in terms of appearance and geometry, and the hardware requirement for viewing the models would be less demanding. As a result, the tile-based photo-realistic model was convenient for supporting different 3D mapping services and applications while maintaining a higher level of detail and photo-realistic texture for analysis and visualisation purposes.



(a) Building (b) Infrastructure (feature basis)

(c) Infrastructure – Road (tile basis) (d) Vegetation (tile basis)

(e) Waterbody (feature basis) (f) Site (feature basis)

(g) Terrain (tile basis) (h) Generic (others) (tile basis)

Figure 4: 3D Individual Photo-realistic Models

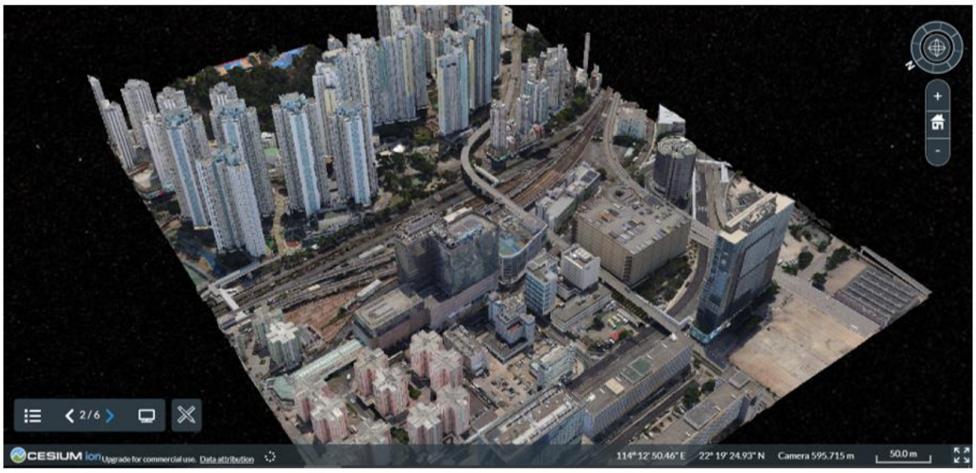


Figure 5: Tile-based 3D Photo-realistic Models

3. FINDINGS AND CHALLENGES

The development of the 3D digital map involves a wide range of data surveyed and mapped with territory-wide coverage. Some findings and challenges were observed and summarised as follows:

3.1 Approach to 3D Digital Map Production

In the 3D digital map production, the approach in other countries mainly relies on using imagery, LiDAR data or both dataset collected solely from airborne platforms. However, this approach might not be suitable for Hong Kong since the density of buildings in the built-up area of Hong Kong is very high, with narrow spaces between building blocks. The situation in Hong Kong is most prominent in old neighbourhoods of low rise buildings (below ten stories) that were re-developed into new high rise buildings of fifty stories or even higher. Therefore, the proposed solution was to combine the aerial survey data and ground-level survey data to generate the 3D digital map of Hong Kong.

However, due to the occlusion of vegetation, the density of buildings, and the three-dimensional infrastructure characteristics (such as footbridges and roads), there will inevitably be many dead angles and blind spots in the aviation angle. At present, much research is working in this direction, but the process of product-level transformation is lagging behind. Therefore, the automatic and efficient fusion processing of multi-angle and multi-source image data and LiDAR data will be the possible direction of the 3D digital map production.

Under the exceptional environment in Hong Kong, the GNSS signal would be severely blocked or suffer from the multipath problem due to the dense distribution of high rise buildings. The loss or shortage of GNSS signals over a long period would downgrade the absolute accuracy of the VMMS and PMMS data. Therefore, for the VMMS and PMMS survey, additional control points were required in this specified area to adjust the trajectory to ensure absolute positional accuracy met the requirements.

Moreover, using many glass curtain walls in residential and commercial development in Hong Kong also creates difficulty in providing high-quality photo-realistic images for building facades. The aerial photos often contain reflections from nearby buildings or features/objects on the ground level. Additional images are therefore required to be taken on the ground level for some landmark buildings such that the facades will reflect the light from the sky and give a more pleasing look.

