Development of the 3D Digital Map in Hong Kong

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Key words: Smart City, 3D Digital Map, 3D Visualisation Map, 3D Indoor Map, 3D Pedestrian Network

SUMMARY

The Smart City Blueprint for Hong Kong released in 2017 sets out the overall framework and strategy for the use of innovation and technology to address urban challenges, enhancing Hong Kong's attractiveness to global businesses and talents, and inspire city innovation and sustainable economic development. The Smart City Blueprint for Hong Kong included the adoption of Building Information Modelling (BIM), the development of Common Spatial Data Infrastructure (CSDI) and the development of 3D Digital Map. The Hong Kong SAR Government has allocated HK$300 million in its 2019-20 budget to expedite the development of CSDI and 3D digital map, to facilitate the dissemination, utilisation and innovative application of geospatial data.

The 3D digital map forms a major building block of CSDI, facilitating the sharing and opening of government geospatial data and meeting digital map applications' needs. To meet the increasing needs of 3D digital map applications and enhance a better understanding of multi-level spaces of a modern city like Hong Kong, the Lands Department of the Hong Kong SAR Government (LandsD) aims to develop a high-quality 3D digital map for Hong Kong by the end of 2023.

The 3D digital mapping project comprises the generation of a set of high-quality 3D visualisation map showing topographical and exterior features of terrain, buildings and infrastructures over the territory; 3D indoor map showing the accessible interior of buildings and structures for 1 250 buildings; and 3D pedestrian network data over the territory. The 3D pedestrian network has been completed and released for public access in December 2020. LandsD has been taking an incremental approach in delivering the project. In 2021, LandsD will develop the 3D visualisation map for the Kowloon East area covering 27 sq. km with over 5900 buildings and 284 km of roads. This stage of the project will also cover the 3D indoor map for about 150 buildings. This paper presents the project planning, current progress, and challenges for developing the 3D digital map in Hong Kong.

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1. INTRODUCTION

Maps are used in Hong Kong for public administration, town planning, housing, land management and development, and leisure purposes by the Government, private sectors, and the general public. The Survey and Mapping Office (SMO) of the Lands Department (LandsD) is committed to providing accurate and up-to-date maps in a wide selection of topics and scales to support the rapid and intensive development of Hong Kong. Today, the production of all series of maps has been computerised in the SMO. Digital maps are proving increasingly essential to support daily life.

The Smart City Blueprint for Hong Kong released in 2017 sets out the overall framework and strategy for the use of innovation and technology to address urban challenges, enhancing Hong Kong's attractiveness to global businesses and talents, and inspire city innovation and sustainable economic development. The Smart City Blueprint for Hong Kong included the adoption of Building Information Modelling (BIM), the development of Common Spatial Data Infrastructure (CSDI) and the development of 3D Digital Map.

The 3D digital map, which forms a major building block of CSDI, facilitates the sharing and opening of government geospatial data. To meet the increasing needs of 3D digital map applications and enhance a better understanding of multi-level spaces of a modern city like Hong Kong, LandsD aims to develop a high-quality 3D digital map for Hong Kong by the end of 2023.

2. PROJECT SCOPE

The project for developing the 3D digital map comprises three parts: the full-fledged 3D visualisation map, the 3D indoor map covering the accessible interior of buildings and structures for 1 250 buildings and the 3D pedestrian network data over the territory.

2.1 3D Visualisation Map

The full-fledged 3D visualisation map provides a high photorealistic city model for visualization. It acts as containers for different spatial and textual information, including various CSDI data, BIM, and different sensors' data. The oblique aerial photos collected from aerial platforms and the images and LiDAR point-cloud collected by vehicle and backpack Mobile Mapping System (MMS) will be processed and integrated to generate the full-fledged 3D visualization map. The map will represent the shape, appearance and position of various types of features, including individualised models for buildings, infrastructure such as flyovers and footbridges, and sites (e.g. park and garden) in a high level of detail; 3D tile-based model for terrain-based features (e.g. at grade roads, vegetation, waterbody, terrain); and geo-referenced 360° panoramas & coloured dense point cloud.

The 3D visualization map will help support and facilitate the execution of works projects and engineering studies with landslip prevention and mitigation, town planning, spatial analysis, simulation, application for smart mobility and other feasibility studies.

2.2 3D Indoor Map

The 3D indoor map, which comprises the buildings' interior structures, comprising 3D floors, 3D units, and 3D indoor network from building plans, could facilitate the floor and unit-based data's linkage and develop routing-related applications for the development of a smart city. With the access points such as unit entrances and exits of each floor created in the indoor map, point to point routes across multiple locations would be supported. The 3D indoor map can support the integration of information obtained from different innovative solutions and technologies such as the Internet of Things (IoT), big data analytic in enabling new applications in the area of public safety, emergency, guidance, indoor wayfinding, facility/asset management, workspace management, unit-based land record management, building maintenance and more to support smart city development.

