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3D LoD2 modelling of Halong City based on UAV point cloud

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ABSTRACT

3D urban building models are crucial for linking, converging, and integrating economic and social urban data. They are extensively utilized in numerous domains such as smart city development, comprehensive social management, and emergency decision-making. Advanced technologies like affordable UAV (Unmanned Aerial Systems) imagery enable a greater level of automation in data acquisition compared to traditional digital photogrammetry methods. The main objective of this research is to build a 3D LoD2 CityGML model with dense point clouds from UAV images. This study presents a completed workflow for generating 3D CityGML models of the city at LoD2 using UAV data. The use of dense point cloud data from UAV technology in the experimental area has been performed using a DJI Phantom 4 Pro. The original point clouds should be denoised using the statistical outlier remover (SOR), the main goal is to reduce noise while preserving the building's geometry. After that, the point clouds of object features were vectored for the level of detail 2 (LoD2) of the object's 3D volume corresponding to its actual height, and objects belonging to the Feature Class 3D layer will represent LoD2 on SketchUp Pro 2021 software to generate a highly accurate 3D model. The evaluation results show that the square errors calculated from the test points for the three axes X, Y, Z are 1.4 cm, 1.6 cm, 1.7 cm, respectively. Conducting research to choose the UAV photography method aims to offer an efficient and cost-effective solution, saving time and human resources, to address the 3D mapping challenges in urban areas across Vietnam.

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1. Introduction

3D city models have become an important tool in many applications across different fields. Typically, these 3D city models only depict the city's geometric attributes, facilitating easy city visualization. Current standard building 3D modelling techniques, such as 2D vector extrusion, point cloud processing, and tilt photogrammetry, utilize various data sources and modelling methods to achieve model results with varying levels of detail (Zhao et al., 2023). The Level of Detail (LoD) concept is commonly employed to assess the detail level in a building's 3D model (Biljecki et al., 2014). The LoD concept of CityGML 2.0, the most widely used OGC standard, distinguishes between five different levels of coherent detail from LoD-0 to LoD-4, and as the level of detail increases the model contains more detailed information about geometry and semantics (Biljecki et al., 2016).

Advancements in UAV sensors and platforms over recent decades have led to a significant increase in their use for 3D mapping (Arnadi et al., 2020). The declining cost of UAV platforms and camera sensors, combined with their ability to cover extensive areas, has likely produced one of the most cost-effective solutions for mapping. Since UAVs are a low-cost alternative to traditional manned aerial photogrammetry, new applications have emerged in short- and close-range domains. A primary outcome of UAV photogrammetry is a point cloud representing the mapped terrain, generated through dense image matching. While this point cloud is similar to lidar's main product, it typically exhibits greater altitude errors due to photogrammetry's inherently low base-to-height ratio.

Creating a 3D city model requires tools and expertise for extracting individual buildings from the collected data (Dušan et al., 2020). From the collected UAV data, a digital surface model (DSM) can be generated that contains information about buildings. However, these models aggregate all data together, lacking the ability to distinguish between individual buildings or separate terrain from structures. To create a 3D city model, buildings must first be identified and extracted from the terrain. Once this step is completed, geometric values such as volume or roof surface area can be calculated for each building from the model (Dorninger & Pfeifer 2008; Haala & Brenner 1997).

Users often encounter issues of data heterogeneity in 3D city models due to differences in data sources, acquisition times, methods, and required levels of detail. CityGML was developed to address these challenges (Gröger et al., 2012). CityGML is a standard that was established in 2008 by the Open Geospatial Consortium (OGC). It is a leading international standard that covers the geometric, semantic, and visual dimensions of 3D city models (Chhatkuli et al., 2015). CityGML defines several classes, including buildings, which can be represented in different Levels of Detail (LoDs). Among these, LoD2 is especially significant because it includes roofs in the model, which is essential for various applications, such as assessing the solar potential of rooftops (Biljecki et al., 2019).

In Vietnam, the construction of 3D urban spatial models using UAV technology has also become widespread. However, these studies are often discrete with small research scales, and their main objective is to build digital terrain surface models. The development of detailed 3D spatial models at the LoD2 level for a diverse urban area with various types of urban land cover is still very limited (La, 2018; Bui, 2021).

This paper aimed to introduce a workflow from UAV photogrammetry point cloud to the generation of 3D LoD2 modelling of Halong City using dense point clouds from low-cost UAV of which a further extension would be its conversion into a CityGML-compatible 3D building model. The proposal is designed to create 3D models that adhere to LoD2 as specified by the CityGML standard. UAV photogrammetry is chosen for this study to offer a cost-effective solution to the national mapping issue.

