Evaluation of Mobile Mapping System (MMS) Survey for Public Housing Estates in Hong Kong

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Key words: mobile mapping system survey, GPS, tree survey, GIS

SUMMARY

The Hong Kong Resettlement Department, later renamed as Hong Kong Housing Department (HD), was established in 1953 with the primary goal of developing and managing the public rental housing (PRH) estates and to achieve the Government's policy objective of meeting the housing needs of low income families who cannot afford private rental housing. As at the end of March 2011, about 2 million people, or 30% of the Hong Kong population are now living in public rental housing units.

In order to collect and exploit the abundance of 3D spatial information that will facilitate the many processes in housing development, such as, estate planning, feasibility studies of potential sites, architectural design, engineering works, green management and facilities management, it is necessary to resort to more advanced and sophisticated technology. Therefore the land surveyors in the HD have embarked on a pilot study of the applications of MMS Survey in public housing estates in Hong Kong in 2010 with a view to evaluate the effectiveness and benefits of such technology in the Hong Kong public housing estates environment. A MMS Service Provider was thus commissioned to conduct the pilot study.

One potential and one existing housing estate were selected to represent the typical environments of initial and as-built situations in which 3D spatial information might be collected for specific applications. At the potential site, the scope of the study focused on the use of MMS for creating 3D Geo-referenced Models, its integration with a design model created from the Building Information Modeling (BIM) System and the local mapping authority's 3D Spatial Data, so as to assist the project team in carrying out feasibility studies of potential sites for public housing development. For existing housing estate, the scope of the study focused on the testing of MMS in the estate environment, the challenges in conducting a tree survey, and the integration of 3D Geo-referenced Images with the HD's Geographic Information System (GIS).

This paper concludes that MMS, though with certain limitations, is suitable in the public housing estates environment in a highly urbanised city like Hong Kong. The tree datasets collected by MMS Survey have proven to be the accurate sources for tree management. One of the most remarkable features of MMS is the ability to produce high resolution 3D Geo-referenced Models for facilitating model integration and utilising the functionalities of 3D model for use by various professionals engaged in the housing development projects.

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1. INTRODUCTION

1.1 Background of the Housing Department (HD)

The Hong Kong Resettlement Department, now known as Housing Department (HD), was established in 1953 with the primary goal of developing and managing the public rental housing (PRH) estates and to achieve the Government's policy objective of meeting the housing needs of low income families who cannot afford private rental housing. As at the end of March 2011, about 2 million people, or 30% of the Hong Kong population are now living in public rental housing units.

1.2 Background of the Task Force on Tree Management

To avoid accident due to felling of trees, the Government announced in 2009 that the Chief Secretary for Administration would lead a Task Force comprising relevant bureaux and departments to examine a range of issues regarding tree management in Hong Kong. These issues include: formulating the guiding principles and approaches to be adopted in greening and tree management; setting up the institutional framework to ensure effective co-ordination; organizing the arrangements for tree risk assessment; providing the expertise and staff training; examining the need for new legislation; soliciting community participation; providing public education; establishing mechanism to handle complaints and enquiries; and providing the resources for staff and equipment. But the most important and fundamental issue is to get to know the location of these trees and their descriptive data, even though each government department knows its area of responsibility. The Task Force then recommended the setting up of a comprehensive tree database so that the position, dimensions, species, health condition, etc. of each tree is readily available for retrieval and assessment by different users within the Government and even in the public. This tree database not only containing the initial collection of data, but also requires to be updated continuously for new trees planted and existing ones removed or deceased.

2. NEED FOR ENHANCED SPATIAL DATA

2.1 Tree Management

The HD is responsible for some 100,000 trees, which has planted in about 200 PRH estates. However, there is no comprehensive information about these trees, and more new trees are to be planted in existing estates and the new estates to be built, therefore, there is an imminent need to explore more efficient methods of collecting information about these trees both initially and for subsequent updating. Besides the basic data, such as location and size, a 3D visualisaton of these trees in the context of the housing environment would be more informative for future green management.

2.2 GIS in HD

The GIS in HD was launched in 2009 and it provides various geographic information based functions to users for capturing, storing, checking, integrating, manipulating, analyzing and displaying planning and related data with spatial information related to the existing public housing estates and proposed housing developments of the Department. The System is now undergoing enhancement so as to cater for tree management and 3D visual impact analysis functions, and in the long term to integrate with the design model from BIM.

2.3 BIM in HD

Before the implementation of BIM, the HD designed the layout of an estate using 2D software, making it difficult to visualize the various relationships and perspective in a 3D context, such as the topography and surrounding buildings. With the implementation of BIM in 2011, the visualization of 3D design models has become helpful and the work flow procedures are streamlined for improvement of work efficiency and quality.

2.4 3D Model from Local Mapping Authority

In the BIM project, buildings, infrastructure and terrain models (i.e. 3D Spatial Data) from the local mapping authority is imported to the BIM to show an accurate 3D model of the proposed redevelopment using animation software for presentation of the design layout. It can be seen that 3D Spatial Data is widely used for housing development, therefore, if this data can be supplied more quickly and addresses closely the needs of users, and with more visualization functionalities, then the quality and process of housing development work can greatly be enhanced.

2.5 Pilot Study of the Applications of MMS in HD

In order to address the need for setting up a tree management database, the provision of high quality 3D model, and the integration of BIM into GIS, a highly sophisticated and state-of-the-art mapping and GIS, with powerful 3D functionalities would be the solution. At this juncture, the MMS survey technology became mature in the surveying industry and made its debut in many international survey conferences and caught much attention. Therefore the Land Surveying Unit of HD took the initiative to conduct a pilot study to critically examine this new technology and its potential applications in HD. The pilot study was therefore conducted in 2011 by a MMS Service Provider. One potential and one existing housing estate were selected to represent the typical environments in which 3D spatial information might be collected for specific applications.

3. MMS SURVEY

3.1 MMS Technology

3.1.1 Hardware

MMS is a survey and mapping technology integrated with the functions of Global Positioning System (GPS) and remote sensing devices for the acquisition of a wide variety of spatially related images of physical features (e.g. 3D Geo-Referenced Images) on a mobile platform (e.g. vehicle-based). The images of physical features are captured by the 360^{o} digital video camera mounted on a vehicle/mobile device or even roving person due to site constraints, whilst the position fixing is by satellite positioning devices and other sensors. The 3D Geo-referenced Images data were captured with adequate accuracy for mapping purpose and can be displayed, retrieved, processed and input into GIS for analysis. The image can also be transformed into the 3D Geo-referenced Models for visualization, integration with other 3D models, spatial analysis, and presentation purpose. Figures 1-3 below show the MMS setup used in the pilot study.