2.3 3D Pedestrian Network

In line with Hong Kong’s smart city initiative of promoting walkability and connectivity, the 3D pedestrian network was designed to support navigation services and meet the needs of people with physical disabilities. Based on the original dataset developed by the University of Hong Kong, the pedestrian network connects footways for over 2 000 footbridges, 400 subways, and the unpaid areas of all Mass Transit Railway stations. Footways supporting wheelchair access at over 2100 public facilities and 1300 public access lifts are also mapped for people with physical disabilities.

Different types of crossings provided by the Transport Department of the Hong Kong SAR Government were also incorporated into the pedestrian network dataset to facilitate secure pedestrian wayfinding. Moreover, height information on the pedestrian network provides the vertical profile along the footways, thereby facilitating a wide range of applications ranging from simple routing to advanced walkability studies. The gradient values of the footways generated can significantly improve the accuracy of estimated travelling time in navigation applications development. The 3D nature of the pedestrian network will also support innovative applications like 3D visualisation of pedestrian routes and navigation with Augmented reality (AR) or voice guidance.

3. STRATEGY FOR PRODUCTION

The development of the 3D digital map will be implemented based on three strategies: incremental implementation, meeting users' expectation, and setting out best practice and exemplars.

3.1 Incremental Implementation

The realisation of a territory-wide 3D digital map takes on an incremental approach. In 2021, LandsD will develop the full-fledged 3D visualisation map for the Kowloon East (KE) area as the first stage of the Project Area, covering 27 sq. km with over 5900 buildings and 284 km of roads. This stage of the project will also cover the 3D indoor map for about 150 buildings in KE. Various aspects of digital mapping and technological capabilities will be tested using KE as a pilot area before full-scale implementation in the subsequent stages. The KE project can help explore different approaches in various aspects of work such as data capturing, data processing, model production, and quality checking. Lessons learnt and experiences gained from KE project can be carried forward into developing data for other regions in Hong Kong.

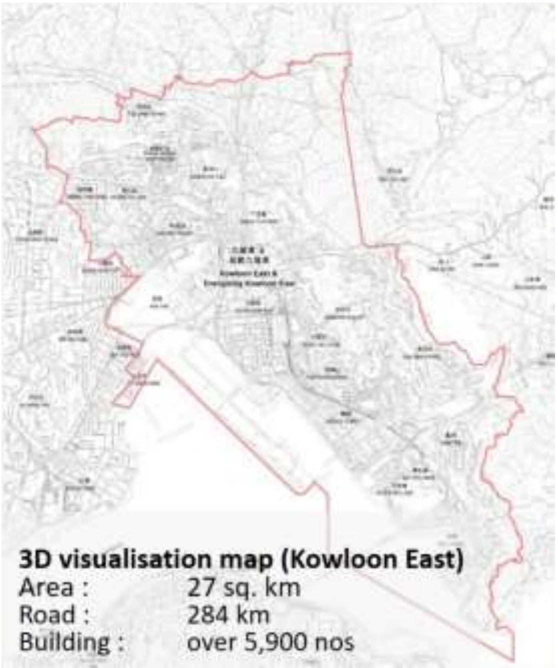


Figure 1: Project Area in Kowloon East

Since October 2020, LandsD interviewed stakeholders on their requirements, including data accuracy, data format, level of detail (LOD), types of features to be mapped, attributes, semantic information, data structure, data coverage, updating frequency, applications, software used and data dissemination; conducted a study of the 3D mapping standards/specifications in different jurisdictions and market research on existing and available technologies and mapping solutions.

The applications of 3D data, and subsequently the 3D digital map, vary significantly between different government departments and businesses. For instance, identifying unauthorized building works requires higher LOD and data accuracy whereas visualisation and 3D printing deman for a lower LOD model. As such, the datasets should have multiple LODs available for users to facilitate the multi-scale use of the models and improve the computational efficiency of spatial operations [2, 3, 6].

The market research was conducted to stock take the specifications/ standards of companies/products/regions in the world's cities. It also aimed at identifying the state-of-the-art technologies for 3D digital mapping generation. European cities and some cities ride on CityGML whereas Chinese cities focused on photorealistic 3D map production. 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 were data capturing technology, which includes 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. These technologies were evaluated with the one adopted in Hong Kong and corresponding key recommendations were made regarding the Hong Kong context.