2. Methodology

2.1. Data acquisition

The main object of this research is to study and apply a low-cost technique for 3D modelling and visualization of a 1 km^2 area in LoD2 using the CityGML standard. The UAS data acquisition has been performed using a DJI Phantom 4 Pro (Figure 1) and Table 1. In order to acquire a complete coverage of the area of interest, thirteen flights have been planned and then executed. The total acquired number of images was 2058 images (Table 2).

To meet 3D mapping requirements, the UAV photography mission should be performed with the flights with the perpendicular flight range (Nadir) and some flights with the linear range (Linear)/Grid) with an oblique angle. Besides, to achieve the requirement of 1:500 topographic mapping accuracy, the important parameters of the designed flight range include:

- Flight height: h = 125 m;
- Vertical and horizontal coverage: 80%;
- Shooting angle: -90 degrees; and -45 degrees;
- Flight mode: Fast mode.

The results of designing the flight on Pix4D Capture software are as follows (Figure 2).

2.2. Methodology workflow

The workflow for creating 3D LoD2 CityGML models from point clouds derived from UAV imagery is illustrated in Figure 3.

3. Results and discussion

3.1. Study area

The study area is the Hung Thang area of Ha Long City, Quang Ninh Province (see Figure 4), Vietnam. The area is surveyed by unmanned aerial vehicle (UAV) about 1.17 km^2 covered by buildings, urban trees, water surface, etc. This is an area with a part built under the new urban structure in the Southeast and a part under construction in the Southwest with adjacent villas and a new high hotel on the beach.

3.2. UAV images and extraction of dense point clouds

Figure 1. DJI Phantom 4 Pro V2.0.

Figure 2. The results of designing the flight on Pix4D Capture software.

Table 1. Specification of DJI Phantom 4 Pro V2.0.

No	Parameters	Specifications details
1	Weight (Battery & Propellers Included)	1375 g.
2	Max Speed	- S-mode: 45 mph (72 kph); - A-mode: 36 mph (58 kph); - P-mode: 31 mph (50 kph).
3	Max Flight Time.	Approx. 30 minutes
4	Satellite Positioning Systems.	GPS/GLONASS
5	Hover Accuracy Range.	* Vertical: ±0.1 m (with Vision Positioning). ±0.5 m (with GPS Positioning). * Horizontal: ±0.3 m (with Vision Positioning). ±1.5 m (with GPS Positioning).

Table 2. The results of UAV flight to establish 3D mapping.

Flight modes	Flight height (m)	Oblique camera configuration	Number of flights	Number of images
Grid/ Olique	125	- 45^0	07	1105
Linear/ Nadir	125÷140	-90^0	06	953

The raw photos captured from the UAV flights were downloaded and processed using Agisoft Metashape Professional 2019 software (Figure 5). The processing consists of several stages: initial processing for image alignment, geo-rectification with Ground Control Points (GCPs) using Pix4D's rayCloud editor to accurately position each GCP based on the original 2D images, point cloud and

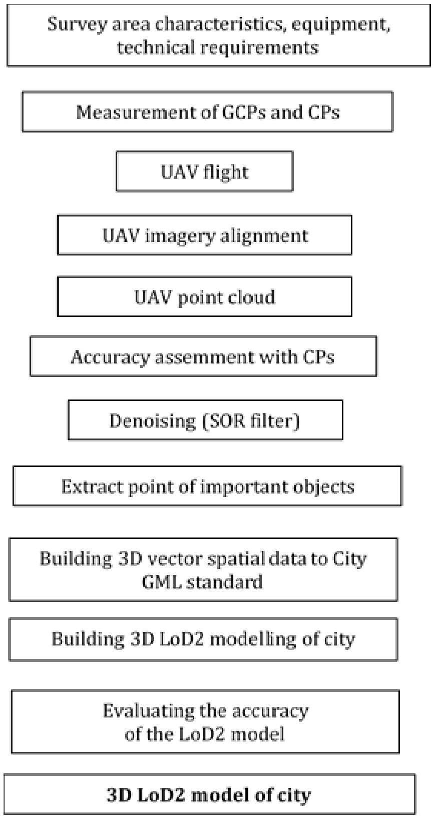

Figure 3. The workflow for creating 3D LoD2 CityGML models from point clouds derived from UAV imagery.

Figure 4. The study site.