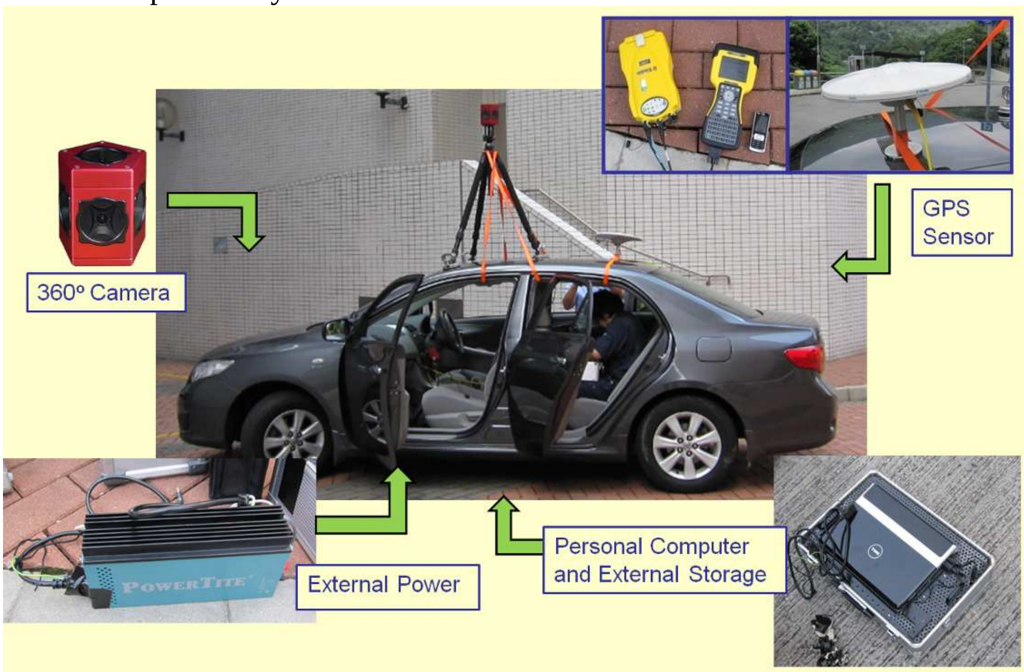


Figure 1 Vehicle-based Mobile Mapping System

Figure 2 Scooter-based

Figure 3 Roving-person-based

3.1.2 Application Software

The 3D measurements of physical features were captured from the 3D Geo-referenced Images using the Active Link Vision (ALV, a plug-in for ArcMap version 9.3) and stored in the Geo-database of ArcMap 9.3. The Images, GPS measurements, ground control points were then processed by Programmable Continuous Combined Image (PCCI) to form 3D Geo-referenced Models. The 3D models were enhanced by 3DS Max 2008 for integration with the design model from the BIM System and 3D Spatial Data from the local mapping authority.

3.1.3 Ground Control Point and Image Accuracy

Studies about MMS (El-Sheimy, 1996) indicate that the Root Mean Square of absolute horizontal accuracy can achieve 0.3m for camera-to-object distances up to 25m under normal conditions. Therefore, for this pilot study, the specifications for the horizontal and vertical accuracy of feature measured from a 3D Geo-referenced Image is +/- 0.3 metre and +/- 0.5 metre respectively, whereas the horizontal and vertical accuracy of survey control for the registration of the Geo-referenced Image is required to be within +/- 0.15 metre and +/-0.25 metre respectively.

3.2 MMS Survey of Potential Site for Feasibility Study

3.2.1 Details of the Study at Fo Tan Cottage Area

A potential site at Fo Tan Cottage Area with an area of 110,000m^2 was selected for the study. The reason for selecting this site was to test the reliability of MMS on vehicle-based and roving-person-based platforms on an undulating terrain, accessibility and variety of ground features. The study focused on using the results obtained from the MMS Survey for creating 3D Geo-referenced Models, and integrating it with a design model created from the Building Information Model (BIM) System, and the local mapping authority's 3D Spatial Data. The outcome would assist the project architects and engineers in carrying out site feasibility studies and visual impact analysis, and to conduct project presentations to different stakeholders.

Site Name	**Fo Tan Cottage Area**
Area (sq. m)	109,760
Distance by Vehicle (m)	4,684 (28 routes)
Distance by Scooter (m)	0
Distance by Roving-Person (m)	800 (16 routes)
No. of Housing Blocks	0
No. of Control Traverses	46
No. of Control Points: *Pre-mark:*	100
Post-mark:	133
Number of Trees Digitised	48
Data Size of Video (GB)	29.1

Table 1 Project Statistics for Fo Tan Cottage Area

3.3 MMS Survey of Tree at Existing Public Housing Estate

3.3.1 Details of the Study at Lei Muk Shue Estate

An existing housing estate, Lei Muk Shue Estate, which was built in 1970, havimg an area of about 95,000m^2 was selected to conduct a tree survey using the MMS technology. The reason for selecting this site was the wide varieties and large number of trees in the estate, and the typical site conditions with slopes, narrow estate roads and footpaths. The study was focused on the testing of MMS technology using vehicle-based, scooter-based and roving-person-based platforms on the estate environment, the challenges in conducting a tree survey, and the integration of 3D Geo-referenced Images and tree database with the HD's GIS.