3.2 Data Format

In the project, seven data formats would be generated for individualised models. In addition, the CityGML format would also be produced for buildings and infrastructure (See **Table 1**).

Among the seven data formats, the quality of the same feature might be varied because of the limitation of a particular format. For example, the KML format limits 64,000 vertices in each file. Since the actual number of vertices in the vegetation model usually exceeded this limit, the number of vertices was trimmed down. However, this would affect the appearance of the vegetation models to a certain extent.

As semantic 3D city models will facilitate a broader range of applications, in the long run, the 3D digital map should be developed primarily in CityGML format as a master dataset, which is an open standard and data format defined by OGC. Other data formats can be exported from the CityGML dataset. The data conversion can be done by the user or by the functions embedded in the 3D digital map data dissemination platform. Currently, the project produces data in proprietory formats as the master dataset. Extra effort would be required to maintain data consistency in different formats and to include semantics into CityGML separately when there is an update of ground-level features in the future. The suggestion of adopting CityGML as a master dataset in the future would make the 3D digital map more sustainable and reduce the effort in data maintenance.

3.3 Data Maintenance and Data Updating

LandsD aims to develop a high-quality 3D digital map covering the whole territory of Hong Kong by the end of 2023. An accurate and up-to-date 3D digital map was crucial to support the dynamic nature of smart city activities and a fundamental element to support the applications related to Digital Twins, which required an up-to-date digital copy of a real-world place or object. The strategies and mechanisms for updating the models and maintaining different dataset versions will be critical for the sustainability development of the 3D digital map [9].

With the rapid development in Hong Kong undertaken by government and private developers, an effective means of obtaining an update would be required. At present, LandsD regularly conducts aerial survey operations over the territory of Hong Kong to identify the changes in topography. It provides the primary aerial survey data for building up the mesh models for part of the 3D digital map that has been changed. In addition, the institutional setting in the government is being enhanced to ensure that data from the completed public works can be transmitted to LandsD via the as-built 3D data like Building Information Modelling (BIM) data.

Updating the 3D digital map of densely developed and fast-changing areas in Hong Kong will demand information collected on the ground. Besides effort from the government alone, crowdsourcing for mapping is one of the vital data sources for producing dynamic digital maps which require up-to-date data on roads, landmarks, buildings, pedestrian walkways, and much more. It is anticipated that mobile data collection, crowdsourcing, and social media are likely to have the most significant impact over the coming decade. These forms of data collection will enable accurate, (near) real-time applications that various users increasingly demand on geospatial data [6].

Crowdsourcing does not imply that the public has to update the complete set of the 3D digital map. On the contrary, the people could report outdated map features and upload mapping-related data such as street view photos, Unmanned Aerial Vehicles (UAV) imagery and 3D models to facilitate the 3D digital map updating. For example, the public could readily contribute their Point-of-Interest (POI) data, such as images captured by their cameras, 360° panoramic images, and POI information using their handheld devices. The collected data can then be shared in a 3D mapping portal with others. Mapillary and KartaView are examples of crowdsource natures with a global focus. Both examples rely on crowdsourced imagery for data updating and are owned and operated by commercial entities [4].

The concept of the crowdsourcing portal is similar to the one for bathymetry called Crowdsourced bathymetry (CSB) by The International Hydrographic Organization. The CSB has long been established practice in the Marine Industry for improving mankind's understanding of seafloor. It provided a good reference in drafting the quality control mechanism to ensure the quality of the crowdsourced data meets the mapping standards.

Although crowdsourcing could be the source for 3D digital map updating, issues of liability and accuracy need to be handled carefully. Crowdsourced information could be adopted for investigative and insight purposes or where nothing definitive exists. However, additional input on quality assurance is required if such data is used for decision-making and certainty in a legal (cadastral) context [8]. Questions around correctness (authenticity) and quality will hinder public bodies' wider acceptance of crowdsourced information. The situation will be improved as the technology matures and new possibilities arise, new processes and algorithms continue to be developed to ensure that data sources comply with the same standards and quality expected of authoritative data [7].

