Heritage Science

RESEARCH

Open Access

Level of detail (LoD) geometric analysis of relief mapping employing 3D modeling via UAV images in cultural heritage studies

Bahadir Ergun[1], Cumhur Sahin[1] and Furkan Bilucan[1*]

Abstract

Unmanned Aerial Vehicles (UAVs) are often preferred for modeling cultural heritage buildings due to their costs and time savings. The need for data collection, analysis, processing, and visual presentation in the context of cultural heritage buildings has become prominent, underscoring the significance of the concept of Level of Detail (LoD). The utilization of CityGML LoD standards enhances the performance of visual presentations, decreases the geometric complexity of objects, and enables users to view the model at the desired level of detail within a computerized environment. Within the scope of this study, it is aimed to determine the accuracy analysis of the 3D model for a cultural building, which is named Hekimbaşı Hunting Lodge, at different LoDs. Drawings were created at LoD 0-1-2-3 levels with 418 photographs taken by the UAV photogrammetry method. Additionally, conservative and UAV measures of facade detail at the same LoD were compared in terms of accuracy. As a result, RMSE values for X, Y, and Z axes at LoD3 standard were calculated as 1.394 cm, 0.861 cm, and 0.694 cm, respectively. It has been concluded that the high-accuracy LoD models for the cultural building could be produced using the UAV photogrammetry method at the desired accuracy.

Keywords UAV, Cultural heritage building, 3D modeling, LoD, Accuracy analysis

Introduction

Cultural heritage buildings embody the history of nations, playing a crucial role in shaping a nation's identity. Preserving these structures holds immense significance for both current and future generations. These buildings carry their own historical narratives, maintaining their relevance across ages. Typically, these are buildings that fulfilled an important religious and cultural role in society, such as churches, castles, and palaces [1]. Therefore, protection of cultural heritage buildings means the protection of the history and identity of the nations. Identification of the current status of cultural heritage buildings is important for documentation, preservation, and restoration. The topic of the documentation and conservation of cultural heritages is well-established in contemporary societies [2]. Given its role as a driving force for socio-economic development, many studies related to the protection, restoration, and dissemination of cultural heritage are being conducted. Employing three-dimensional (3D) modeling for cultural heritage buildings proves to be a potent instrument in their identification, monitoring, preservation, and restoration [3]. Digitization is the first stage in the documentation and protection of cultural buildings. In addition, digital spatial data facilitates the planning and execution of protection and restoration works [4].

3D modeling is the process of using software to create a mathematical representation of a 3D object or shape [5]. Among the essential tasks within the policy of cultural heritage protection and management, the geometric

*Correspondence:
Furkan Bilucan
f.bilucan2020@gtu.edu.tr
[1] Department of Geomatics Engineering, Gebze Technical University, 41400 Kocaeli, Turkey

documentation of buildings holds utmost significance. 3D documentation is considered a prerequisite for the protection, understanding, transmission, and appreciation of cultural heritage sites and objects before any conservation and restoration work. Therefore, 3D models have become the usual way to protect, transmit, explain, and disseminate cultural information digitally [6]. The cultural building is usually digitized with photogrammetry-based imaging sensors or laser scanning techniques. The adoption of image-based methods to document heritage sites has accelerated in recent years with the advancements in optical sensors as well as computing technology [7].

Photogrammetry is a science that aims to accurately determine the shape, dimensions, and position of any object in space by using images. In classic aerial photogrammetry, photographs are captured from an aircraft at a specific altitude. Unmanned Aerial Vehicle (UAV) photogrammetry is the production of photogrammetric data from photographs taken during UAV flights. The UAV platform was produced in the 1970s as an alternative to the various platforms that emerged in 1858 and were used to obtain photogrammetric data [8]. Unlike conventional manned aircraft and satellites, UAVs are frequently preferred due to their cost-effectiveness, operational flexibility, and better spatial and temporal resolution [9]. A UAV is a mobile mapping platform which is capable of taking an automatic/semi-automatic route according to the desired flight plan or that can be flown remotely by a pilot in the control center. UAVs are generally equipped with digital cameras and GPS/IMU systems, and LiDAR can also be included [10]. 3D point clouds and 3D models can be produced using UAV photogrammetry [11].