Site Name	Lei Muk Shue Estate
Area (sq. m)	94,958
Distance by Vehicle (m)	2,314 (15 routes)
Distance by Scooter (m)	4,166 (43 routes)
Distance by Roving-Person (m)	220 (7 routes)
Number of Housing Blocks	11
Number of Control Traverses	67
Number of Control Points	
Pre-mark	180
Post-mark	125
Number of Trees Digitised	828
Data Size of Video (GB)	44.7

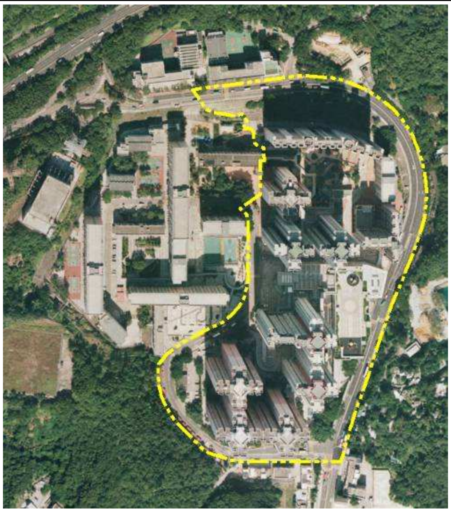
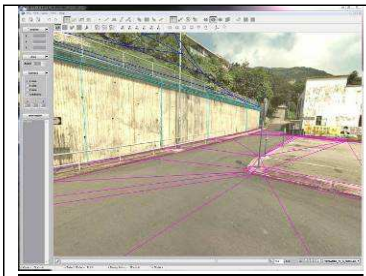


Table 2 Project Statistics for Lei Muk Shue Estate

3.4 Deliverables

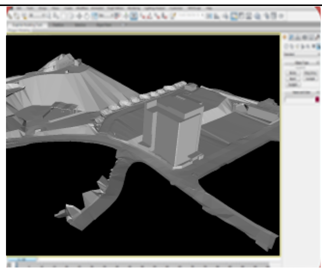
3.4.1 3D Geo-referenced Models for Fo Tan Cottage Area

The MMS Service Provider delivered one set of Geo-referenced Images each for the two pilot project sites. The Geo-referenced Images of Fo Tan Cottage Area provided coordinates, levels and images for creating 3D models of terrain, buildings, roads and utilities. The 3D lines and photo-realistic images are extracted from the ALV software to create 3D wireframe models and facades of the models. The finished models are imported to the ArcGIS 3D Analyst together with other design models from BIM and 3D Spatial Data from the local mapping authority. (Figure 4)



Digitizing and creating 3D models from captured video in PCCI (3ds max)

→



Post-processing 3D models in 3ds Max (3ds)

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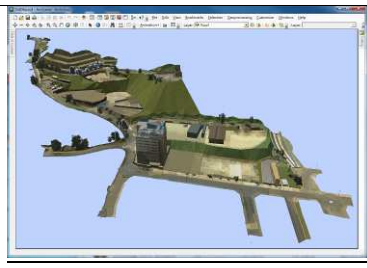


Convert 3D models to Geo-Database in ArcGIS (Multi-patch)

Figure 4 Workflow of model integration

3.4.2 <u>3D Geo-referenced Images for Lei Muk Shue Estate</u>

With the customization of the functions of ALV, the crown width, height, diameter, and position of trees were measured and digitized from the Geo-referenced Images of Lei Muk Shue Estate and stored in the geo-database. (Figure 5) Features such as trees and fences from the library in the ALV could be created in the form of Computer Graphics and be inserted in the Images for visual analysis.

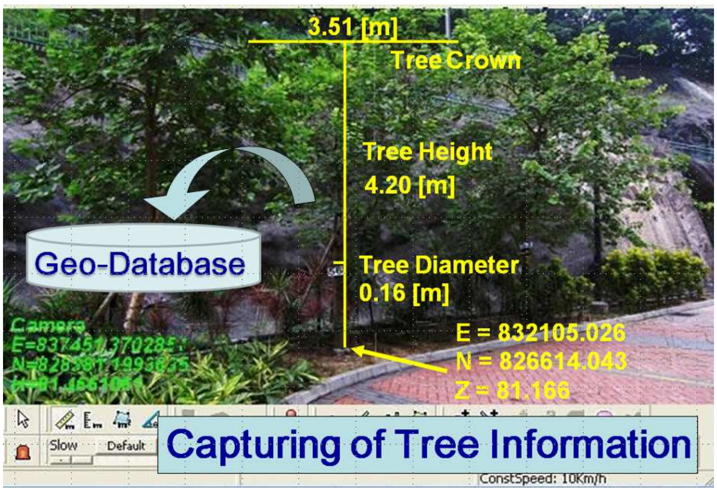


Figure 5 Geo-referenced Image and Tree Database

3.5 Verification of the Deliverables

The verification of the results was based on comparisons of surveyed ground features as the check points against the measurements of the same feature from MMS. The field survey was carried out by total station using the unique territory control network. The image quality was verified by independent technician through visual inspection.

3.6 Integration of MMS with HD's GIS

At the time of the pilot study, the viewing of Geo-referenced Images produced by MMS was only supported by ALV plug-in on ArcMap. The data integration of the Geo-referenced

Images to the HD's GIS was tested. The system design of the integration is shown in Figure 6. Since the web-based solution of the ALV was not available at the time of the pilot study, it will be further explored in the future.