3.4 Data Quality

The data quality shall conform to the standard with completeness, logical consistency (including conceptual, attribute, visualisation, topological, performance, and format characteristics), positional accuracy, attribute accuracy, temporal quality and metadata. Unfortunately, there is no authoritative quality standard for the 3D digital map. Therefore, it would be a good exercise for Hong Kong to develop and contribute the best practices and lessons learnt to the global community.

The ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) might provide an excellent reference to address the positional accuracy of geospatial products. This standard, developed by the ASPRS Map Accuracy Standards Working Group, includes positional accuracy standards for digital orthoimagery, planimetric, and elevation data. The standard also includes additional accuracy measures, such as orthoimagery seam lines, aerial triangulation accuracy, LiDAR relative swath-to-swath accuracy, recommended minimum Nominal Pulse Density, the horizontal accuracy of elevation data, delineation of low confidence areas for vertical data, and the required number and spatial distribution of checkpoints based on project area [3].

In this project, over 5,900 building models were generated. Therefore, a cost-effective method for the quality control of 3D building models was important. Since Hong Kong had conducted the airborne LiDAR survey for the whole territory of Hong Kong in 2019, a 3D surface matching method raised by Acka, D et al. [2] can be used where the 3D building models are co-registered to the airborne LiDAR dataset. The 3D surface matching method evaluates the Euclidean distances between two datasets to give appropriate metrics for the 3D model quality regarding reference system accuracy, positional accuracy and completeness.

Regarding the texture quality, occluded areas in the texture often happen in narrow streets or areas that aerial survey, VMMS and PMMS can not capture. In addition, owing to the dense and cramped nature of urban spaces in Hong Kong, there are many occasions where mapping of the foreground objects close to a building onto facades is unavoidable.

Figure 6: Vegetation Projected on Building Facade

Similarly, aerial imagery as textures may result in unavoidable skewing of objects (e.g. air conditioning units appearing longer and slanted), and each model may skew at a different angle. It may result in an unrealistic representation of the series of building facades when multiple models are placed together. A similar anomaly arose for cases when a single building was mapped with various aerial images. Additional site photos with accurate position and orientation parameters will be required to improve the quality of the models.

Sometimes, acquiring photo-realistic texture may be physically impossible. For example, buildings located on cliff edges are surrounded by dense foliage. In such cases, the surface extracted from the mesh model can only be used for texture mapping for individual models. However, if the textures from the mesh models were deformed severely, the models would be filled with plain colours or texture-tone colours.

Figure 7: Texture of Building Façade Skewed in Different Directions

3.5 Data Privacy and Security

During data capture for the generation of the 3D digital map, a large amount of information is considered sensitive to the public, such as human faces and car plate numbers. Since seeking consent from individuals for large-scale data collection was not feasible, an alternative method was to anonymise the images, eliminating the need to seek permission. It was suggested that image anonymisation measures should be applied to sensitive parts to protect personal data privacy and ease the public's concerns about their data. For most mobile mapping use cases, blurring offers the best trade-off between performance, anonymisation and reduced distortion. For sensitive buildings or sites, facades of the corresponding models might be required to be pixelated or blurred.

4. OPEN ACCESS TO DATA

In 2018, the HKSAR government promulgated the open data policy to promote technology research, innovation, and smart city development. Under the policy, government bureaux and departments will endeavour to release their data for free public use unless there are justifiable reasons (such as involvement of personal privacy).