The KE project will be conducted progressively in two stages. Currently, CityGML is undergoing a version transition; therefore, we have been careful in adopting the latest version of City GML at stage 1. Nonetheless, the KE project in stage 1 will test out CityGML on three buildings and three infrastructure to examine how best the current CityGML version model complex buildings in Hong Kong. It will also verify vendors' capability and process of producing CityGML compliant models. As production of models on CityGML standard is anticipated to require more resources, due to the embedded attributes, and given the constraints of the project, three buildings were chosen for their landmark quality and representation of class; including a high-rise residential building, a hospital, and large scale multi-purpose complex. These buildings range in the complexity of location, geometry, and building purpose; therefore, they could best test the feasibility of CityGML. The case for infrastructure is similar. Road, flyover, and bridge are selected. They are the primary infrastructure type in the study area. The selected features are supported by the existing CityGML schema and applied internationally.

	Stage 1	Stage 2
Data Format	• Non-CityGML tile-based mesh model (OBJ / OSGB / Cesium 3D Tiles) • Individual tile-based models for 7 feature classes (non-CityGML) • CityGML models (Version 2.0) for 3 buildings and 3 infrastructure	• CityGML models (Version 2.0) for remaining buildings and infrastructure
Data Accuracy	• Sub-structure dimension for individual object models (for all buildings and infrastructure objects): 0.5m • Photorealistic textures accurately attached on all class types • PMMS to cover peripheral area of 10 selected buildings (total length 50km) • Accuracy requirements – Absolute accuracy 0.3m (H) and 0.5m (V); Relative accuracy 0.2m (H) and 0.2m (V)	
Data Features	• Provide attributes / semantics for the 3 selected buildings and 3 selected infrastructure in CityGML models	• More detailed attributes / semantics provided for CityGML models • Some indoor data included • Test out OGC compliance mechanism

Figure 2: Kowloon East pilot divided in two stages

For non-CityGML mesh model in stage 1, we will enhance the model through separating features into seven classes (Building, Infrastructure, Vegetation, Site, Waterbody, Terrain, Generic) with individualised objects for buildings and infrastructure. This approach will likely yield two sets of data (CityGML and non-CityGML) that could be used to compare against each other to assess the quality of output and production method. Stage 2 would take up a full-scale production of CityGML to cover the remaining buildings and infrastructure of KE.

3.2 Meeting users' expectation

The architect Cedric Price once said, "Technology is the answer, but what was the question?" When thinking about the impact of technological progress on the 3D digital map, it is expected to be able to address users' expectation for class separation on the map, data formats catering requirements from an extensive range of end-users, providing a higher degree of realism on textures and render finishes, providing attribute data, and a higher degree of geometric accuracy to meet application needs.

The 3D mapping data may like the flour in a flour mill. Different customers could use the flour to make bread, cake or noodle. Both the potential applications and benefits of 3D mapping data are beyond imagination. OGC has listed the top-level use cases for CityGML models [9], which is divided into five main groups: archive, visualisation, navigation, simulation and analysis. On top of that, more applications and use cases were established and described in detail by Biljecki et al. [4].

However, its not an easy task to fulfil the requirements of all users, not to mentioned that requirements may be changed from time to time. In the KE project, we have consulted a host of stakholders comprising government departments, academia, professional institutions and stakeholders in construction industries, as well as players in BIM and GIS fields, aiming to collect the user's expectation. We expected that we will continue this kind of consultation regularly when more data is ready and continually update the strategy in developing the 3D digitial map in a sustainable manner.

3.3 Setting out Best Practice and Exemplars

From the review conducted in the KE project, we noticed that the modelling requirements is unique as compared with other countries since users demand for high positional accuracy of various features in the model. This might be due to the fact that the built environment is one of the most congested in the world, in particular the underground structures and utiltites.

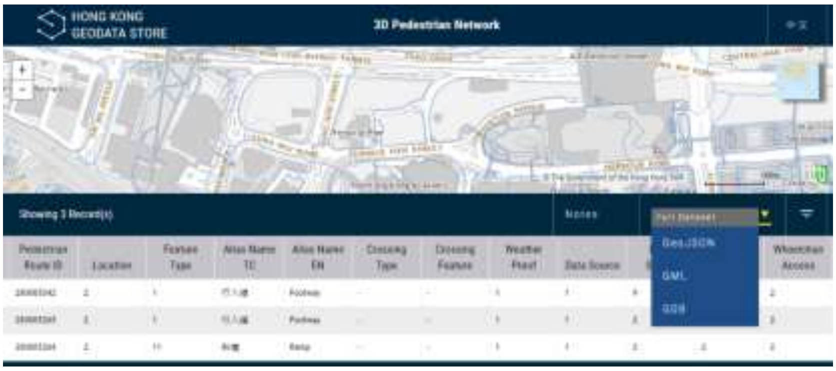
The experience gained from the KE project will help shape the requirements for implementation in the next mapping area and setting out best practices in terms of 3D mapping standards and technical specifications. It is anticipated to drive more innovative ideas and applications for 3D mapping data, justifying the value of the data and the need for high LOD, high-quality data to assist in government works. It will send a strong signal to the industry, encouraging investment and development into building technological capacity and the industry's capabilities.