Thanks to the developments in software algorithms, UAV photogrammetry attracts attention as a competitive technology. It is a pioneer in new real-time applications for the production of 3D models of objects in studies such as the modeling of buildings and monuments, where aerial and terrestrial photogrammetry methods can be combined. Image-based UAV surveys and 3D modeling now deliver results with geometric properties comparable to LiDAR, an alternative method for many terrestrial and aerial applications, within a reasonable timeframe. Therefore, the market, once primarily dominated by airborne and terrestrial range sensors, presently offers more image-based UAV measurement tools for 3D recording and modeling [12]. Despite the advantages of UAVs such as cost and time savings, there are also physical and technological limitations. The flight plan should be carried out safely within the total flight time based on the UAV model and the number of batteries [13]. Time and distance must be considered for returning to the starting point for battery changes, as well as the safety margin as changes in weather conditions might affect the UAV's flight efficiency, such as changes in wind speed or direction [14]. To achieve heightened image resolution through UAV photography, the UAV must be operated at lower elevations from the ground surface or object in which the 3D model will be produced. However, lower altitudes result in a narrower image coverage area, necessitating more images to achieve the required image overlap.

The UAV aerial photogrammetry method provides an efficient solution for both little areas and large-scale surveys. Some of the cultural building modeling studies made with UAVs in the literature are as follows. The feasibility of the image-based 3D model creation method obtained from the UAV was evaluated for the registration and preservation of the Angukdong Byeolgung building, assumed to have been completed in 1880 in Korea [15]. Evaluating the relative positional accuracy of a 3D model involved comparing the distance values between distinguishable points in the model to those in a drawing. In [16], it was created 3D model of Otag-i Humayun (in Istanbul, Turkey), which was built in 1483, using an ultra-light drone (ULD) and a low-cost UAV. The produced 3D models were compared with terrestrial laser scanner data. The maximum standard deviations were calculated as 0.62 cm and 1.87 cm for low-cost UAV and ULD, respectively. The results indicated that ULDs could be used under suitable circumstances as a low-cost alternative for cultural heritage documentation. In [17], it was aimed to investigate historical building defects by using UAV to identify the type of defections that occurred at the exterior structure of a museum. The case study involved the building of Perak Museum (in Taiping, Malaysia). The produced 3D model illustrated in detail the severity of the defect in the building. In [18], the Auspicious Multi-Door Stupa at Palcho Monastery which was built from AD 1418 to 1436 in Tibet, was considered for the case study. The results suggest that the UAV-derived 3D model is accurate enough for most surveying purposes (RMSE = 2.05 cm; 1/2000 of the stupa's dimension). It is concluded that the accuracy and completeness of the produced 3D model using images taken by UAV are sufficient to create Historic Building Information Modeling (HBIM). Considering the low cost, portability, and completeness offered by UAV, this tool offers great promise for surveying Tibet's architectural heritage.

The importance of 3D building modeling has gained importance for many scientific disciplines and applications [19, 20]. Starting from computer-aided design (CAD), tools for building design and management have evolved over several decades. After 2009, the application of Building Information Modeling (BIM) to historical/cultural buildings has been called heritage building information modeling (HBIM) [21]. Using heritage building information modeling (H-BIM), heritage experts can perform complex spatial analyses, ask what-if questions, run simulations, and predict the results to inform the preservation and restoration projects [4]. Nowadays, BIM/HBIMs are becoming more and more similar to GIS models that contain all environmental and territorial information. This convergence underscores the overlap between the two methodologies, GIS and BIM [22]. Generally, in BIM, the Level of Detail (LoD) of the project must be represented, so as to determine the degree of certainty, precision, and richness of the information contained in the modeled element and to estimate the specific use for which this information is intended [21]. The LoD is one of the most important characteristics of 3D building models and it shows the connection of 3D models with the real world. This interrelation affects the applicability of the model. It is significant that the details of the building (i.e., window or door) can be expressed in the data model. The Level of Detail (LoD) concept created by CityGML allows the representation of various components of structures at different levels of detail, but it is usually modeled manually [19]. Research on highly precise and detailed 3D modeling is constantly being developed. LoD, which is a very important concept for 3D city models, can be defined as the degree to which objects in the real world are summarized or their priority is displayed at the optimum detail level [23]. Moreover, the highest LoD includes the most detailed features of the 3D-represented geometry [24]. The concept of LoD is one of the important terms used in GIS and 3D city modeling to describe the difficulty and complex structure of the representation of a geographic object in the real world. The LoD concept enables a model to be displayed faster in the computer environment by increasing the presentation performance of the visuals, decreasing the geometrically complex state structures of the objects, and reducing the load on the computer graphics [23].