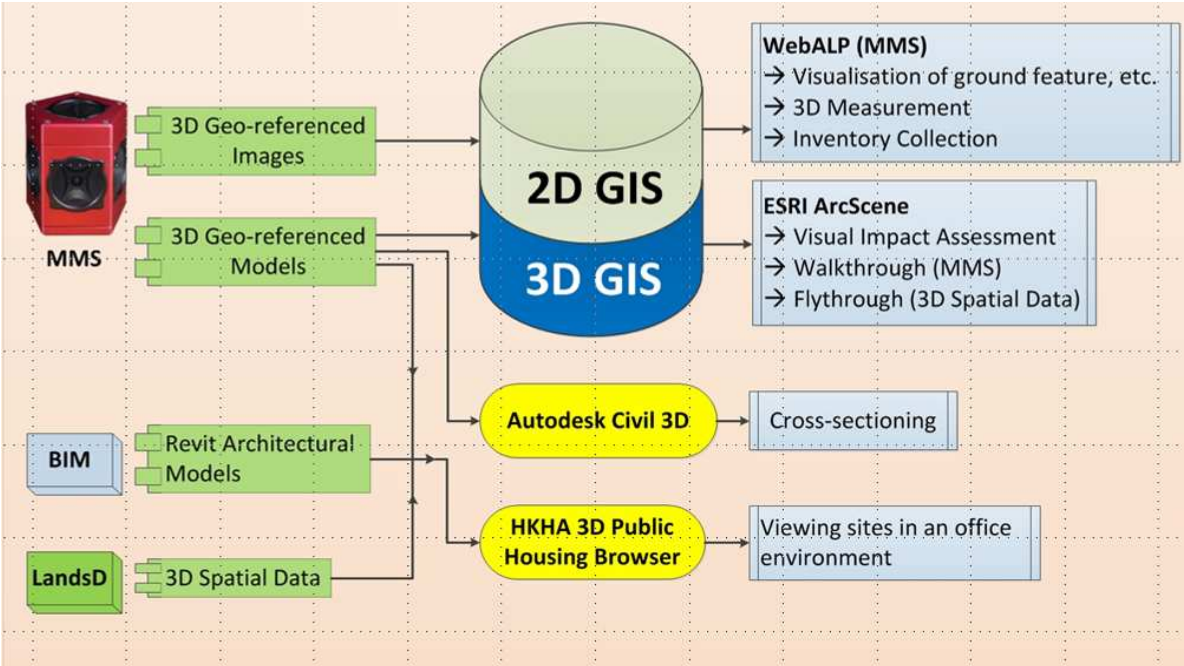


Figure 6 Schematic Diagram of Interrelationship between GIS, BIM, and MMS

4. CHALLENGES

4.1 Increase of Ground Control Points

Initial estimation of the number of pre-mark ground control points is based on an average of 50 metres apart along both sides of the routes of the camera position. However, due to the weak GPS signal at most of the area, the initial configuration of ground control points had to be densified by adding a large number of post-marked ground control points as shown in Table 3 below, thereby requiring additional survey effort.

Number of Control Points Established	Fo Tan	Lei Muk Shue Estate
Pre-mark	100	180
Post-mark	133 (+133%)	125 (+69.4%)
Total	**233**	**305**

Table 3 Number of Control Points Established

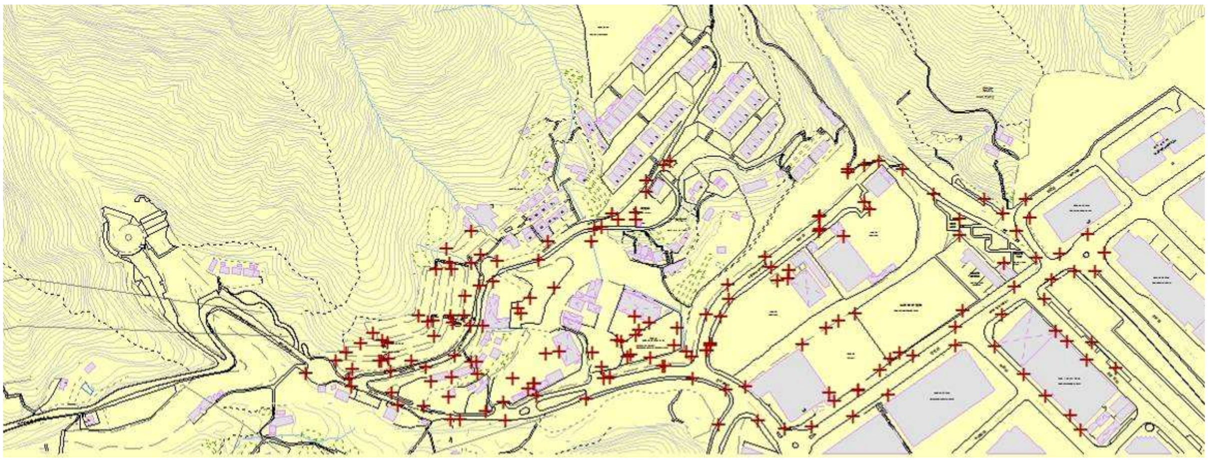


Figure 7 Distribution of Ground Control Points in Fo Tan Cottage Area

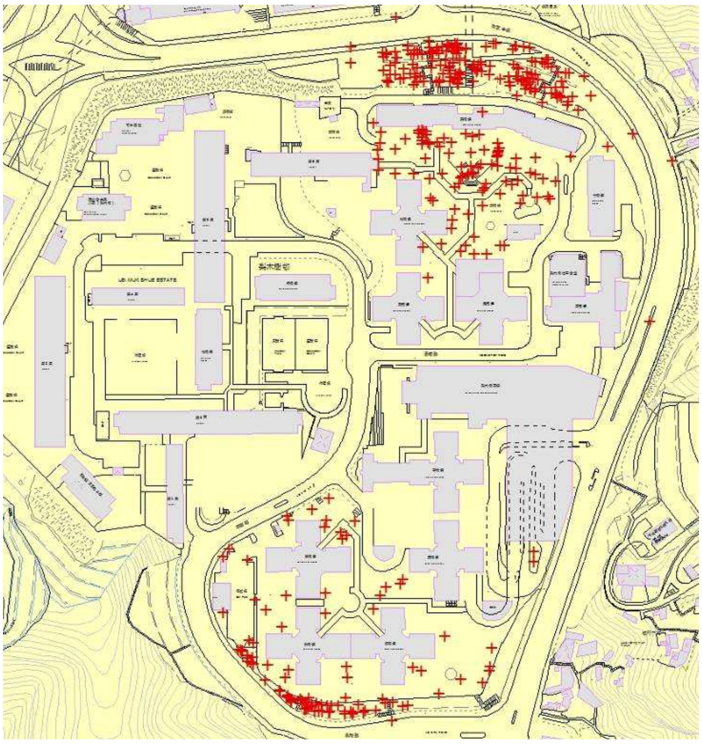


Figure 8
Distribution of Ground Control Points in Lei Muk Shue

4.2 Image Quality

4.2.1 <u>Image Exposure Problem</u>

Under or over-exposure of image would appear if the image captured is outside the normal dynamic range due to its huge contrast in the image, e.g. bright sunlight and shadow in the same image. In extreme cases where the image pixel was skewed to 0 or 255 in a histogram, the image would be under or over-exposed. The features appeared on these images cannot be discerned or measured. (Figures 9 &10)