From a strategic perspective, Hong Kong might demonstrate herself in delivering the tasks following international standards and help contribute best practices, and can take this opportunity to participate in related organisations (e.g. OGC) for knowledge sharing and furthering development in various aspects. For example, the positional accuracy information that we will achieve in Hong Kong can be a good reference for other similar built environments.

4. PROJECT PROGRESS

The 3D pedestrian network and the initial set of 3D visualization map was released for public access in December 2020. The initial set of 3D visualisation map was a tile-based mesh model produced solely by aerial imageries taken in 2017 and 2018. It enabled the public to have an early perception of the 3D visualization map. The 3D pedestrian network and the initial set of 3D visualisation map in machine-readable formats are available for previewing and downloading on the Hong Kong GeoData Store (geodata.gov.hk) and the Public Sector Information Portal (data.gov.hk).

(a)

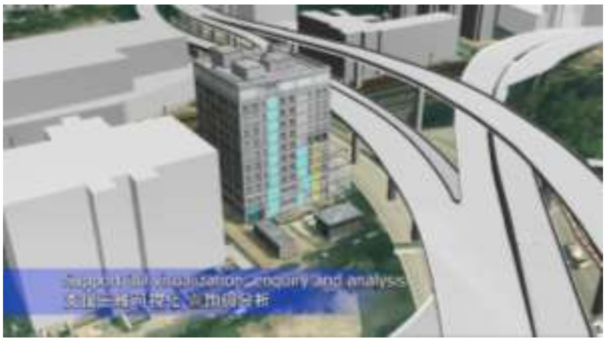


(b)

Figure 3: (a) The initial set of 3D visualisation map and (b) the 3D pedestrian network, both are now available for previewing and downloading on the Hong Kong GeoData Store (geodata.gov.hk)

In 2021, the pilot production of the 3D indoor map for about 150 buildings in KE was conducted. The data included unit-based information and routing designed to support different indoor mapping related potential applications. The feedback from different stakeholders on using this dataset will be collected to make references for enhancing the requirements for further developing the 3D indoor maps of 1 250 buildings by the end of 2023. Landmarks and major government, institutional and community facilities (e.g. Government offices, hospitals, community halls, schools, clinics, municipal buildings) accessible to the public will be given priority in drawing up the list.

(a)



(b) (c)

Figure 4: The pilot production of 3D Indoor Map in Kowloon East (a) Support indoor navigation, point to point wayfinding; (b) Support accessible wayfinding for wheelchair users; and (c) Support 3D visualisation, enquiry and analysis

5. CHALLENGES

5.1 Data Standardization

Standards are of utmost importance if we want to integrate information and make it accessible and easy for different stakeholders to share and improve decision-making. In implementing open standard and best practice, revelant agencies has to get together and uncover how they could better use their resources by eliminating work duplication and benefiting smart city development in Hong Kong. Standards for geospatial information can also be seen as a continuum enabling the achievement of increasing levels of geospatial data interoperability as more standards are adopted to keep pace with evolving requirements, technologies and tools [1].

However, the world of 3D city modelling is too diverse. Although CityGML is the standard data model for 3D city modelling, it is mainly adopted for the European context. The acquired data in Hong Kong might result in uncertain modelling situations in which current standards fall short of or the information content of the data is not sufficient to support applications. One of the alternatives currently used in the industry is to extend the standard for specific domains by defining application domain extensions (ADEs), such as designing ADE for the energy demand estimation or a city-specific data model. However, ADEs do not have prescribed rules, and hence software packages and libraries often cannot process the application-specific information automatically [14]. We need to consider the formalization, consistency, continuity, and more adequate specifications of LODs. The refined specifications should be in line with the specifications of CityGML; able to supplement the geometric part of the current specifications; and compatible and practical to implement in the Hong Kong context. This come to an important indicator that the standard should be able to support the use cases and applications from the community, including the Government, industry, academia, research and public, in Hong Kong.