Opening up the digital map products, including the Map Application Programming Interface (Map API) services, enables the public, academia and businesses to use spatial data in research and application development. In December 2020, three Map API services, including Topographic Map API, Imagery Map API and Map Label API, were made available to the public free of charge on the Public Sector Information Portal (data.gov.hk) and the Hong Kong GeoData Store (geodata.gov.hk). In April 2021, LandsD started to open its digital map products free of charge. Products including Digital Topographic Map, Digital Land Boundary Map, Geo-

Reference Database, Digital Orthophoto, Digital Aerial Photo (300 dpi resolution), GeoCommunity Database and 3D Spatial Data were released for free downloading on the Hong Kong Map Service 2.0 (hkmapservice.gov.hk). The availability of free digital map data will facilitate the development of a digital economy, realising the visions of the Smart City Blueprint for Hong Kong 2.0 and bringing benefits to society as a whole.

To promote the development of Hong Kong into a smart city, the HKSAR government is developing the CSDI, which consists of an institutional framework and digital infrastructure facility to facilitate the consolidation, exchange, sharing and innovative application of geospatial data among government departments and public and private organisations. The CSDI portal is one of the key digital infrastructures underpinning the smart city development in Hong Kong. It aims to enhance the use, management, discovery and sharing of spatial data for robust policy-making, driving innovation and value creation.

The CSDI portal will be ready for operation by the end of 2022, with about 320 datasets from different government departments, including the Agriculture, Fisheries and Conservation Department, the Census and Statistics Department, the Education Bureau, the Leisure and Cultural Services Department, for free download and use by the public. The datasets will mainly cover geography and development, government and public administration, land information, transportation and utilities related datasets, community and social welfare, education, environment, health, population census / by-census, recreation and culture, sports, and technology-related datasets.

The datasets to be released through the CSDI portal will meet the CSDI standards, including geotagging of non-spatial data, documentation of data specifications and metadata, and conversion of spatial data to an open and machine-readable format, as well as the establishment of API. In addition, the 3D digital map, which forms a major building block of CSDI, will facilitate the sharing and opening of government geospatial data and meet the needs of digital map applications and shares to the public via the CSDI portal with enhanced Map API services.

5. POTENTIAL APPLICATIONS

The 3D digital map is the core component of the digital infrastructure underpinning Hong Kong's smart city development at a strategic level. By having the ability to integrate, analyse and present a large volume and different datasets in innovative and informative formats, the 3D digital map can open up a wide range of applications. Below are some examples of the potential applications and benefits of 3D mapping data.

5.1 Asset Management

The project captured the features from aerial to ground-level on a territorial scale and in three-dimension. The infrastructure models such as flyovers, underground passages and footbridges can be used for asset management for public administration. Attributes associated with infrastructure such as the bridge's name, identification number, and maintenance records could be easily linked with the model for visualisation and spatial analysis.

In road pavement maintenance, point cloud data and 360° panoramic images collected by VMMS can be used to monitor the damage and defects of urban road pavements. In addition, the number and location of street furniture such as fire hydrants, street lights, road signs and other road accessories can be inquired and counted using the 360° panoramic images and individual high-resolution images collected by VMMS. These datasets and models can facilitate road administration and assist other government departments such as Highways Department and Transport Department for monitoring and maintenance in an accurate positioning manner on roads and ancillary facilities.

Combining the Internet of Things (IoT) sensors installed in the road networks with the big data and Artificial Intelligence (AI) technology makes it possible to analyse the traffic congestion situation in real-time. Moreover, it depicts the areas under investigation with the semantic and accurate data extracted from the 3D digital mapping datasets that will AI-driven location intelligence and such integrated data could be utilised in ever more automation applications in the long run. For example, to adjust the traffic lights time at each road junction, thereby improving the transport management smartly and more intelligently.

5.2 Emergency Response

The 3D digital map can provide the terrain and the ground-level features in three-dimension, which can support emergency applications to different government departments, e.g. Fire Services Department. Furthermore, the photo-realistic characteristics of the 3D digital map and other 3D data collected at the fire scene (e.g. via UAV) enable fast appraisal of the vicinity of the fire scene that enables better communication among emergency personnel and operation planning.