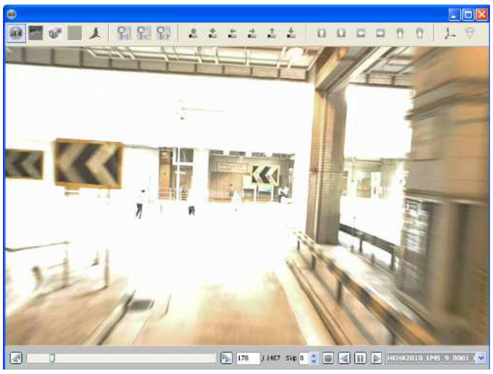


Figure 9 Over-exposure Image

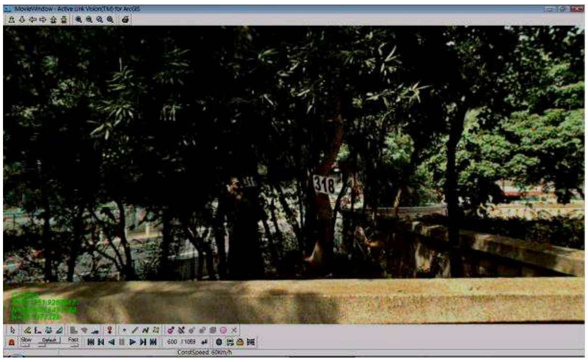


Figure 10 Under-exposure Image

4.2.2 Dynamic Moving Objects

During the shooting of video, any dynamic moving objects following closely to the camera, such as people and cars, would appear on the images on sequential basis and eventually form part of the image. (Figure 11). This reduced the overall image quality and made that portion of image unusable.

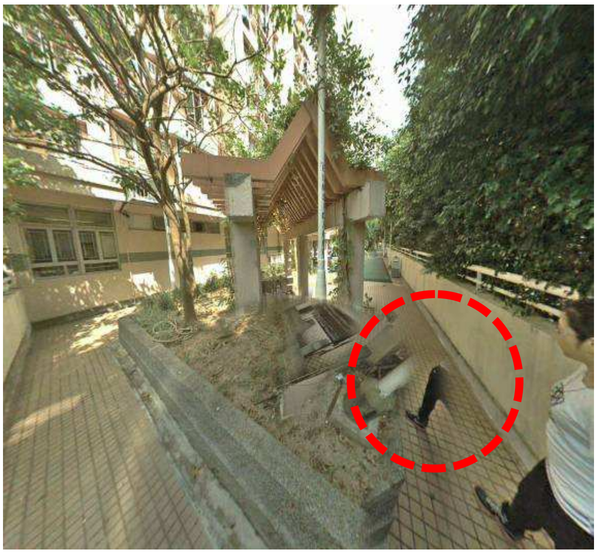


Figure 11 Image of Dynamic Moving Object

4.2.3 Limitation of Image Compensation

During the shooting of video, a dead hole is created at the bottom of the 360^0 camera. Normally, the image of the dead hole is replaced by automatic projection technology using the clear images taken from another camera position along the route during the image post-processing procedures. However, the automatic projection technology cannot overcome the problem where spatial features are clustered too close to each other thus creating a distorted image. (Figure 12)

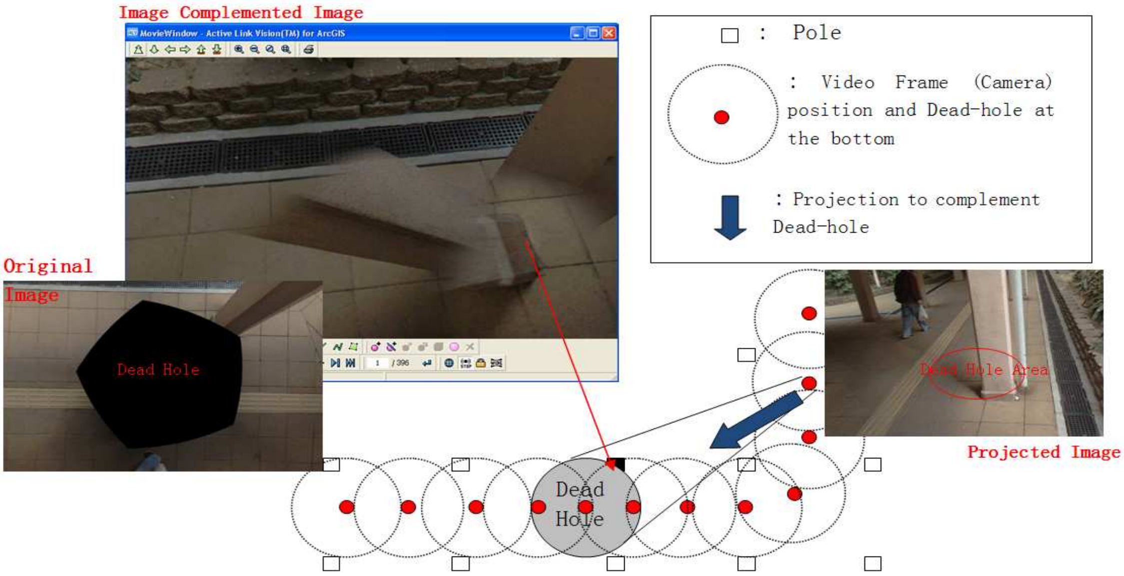


Figure 12 Automatic Projection Technology

4.3 Measurement of Trees

Owing to the site contraints that some video shooting paths were close to the trunk of the trees, the top most level and crown spread of the trees could not be seen and measured. (Figure 13)

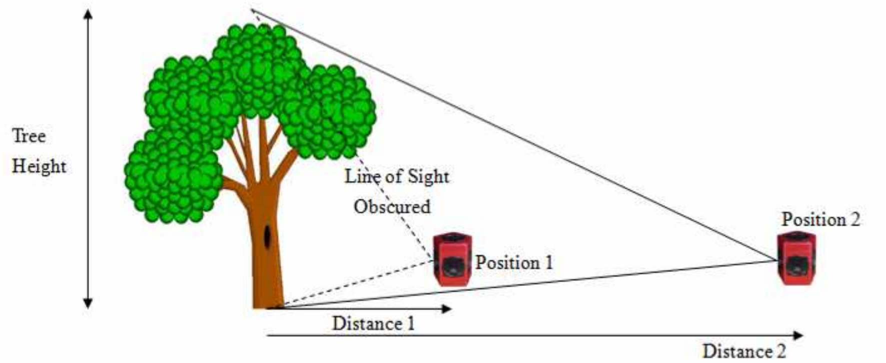


Figure 13 Effect of Camera Position on Measurement of Tree

5. THE RESULTS OF THE PILOT STUDY

5.1 Fo Tan Cottage Area

In the Fo Tan Cottage Area Project, a total of 5,484m of shooting routes of which 4,684m by vehicle-based and 800m by roving-person-based were surveyed. The digital terrain model and the associated texture of 1 hectare had been created (edged yellow area in Table 4) from the Geo-referenced Image. The model includes detailed building blocks, road signs, street furniture, trees and fences etc. The model was then integrated with the design model from BIM and the lower resolution 3D Spatial Data from the local mapping authority. (Figure 17)