Increasing the degree in LoD levels means that 3D geometry is enriched in terms of detail content. By generalization with the decrease of the LoD degree, geometric visuals with a lower level of detail are obtained. LoD facilitates the measurement of the reliability and security of building information modeling (BIM)-related information, from planning and construction to maintenance in the building process [25]. In the context of 3D modeling as defined by CityGML, the concept of LoD is categorized into five levels (Fig. 1):

- LoD0: It is generally used in regional and plane maps. It is a 2.5D digital terrain model.

Fig. 1 LoD levels [26]

- LoD1: It is a block model with flat roof structures.
- LoD2: It is a model where the boundary surfaces of the buildings and the roof structure can be distinguished thematically.
- LoD3: It is an architectural model that includes walls, roofs, and claws in detail.
- LoD4: It is the model formed by adding interior details to the model at the LoD3 level.

One of the most important data collection methods to produce a 3D cultural building model suitable for LoD levels is the use of UAVs. Extensive research exists within the literature on this subject. For instance, the objective of [27] is to evaluate the potential of UAV imagery as an information source for automatic 3D building modeling at LoD2. The developed algorithm aims to produce 3D models complying with LoD2 [28]. The LoD3 level model has the highest similarity with the point cloud data, whereas the similarities of LoD1 and LoD2 decrease in turn [29]. The use of LoD3 models has a wide range of applications where only outdoor information is required, from general ones such as city planning to more specific ones such as building envelope analysis or structural analysis of stone masonry buildings [30]. The LoD3 model has a high geometrical accuracy and semantic richness. Many studies have been carried out to increase the accuracy of LoD3 level. For example, [31] proposed an approach that successfully employed photogrammetric point clouds generated from UAV imagery data in 3D reconstruction of buildings and their footprints with the geometrical accuracy of LoD3. 3D roof and facade geometry, topology construction, facade elements semantic modeling were found to be related to LoD3 level [32]. In [18], different modeling methods based on UAV were employed depending on the required LoD, the geometry of the objects, and the expected degree of automation. The structural deformation of architectural heritage has been closely monitored. A digital representation of architecture and the surrounding environment was provided with different LoD options.

This study aims to analyze the geometric dimensions of the details at the LoD3 of the facade reliefs obtained from the produced 3D building model in detail using UAV photogrammetry. The accuracy analysis of the 3D model produced at different LoDs was performed for the historical building namely Hekimbaşı Hunting Lodge.

For this purpose, 418 photographs were taken using UAV. The rest of this paper is organized as follows: "Methods" Section presents a detailed description about the study area and the methodology of the procedures performed. "Results and discussion" Section evaluates and discusses the results in terms of accuracy. "Conclusion" Section concludes that cultural buildings can be 3D modeled at the LoD3 level with high accuracy using a low-cost UAV.

Methods

The study area is the Historical Hekimbaşı Hunting Lodge, which is located on the boundaries of Istanbul, Turkey. It is also known as the Historical Hekimbaşı Hunting Lodge, Sultan Abdülaziz's Hunting Lodge, and Yusuf İzzettin Mansion. It was commissioned by Küçük Hayrullah Efendi and was built in the nineteenth century by Architect Sarkis Balyan (www.umraniye.gov.tr).

The internal and external orientation stages of the UAV photogrammetry can be carried out with commercial software (i.e., Pix4D). These software correct the UAV images geometrically and ensure high accuracy in the orientation process. The main steps of the methodology adopted in the study are shown in Fig. 2.