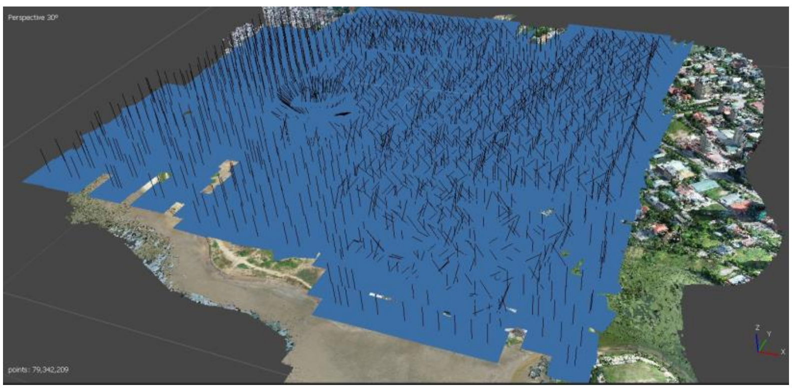

Figure 5. Experimental result from Hung Thang area, Halong city.

Figure 6. Orthophoto image of the Hung Thang area, Halong city.

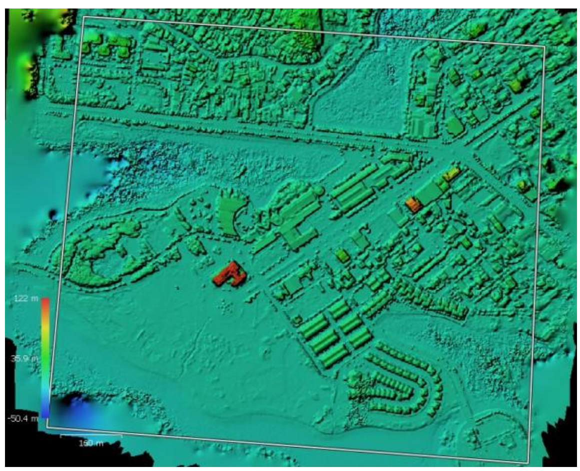

Figure 7. Digital Surface Model (DSM) from UAV.

mesh processing, and the creation of the orthophoto image (Figure 6) and Digital Surface Model (Figure 7).

After the processing was completed, the orthophoto that was generated was imported into ArcMap software, where four main urban land cover features (buildings, water bodies, traffic infrastructure, and vegetation) were vectorised on the orthophoto and displayed in the form of a map.

3.3. UAVs point clouds accuracy evaluation

The validation dataset was based on the static post processed-GNSS derived coordinates of the CPs. Table 3 presents the RMS results of the GCPs following triangulation during the initial processing stage. According to the ASPRS accuracy standards for digital geospatial data (ASPRS, 2014), the accuracy standards for aerial triangulation errors can be up to three times the ground sampling distance (GSD) of the images. The 11 CPs show quite good residuals in XYZ the highest being 13.7 cm in X, 5.9 cm in Y and 5.2 cm in H.

In summary, the achieved horizontal and vertical accuracies are 6.5 cm and 0.9 cm, respectively, after applying the second condition without assuming normality. This indicates a high level of accuracy in both horizontal and vertical positions on the orthophoto. Such accuracy is well-suited for 3D mapping and other applications, including earth volume determination in engineering projects and monitoring and managing incidents.

Table 3. Summary of errors in the 3D coordinates.

CPs	Error X (cm)	Error Y (cm)	Mp (cm)	Error H (cm)
K02	13.7	2.9	14.0	1.6
K05	3.3	1.3	3.6	0.7
KB3	0.4	0.9	1.0	3.7
K17	-0.7	-0.5	0.8	2.5
K4	0.7	-0.1	0.7	1.3
BS9	3.6	-3.6	5.1	2.1
TD1	-0.4	-5.9	5.9	-1.2
TD3	7.1	0.5	7.2	-5.2
TD4	9.2	0.6	9.2	3.3
TD6	-4.1	-1.3	4.3	-2.2
TD16	3.5	-5.1	6.2	3.1
RMSE	5.9	2.8	6.5	0.9

3.4. Denoising point clouds (SOR filter)

The original point clouds should be denoised using a proper filter. In our study, the statistical outlier remover filter has been used. The SOR filter computes the average distance between each point and its neighbours using a specified number (N) of neighbouring points. Then, the filter removes the points whose distances are greater than the average distance plus a multiplier of standard deviation. The mathematical expression of the SOR filter can be written as follows:

$$D_{max} = D_{mean} + N \text{ x } STD \qquad (1)$$

Where: Dmax - the maximum distance (mm); Dmean - the average distance between the point and its neighbours (mm); STD - the standard deviation (mm); N - the standard deviation multiplier (Abdelazeem et al., 2021).