When there is a wildfire in Hong Kong, the fire coverage, the affected vegetation area or burnt condition, houses and facilities possibly be affected can be estimated, measured and recorded. In addition, through the measurement and analysis of the road model and VMMS data, the impact of the fire on the surrounding buildings and facilities can be analysed.

The 3D digital map could increase a city's capabilities in response to natural disasters. For example, during the typhoon or rainstorm peak seasons, the 3D terrain models could assist in monitoring and forecasting flooding by analysing the height of the water level and the inundation range. The analysed results will be helpful for residents, especially for those living in low-lying submerged areas.

5.3 Prevention and Control of Pandemic

The HKSAR government used GIS, supplement with dashboard statistics and information, to assist in mapping various information about Covid-19 to help fight the pandemic. The availability of the 3D digital map data in the future can support the visualisation of the pandemic situation in a 3D viewing environment. Data with a locational element like the workplace and residence of the confirmed cases, the activity trajectory, onset and diagnosis time, and distribution of the vaccinated population can be integrated into the 3D digital map to support simulation and spatial analyses to help control the pandemic. Locations of areas with higher risk, infected paths, numbers and places, and quarantined people can be accurately mapped, providing helpful information for public reference and anti-pandemic policy formulation.

5.4 Real Estate Management and Land Administration

The 3D digital map supports land utilisation analyses by providing accurate 3D photo-realistic contexts, such as the layout of residential areas, commercial areas and industrial areas, non-built-up areas and rural areas, to analyse and facilitate land valuation and assessment accurately. In addition, the 3D animation of land sale sites with the surrounding environments can be provided to assist in valuation assessment by viewing the surroundings from the internal units at different floors and positions.

The ability of governments to organise and integrate land and property information can be significantly improved if attributes relating to ownership rights, leases, and land records are geospatially enabled, defined in a coherent fashion, and stored as authoritative records [10]. The 3D digital map can provide a foundation for linkage with the ownership rights and land boundary records. Although the 3D cadastre is still a research topic in Hong Kong, it is anticipated that land or property ownership information can be gradually built up and managed in a geo-referenced and three-dimensional context. It can be further enhanced with links between legal spaces occupied by buildings and their physical counterparts by integrating the Land Administration Domain Model (LADM, ISO 19152) in the future.

Each 3D photo-realistic building model can be linked with information prepared by other government departments or property owners, such as building ancillary installations, building facade advertisements, street-facing shops at the lower part of the buildings and outdoor facilities. The cost evaluation of the real estate can be analysed by floor and viewing angle. The data can also support the design and cost estimation of the building maintenance or renewal. Furthermore, the 3D digital map can facilitate property management, environmental simulation and assessment by combining with the energy consumption data of the buildings, such as water, electricity and natural gas per household and the total consumption of each building.

5.5 Urban Planning

The 3D photo-realistic models can provide a new dimension for urban planning that is hardly achievable if the 2D traditional map is used only. For example, project design models can easily be placed side by side with the 3D digital map of the surroundings. The designed buildings or large-scale infrastructure can be effectively analysed on the 3D platform. Different analyses such as insolation analysis, viewshed analysis, landscape analysis, urban greening analysis, air ventilation and pollution assessment and noise assessment (e.g. traffic) could be simulated on a 3D virtual city layout platform. It lays a solid foundation for building the Digital Twins for Hong Kong in the future.

6. CONCLUSION

Being a major component of the CSDI, the 3D digital map facilitates the sharing of open geospatial data, enables a better understanding of multi-level developments and enhances urban planning in Hong Kong. In addition, the results of the 3D digital map in the pilot project will share with the public to make greater use of spatial data in research and application development and provide valuable insights to refine the implementation strategies for the 3D mapping development of the remaining areas in Hong Kong.

In opening up the 3D digital map, the pilot project in KE is the first step and not the final curtain. It is expected that when the Hong Kong territory-wide 3D digital mapping project is completed, the 3D digital map will facilitate the development of smart cities and enable Hong Kong to spearhead the continual development of the 3D mapping for the greater benefit of the community.

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