As an application step, firstly, the Ground Control Points (GCP) and building 3D control points were established and measured before the flight. In UAV photogrammetry studies, it is a well-known fact that the most important variables affecting the accuracy are the number of control points and the distribution of these points [33]. The control points were homogeneously distributed in the study area so that the root mean square errors (RMSE) were calculated as small values. RMSE is one of the most widely used measuring methods for interpreting the quality of predictions. RMSE is the square root of the average of the squared differences between the coordinate values from the dataset and the coordinate values from a different source that has higher accuracy for identical points. In other words, it indicates how far the predictions are from the actual values measured using Euclidean distance (Eq. 1). Therefore, a small value of RMSE means that the estimated values are closer to the mean values of the target.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \widehat{y}_i\right)^2} \quad (1)$$

where n is the number of measured points, y_i and $\widehat{y}_i$ represent the measured point and its corresponding prediction at point i, respectively.

6 GCP and 18 control points on the building were established within the study area (Figs. 3 and 4). For GCP measurement, Viva GS 14 GPS and Geomax Zoom35 PRO total station without reflector were used. The coordinate measurements of 18 control points on building facades and detail points required for accuracy analysis were performed based on the GCPs. Within the scope of the study, the flight plans were created by transferring the workspace created on Google Earth to the DJI Pilot PE program. Before acquiring images with UAV, it was required to carefully flight plan to collect high-quality data considering the equipment, study site, and technical limitations. Parallel to this limitation, the photogrammetric flight strip was determined by the size and location of the cultural building. The transverse and longitudinal overlap ratio was determined as 80%, and the front overlap ratio was determined as 90%. Five different flights were conducted to acquire high-quality images to produce 3D models in detail. The initial flight was carried out to acquire roof images of the historic building. Other flights were conducted to acquire images of the south, west, north, and east facades of the building, respectively. Then, flights were executed successfully. Based on the selected area and features of the DJI pilot program, five distinct flight routes were automatically generated and the flights were completed as planned. DJI Mavic 2 Pro unmanned aerial vehicle was used to obtain aerial photographs. In addition, the flight was executed during overcast weather conditions and minimal wind to mitigate the impact of shadows. The photographs captured by the UAV, which were considered to be unnecessary, unclear, or beyond the program's automated guidance capabilities due to their indistinct nature, were excluded. This step was taken to ensure the process remained streamlined and to prevent any unnecessary burden that could potentially compromise accuracy. After these processes, a total of 418 aerial photographs were obtained. In practice, Pix4D was employed to evaluate the photogrammetric data and produce a 3D model and orthoimage in a computer environment. The final product created in Pix4D software has been imported into AutoCAD software. 2D survey drawings of the relief were obtained with AutoCAD software.

After the image acquisition process, a new project was opened in Pix4D software and 418 images were imported into the project and the coordinate system was selected as TUREF30. Then, the first step of the process was initiated by directing the aerial photographs and determining the instant coordinate and rotation values automatically by the program. Subsequently, the program automatically created connection points considering the relationships the photographs obtained. After this stage, the location and building control points, whose coordinates were obtained from the field with geodetic methods, were imported with the GCP/MTP manager. The positions of these points were marked on the photos and the "match" and "optimize" options were clicked again from