3D Items Created	Count
Buildings / Structures	26
Trees	48
Road Furniture	136
Fence (Length)	1,912m
Terrain (Area)	1 hectare

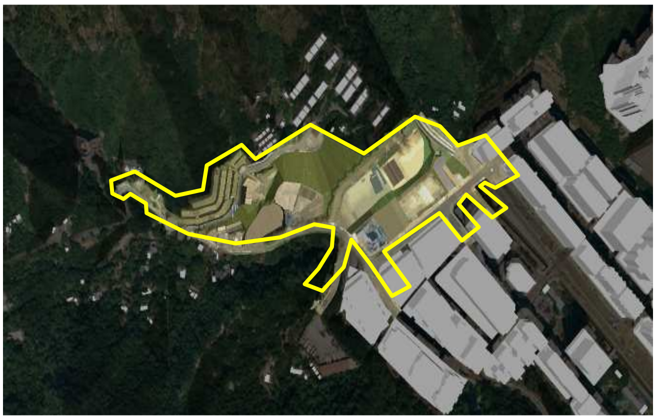


Table 4 Statistic of models created

5.2 Lei Muk Shue Estate

In Lei Muk Shue Estate, a total of 6,700m of shooting routes of which 2,314m by vehicle-based 4,166m by scooter-based and 220m by roving-person-based were surveyed. 830 numbers of tree were digitized from the Geo-referenced Images. Essential attributes of there trees were surveyed and updated to the standard tree database of the Departmental GIS. (Figure 14)

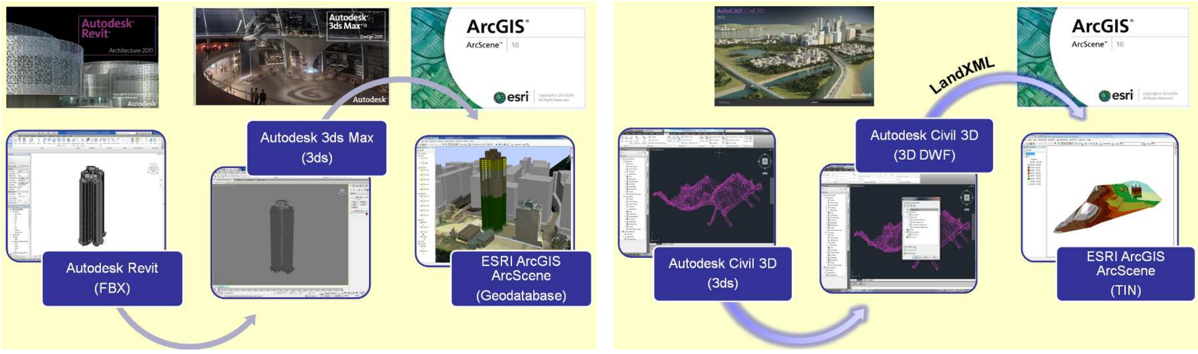
LMS Tree

FID	Shape *	TREE_NO	OVERALL_HT	GIRTH_1000	GIRTH_1300	AVG_SPREAD	X_COORD	Y_COORD	Z_COORD
0	Point ZM	1	3	0.22	0.22	2	832024.234	826736.769	76.36
1	Point ZM	2	10	0.79	0.79	5	832024.398	826737.747	76.367
2	Point ZM	3	10	0.79	0.79	5	832024.294	826740.593	76.368
3	Point ZM	4	10	0.94	0.94	5	832024.213	826743.488	76.365
4	Point ZM	5	10	0.79	0.79	5	832106.056	826759.749	76.177
5	Point ZM	6	10	0.79	0.79	5	832110.19	826758.979	76.193
6	Point ZM	7	10	0.79	0.79	6	832114.494	826758.078	76.224
7	Point ZM	8	9	0.63	0.63	5	832117.907	826757.338	76.224
8	Point ZM	9	9	0.63	0.63	5	832121.42	826756.507	76.232

Figure 14 Attributes Table of Trees in Lei Muk Shue Estate

5.3 Workflow of Model Integration

The coordinate systems of the Geo-referenced Images from MMS, 3D Models from BIM and the local mapping authority are all in the common framework of Hong Kong 1980 Grid (horizontal) and Hong Kong Principal Datum (vertical). No additional effort is required for the coordinate transformations. Additional software is required for data conversion from the native formats of respective sources of data to ArcGIS 3D Analyst. (Figures 15, 16, 17)



a) Import Building Model from BIM to GIS *b)* Import MMS 3D Geo-referenced Models from 3ds to GIS (Terrain)

Figure 15 Additional software is required for data conversion from the native formats of respective sources of data to ArcGIS 3D Analyst