5.2 Evolving Technologies

Technology in the 21st century, in particular, plays a prime role in disrupting 3D mapping. With the rapid changes in technology tools, much modern surveying equipment and software are now available and widely adopted. The methodologies of 3D data capturing and modelling are continuously enhanced and updated. The data collection methods have been continuously enriched from the early traditional topographic maps and architectural drawings to the current high-resolution satellite imaging, UAV imaging, and mobile mapping system data and GIS data extraction from BIM. One of the most expected impact yet to come is the application of Artificial Intelligence (AI) and IoT in automatic change detection, data collection and analysis in the context of Digital Twins. It is expected that the data captured related to 3D digital map is, by its very nature, part of the 'big data'. Detailed and accurate data from the 3D digital mapping project will take advantage of AI-driven location intelligence and be utilized in ever more automated ways in the long run. AI technology is turning millions of aerial photos, ground-level images and point clouds, captured from time to time, into valuable and insightful datasets. These datasets can be used for change detection and quantify attributes, such as solar panels, roads, vegetation, roofs or construction sites. Applications range from automated building and feature extraction, change detection and other AI-related intelligent applications.

5.3 Unified Approach of QA / QC Mechanism

When compared with 2D spatial data, 3D model has more complex and diverse data content. It has complexity and particularity in data quality evaluation and control. In the data collection, there may be problems such as registration of the surveyed points and the images, unclear image texture, mismatched model height, adjacent surfaces that cannot be spliced. The geometric and topological errors such as duplicate vertices and missing surfaces of the models might not be detected at the scale on which the datasets are visualized, or the problem arises only within the specific software in which they are modelled [5] Therefore, timely quality assurance/quality control is necessary.

5.4 Value Creation and Impacts

The 3D digital map is the core components 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, they can open up a wide range of applications.

The development of the 3D digital map involves various stakeholders, including the Government, industry, academia and public. It is crucial to grasp their concerns and carefully address them by accommodating different user requirements in digital map production, thereby generating a useful and user-friendly 3D digital map for Hong Kong. Therefore, the data production should go hand-in-hand with the data application, enabling the 3D digital map to be more readily available and interoperable for different 3D applications among different internal government and external (academic, professional) users, creating value and realizing the anticipated benefits of 3D data production.

5.5 3D Mapping in High-density Urban Hong Kong

As suggested by Bloomberg [7], Hong Kong is one of the densest developed cities in terms of population density and is anticipated to remain at the top in 2025. Based on the topical paper "Planning and Urban Design for a Liveable High-Density City" of research series under "Hong Kong 2030+: Towards a Planning Vision and Strategy Transcending 2030", the average population density is about 27,330 persons/km2 if only the built-up area is accounted [12]. It is challenging to ensure the integrity of mapping building structure and texture in such a high-density built-up area in terms of accuracy and completeness. The most significant location issue in the builtup area in Hong Kong is the inaccuracy of GNSS positioning due to densely constructed high rise buildings. GNSS signal might be lost, multipaths are servere, and accuracy downgraded. Additional ground control points are required for every survey scheme.

5.6 Data Maintenance and Governance

LandsD aims to develop a high-quality 3D digital map covering the whole territory of Hong Kong by the end of 2023. Strategies and mechanisms for updating the models and maintaining different versions of the dataset will be important issues and challenges [14]. It is vital for the applications related to Digital Twins, which required an up-to-date digital copy of a real-world place or object. Converting from the BIM model in IFC standard to the 3D city model can be explored to facilitate updating 3D models from BIM data. Crowdsourcing and open data could also be the sources for 3D updating, but issues of liability and accuracy need to be handled carefully. Crowdsourced information could be adopted for investigative and insight purposes or in places where nothing definitive exists. However, additional input on quality assurance is required if such data is to be used for decision-making and certainty in a legal (cadastral) context [10]. Reliable, definitive and consistent geospatial data provided by the Government or authoritative agency will always be needed for a wide range of applications such as effective administration of land, property and resources, construction and urban planning [15].

6. CONCLUSION

The Hong Kong territory-wide 3D digital mapping project is ambitious in terms of scope and time frame. It can set an example for developing 3D spatial data, enabling Hong Kong to keep ahead of the industry on an international level, share our experience in facilitating spatial data and application development.

The successful development of the 3D digital map in Hong Kong requires all stakeholders' support, including full interaction and synergy among the Government, industry, academia, research, and public. Hong Kong shall capitalise on our advantages and opportunities, together with the Government, industry, academic and research sectors' joint efforts, to achieve remarkable progress in the 3D digital mapping project and benefit the smart city development.

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BIOGRAPHICAL NOTES

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