The number of neighbouring points should be chosen according to the quantity and density of the original point cloud dataset. The standard deviation multiplier parameter depends on the desired confidence interval level. In our study, various values for the number of neighbouring points and confidence intervals were tested. The main goal is to reduce noise while preserving the building's geometry.

In this study, the statistical outlier removal (SOR) filter, one of the most commonly used methods was employed (Abdelazeem et al., 2021). This method includes the following steps: (1) Users specify the number of neighbours for each point, and these neighbours are identified using the k-nearest neighbour algorithm; (2) The average distance between each point and its nearest neighbours is calculated. (3) Calculate the average distance of all points in the point cloud and then determine the standard deviation of this average distance. (4) Outliers are identified if their distance exceeds the average distance from step 3 plus n times the standard deviation, where n is specified by the user.

3.5. Building 3D vector graphics data

For this study, the point clouds of object features were vectored for the level of detail 2

(LoD2) of the object's 3D volume corresponding to its actual height. Here, objects belonging to the Feature Class 3D layer will represent LoD2 on SketchUp Pro 2021 software.

In addition, a model with LoD2 with photos taken from the field will represent images of the surrounding faces of the object by capturing the faces of the actual object and pasting them onto the faces of the 3D model. This model was built using the ground photo-pasting tools in SketchUp Pro 2021 software. The principle of photo pasting is based on the feature points on the surface to be pasted (house corner, window corner) found on the vector graphic model and on photos of the ground surrounding the objects to adjust the surface of the object.

3.6. Building 3D LoD2 models of city

Since the outcome of this study is 3D models of structures, it is crucial to establish the LoD for these models. Subsequently, point cloud feature extraction is carried out to ensure the desired LoD (Figure 8÷11). 3D city models at LoD2 (Level of Detail 2) or higher incorporate roof geometries, which are useful for 3D GIS applications such as estimating solar potential, evaluating and verifying existing data quality, reconstructing roofs, and enriching LoD0/LoD1 data with roof type attributes (Biljecki et al., 2019). CityGML defines LoD2 as containing basic roof shape and orientation. In other words, a building in LoD2 has differentiated roof structures and thematically differentiated boundary surfaces (Gröger et al., 2012).

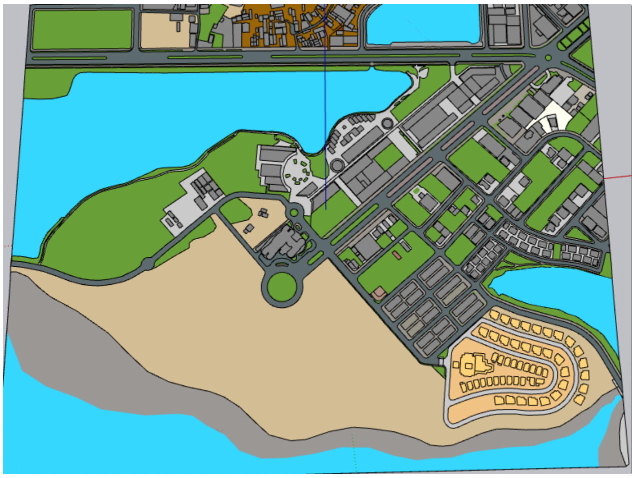

Figure 8. Result of original footprint map in SketchUp (LoD0).

Figure 9. 3D LoD1 modeling of the Hung Thang area, Halong city.

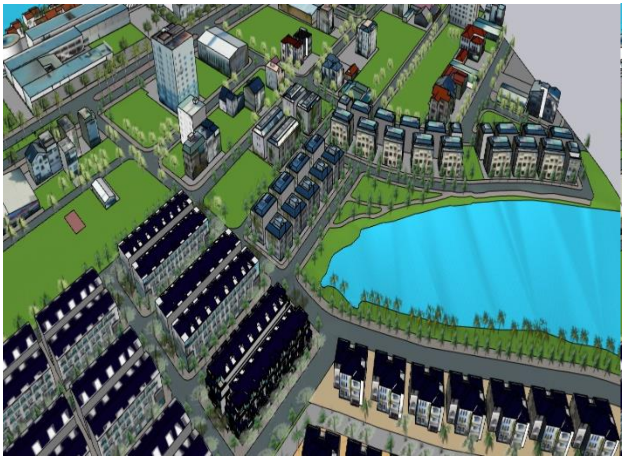

Figure 10. 3D LoD2 modeling of the Hung Thang area, Halong city.