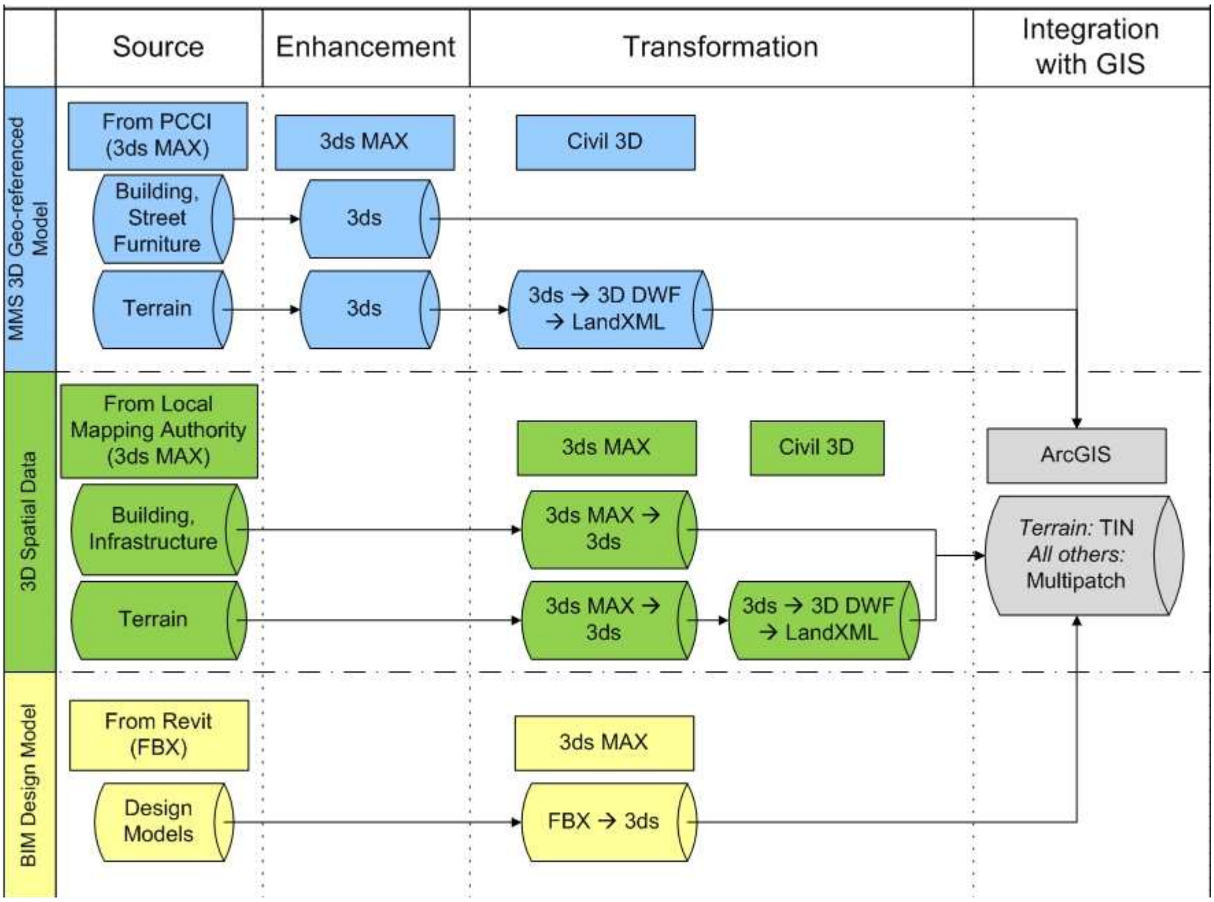


Figure 16 Workflow of Model Integration

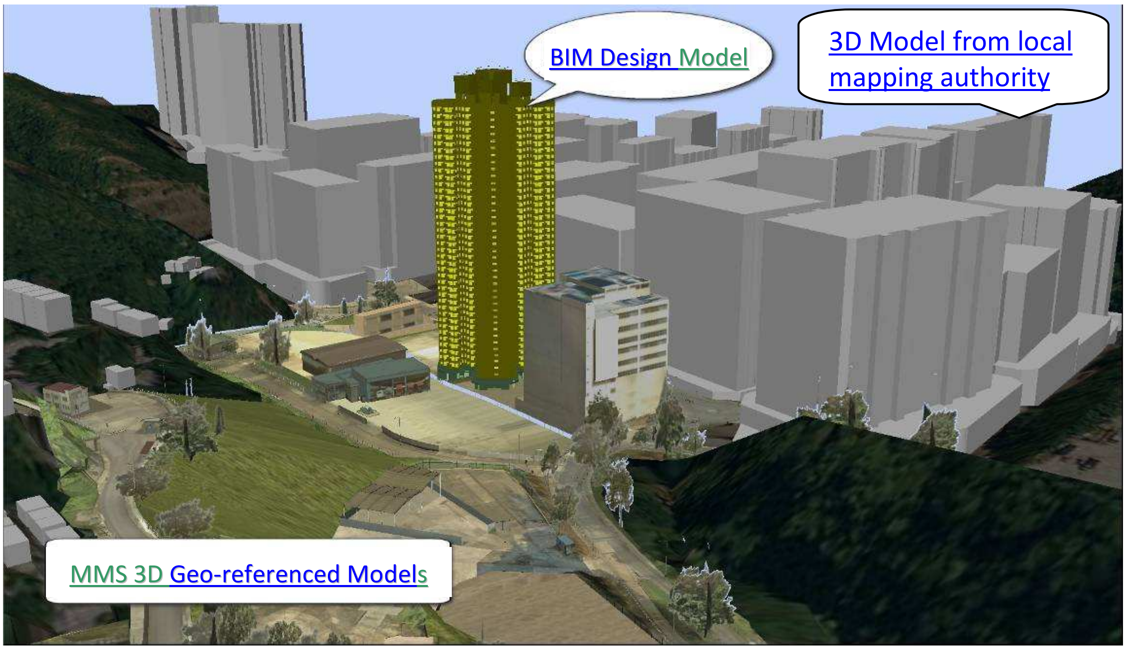


Figure 17 Integration of 3D models from different sources in GIS environment

6. RESULT ANALYSIS

6.1 Image Quality

The overall image quality of the 3D Geo-referenced Images is good in colour balancing. When comparing the quality of the image of building and terrain abstracted from the MMS with that of the 3D Spatial Data from the local mapping authority, (Figures 18 & 19) it can be seen that the resolution of the former is much higher that the latter.

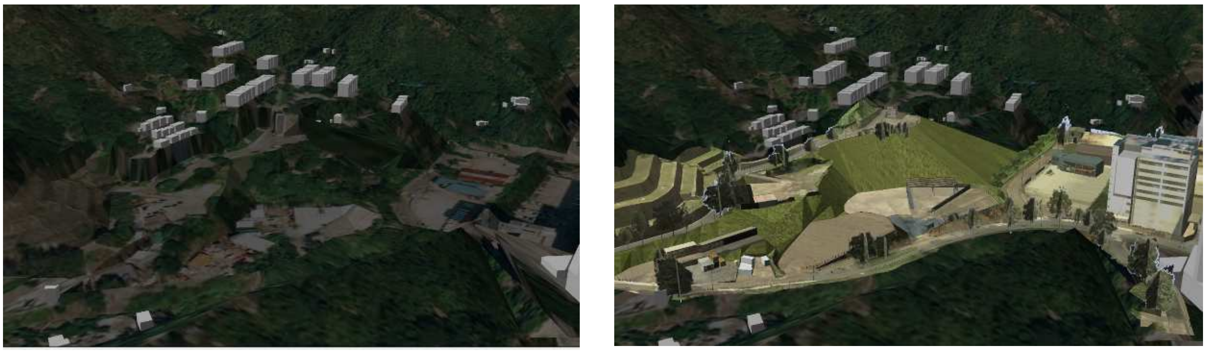


Figure 18 Comparison of terrain model between local mapping authority (*left*) and MMS *(right)*

Figure 19 Comparison of building model between local mapping *(left)* and MMS *(right)*

6.2 Survey Accuracy

The coordinates of the measured points from the model are compared against those features surveyed by conventional field survey. The summary is shown in Table 5. This shows that the horizontal and vertical accuracy of measurements from MMS meet the specifications.