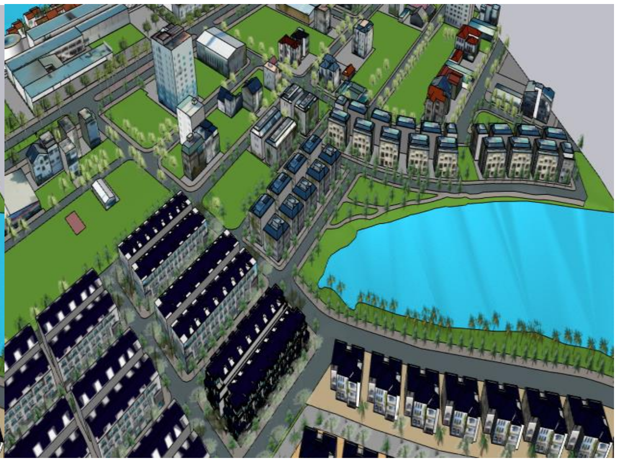

Figure 11. 3D of adjacent villas in LoD2 of the Hung Thang area, Halong city.

The LoD2 model generates representative roof shapes by examining the planarity and orientation of the point clouds.

3.7. Evaluating the accuracy of the LoD2 model

The evaluation results in Table 4 show that the square errors calculated from the test points for the three axes X, Y, Z are 1.4 cm, 1.6 cm, 1.7 cm, respectively (Table 4). This confirms the tolerances required by the regulations to carry out the next steps in the process of building 3D geospatial data.

4. Conclusions

This paper aimed to evaluate the current process of building 3D LoD2 of city from UAV data and exporting these models in the CityGML format. This study presents a completed workflow for generating 3D CityGML models of city at LoD2 using UAV data. The research on selecting the UAV photography method aims to provide an efficient and cost-effective solution that saves time and human resources, addressing the mapping challenges in urban areas throughout Vietnam.

To adhere to the OGC's CityGML 2.0 standard for LoD2 buildings, the modelling of building installations must be done within the CityGML framework. The study's test results indicate that automating this process remains a considerable obstacle.

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Contributions of authors

Ha Thu Thi Le, Long Huu Nguyen - methodology, writing, supervision; Trung Van Nguyen, Hang Le Thi Nguyen, Lan Thi Phan, Cam Dinh Pham, Ha Duy Nguyen, Hai Thanh Tran, and Tai Thanh Nguyen - methodology, review & editing; Nghia Viet Nguyen, Dai Trong Do, Tuan Thanh Dinh - methodology, review & editing; Hang Le Thi Nguyen - writing, and review & editing.

Table 4. Results of LoD2 data accuracy assessment.

Order	Checked point	Points taken from LoD2 model			Points taken from total station measurement			Comparison of two methods		
		X (m)	Y (m)	Z(m)	X (m)	Y (m)	Z(m)	ΔX (cm)	ΔY (cm)	ΔZ (cm)
1	206	2317860.907	423488.709	15.231	2317860.507	423489.309	14.731	0.4	-0.6	0.5
2	208	2317874.369	423509.929	15.936	2317876.869	423513.229	14.736	-2.5	-3.3	1.2
3	209	2317854.096	423478.560	6.682	2317852.196	423477.960	6.882	1.9	0.6	-0.2
4	216	2317876.050	423509.368	11.268	2317874.850	423511.068	7.468	1.2	-1.7	3.8
5	224	2317876.282	423456.367	12.857	2317874.482	423456.767	11.557	1.8	-0.4	1.3
6	228	2317867.293	423461.408	7.344	2317865.493	423460.308	6.044	1.8	1.1	1.3
7	244	2317877.199	423462.313	8.805	2317877.099	423460.913	6.905	0.1	1.4	1.9
8	246	2317885.009	423470.343	17.139	2317884.709	423472.743	14.739	0.3	-2.4	2.4
9	265	2317890.242	423515.297	9.391	2317890.042	423513.297	10.291	0.2	2.0	-0.9
10	269	2317901.673	423504.768	6.292	2317902.573	423505.668	7.792	-0.9	-0.9	-1.5
11	273	2317897.669	423491.230	7.443	2317897.369	423490.530	7.543	0.3	0.7	-0.1
12	275	2317893.952	423485.024	16.693	2317891.352	423483.324	18.793	2.6	1.7	-2.1
Root mean square errors								1.4	1.6	1.7

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