Summary	Horizontal Accuracy (m)		Vertical Accuracy (m)	
	Tree	Checkpoint	Tree	Checkpoint
Number of points	477	97	43	105
Maximum Diff.	0.40	0.15	0.50	0.46
Average of Squared Diff.	0.05	0.02	0.03	0.01
RMSE	0.23	0.14	0.18	0.09

Table 5 Summary of horizontal and vertical accuracy

6.3 Effectiveness of using Scooter-based and Roving Person-based in the MMS Survey

A scooter-based approach to capture images is more preferable under typical site conditions of existing housing estate with narrow estate roads and footpaths because of its high maneuverability along winding and narrow passages and causing less obstruction and danger to pedestrians. Another advantage of scooter-based over roving-person-based is that it can maintain a constant speed for video shooting so that the scale can stay constant from frame to frame. Where the terrain and slope areas are difficult for access by both vehicle and scooter, the roving-person-based approach becomes the only choice yet acceptable to cover these difficult areas.

7. PROS & CONS OF MMS

7.1 The advantages of MMS are summarised as follows:

a. The image model produced by MMS offers a rich 3D pictorial view of the surroundings along the shooting routes thereby giving a greater visual experience by viewing from various perspectives.

b. MMS can collect a lot more ground features faster than by conventional ground survey methods and with little chance of missing or misidentification of features.

c. The comprehensive ground features appearing on the 3D Geo-referenced Images can be viewed, measured and retrieved by different users in the office for different purposes, such as facility management, progress monitoring during construction, and feasibility study for potential sites, etc

d. The products produced can be integrated with other spatial information thereby increasing the usefulness of the imagery and helps to enrich the spatial information from different sources, and serves as a powerful supplement towards building a comprehensive spatial database for the whole territory.

e. MMS offers a safer environment for surveyors by avoiding having to access to the difficult or dangerous terrain and causing less obstruction or inconvenience to the general public.

7.2 Limitations of MMS:

a. Survey accuracy is only up to 0.3m which may not be adequate for more precise work.
b. Accuracy would be degraded if camera-to-object distance is approaching and beyond 30m.
c. It is unable to capture blocked objects and some supplementary survey may be required.
d. Visible features at the rear of the image may not be measurable.
e. Operation is affected by daylight and weather as well as strength of GPS signal though not to a great extent
f. As a result of the image problems mentioned above, i.e. image exposure, dynamic moving objects, limitation of image compensation, a lot of re-shooting had to be done and a better planning of shooting route is required.

8. CONCLUSION

As more new housing estates are in the pipeline and the number of estates is escalating, more efficient ways of planning, design, construction and maintenance of PRH estates have to be explored and exploited by HD. It is generally recognised that up-to-date and comprehensive spatial information plays a vital role in many stages of the work of HD. The Land Surveying Unit of HD has been endeavouring to identify state-of-the-art of surveying, mapping and GIS technology to support the various work of housing development.

The MMS appears to be a potential technology for application in housing development, therefore a pilot study of its technical capability and functionality was embarked in 2011. The whole field process was monitored closely, from the assembly of parts, operation of the camera, image taking, to placing the ground control points, with a view to understanding the system-environment relationship. Back in the office the Service Provider explained the various post processing stages, including controlling the model and creating the model and surface. Various checks were applied to verify the accuracy achieved. Finally, demonstration was made on how to integrate with the other 3D spatial databases.

In this paper, the MMS survey is evaluated as a technology, which provides not only 3D Geo-referenced Images, but also 3D Geo-referenced Models by using 360^o digital video camera and operable on several mobile platforms. The workflow can be drawn up to cover the MMS setup in the different mobile platforms and the checking procedures to determine the accuracy of mapping features in 3D Geo-referenced Images. There is indication that a combination of 3D Geo-referenced Models from MMS. the design building model from BIM, and 3D Spatial Data from the local mapping authority can supplement each other to build a rich and coherent pool of 3D spatial information for public housing estates development.

Utilisation of MMS data in 3D Geo-referenced Images and in the 3D Geo-referenced Models have been demonstrated to the GIS and 3D spatial data users who expressed immense interest. The 3D Geo-referenced Models for the potential housing estate provides the users with a higher resolution of 3D spatial information. The insertion of 3D computer graphics into the 3D Geo-referenced Images gave a good overview of the integration of 3D Geo-referenced Images with GIS database.

9. WAY FORWARD

9.1 Web-based Solution to Disseminate 3D Geo-referenced Images

At the time of writing the paper, the Service Provider started the development of web-based solution to disseminate the 3D Geo-reference Images. As the technology is evolving, further study on the technical requirements is needed. Some issues on the support of the enterprise web services architecture system, database management system, and the Information Technology Security need to be addressed when the web-based solution is going to be implemented in the Department's GIS.

9.2 Inclusion of Inertial Measurement Unit (IMU) to MMS

The MMS discussed in this paper had not utilised IMU. It is proposed to study the inclusion of IMU to maintain the quality of positioning when GPS signal is weak during the video shootings. Hopefully, it can reduce ground control points in order to improve the cost-effectiveness of the MMS.

9.3 Potential Applications of MMS

Survey of trees, terrain, buildings, street furniture is the starting point for the application of MMS in HD. Further applications can be explored in accident investigations, facilities management and as-built survey records.

9.4 Supplementary 3D Spatial Information

MMS has the limitation for not being able to survey the roof-top structures. It is recommended to explore the usage of Unmanned Airborne Vehicle System to supplement the left out information in order to form a complete terrain, building and infrastructure models.

- End -

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