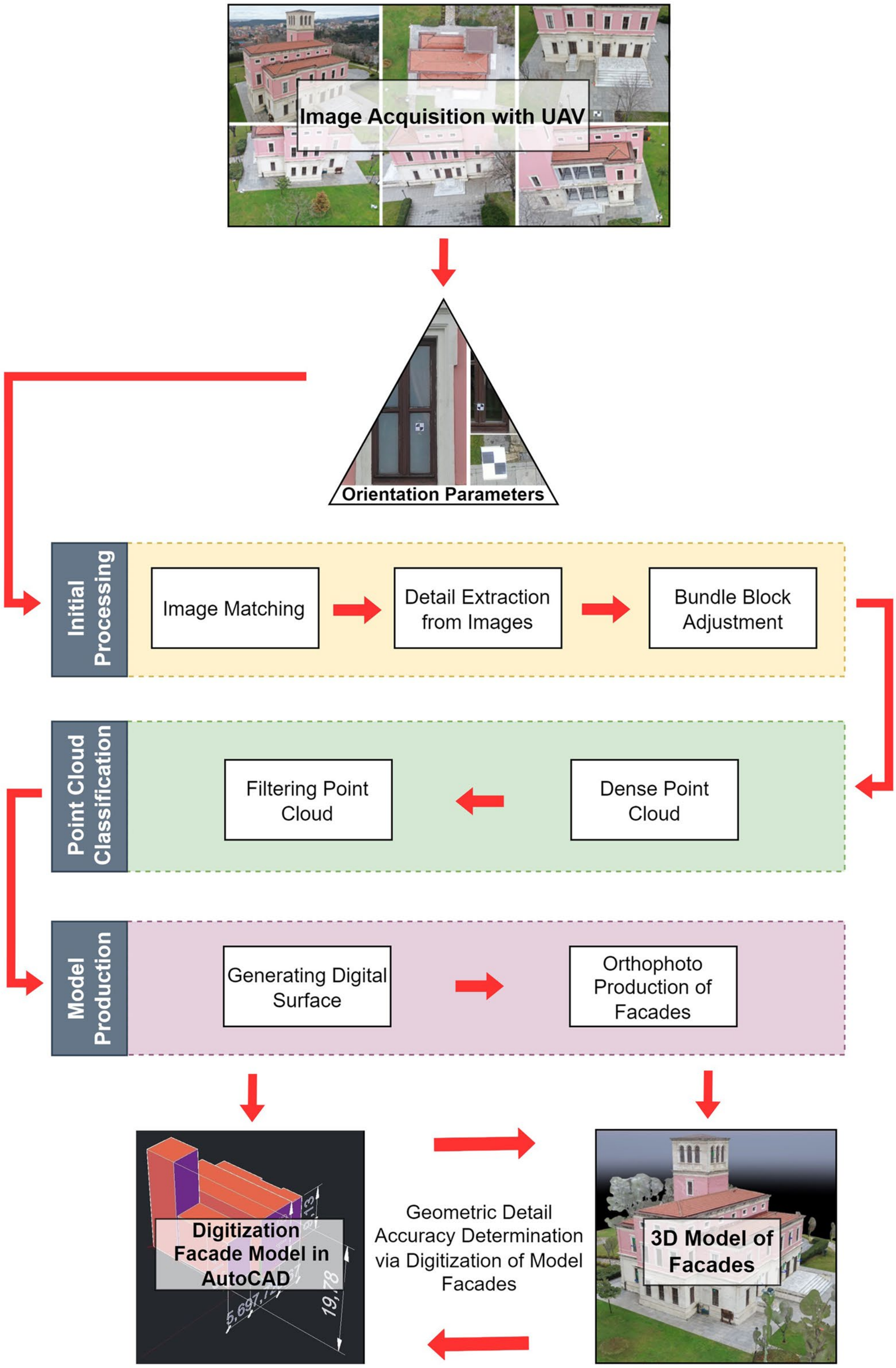

Fig. 2 Main steps of the methodology adopted in this study

Fig. 3 Study site and GCP locations

the process tab. In the first step of the application, 410 of 418 photographs were used, and all photographs were matched by marking and re-optimizing the control points on the photographs. Thus, photos were redirected using ground and building control points. After the process was completed, the quality report was reviewed and the suitability of the project for other steps was checked. With the quality report, it has been determined that the RMSE of the GCP was 0.006 m. Then, by starting the second step of the process, a point cloud and 3D mesh were produced. Arrangements were made by selecting the concentrated point cloud in the generated point cloud. In this application, noises occurred in the image due to the trees located close to the building and the transparent surfaces on the building. Noises in the point cloud and the points that were unnecessary to create mesh have been deleted in order to avoid a burden on the system. Hence, this approach not only reduced processing time but also eliminated unnecessary points. By running the point cloud classification, first, the point cloud classes were created by the program, and then the classes were arranged manually.

Point cloud classification can be defined as the process of selecting and grouping points with similar properties from the raw point cloud set according to the desired criteria. To extract relevant information from the point cloud, it is necessary to segment and classify the interested object inside the acquired scene [34]. After producing point clouds with photogrammetric techniques, their classification should be performed.

Fig. 4 Building control point locations

In the literature, a variety of methods for classification are present. These methods can be categorized into two main groups: classical approaches and novel methods like machine learning and deep learning [28]. The point cloud classification process of the software employed in this study is based on machine learning techniques. Also, both the geometry and the color information are used to assign the points of the densified point cloud in one of the predefined groups. Depending on the quality of the dataset there are areas where the classification is not expected to perform perfectly since manual intervention is a requirement. In the future, more training data is likely to be used to improve the algorithm and give more reliable classification results for different datasets [35]. After the point cloud classification process step, raster mesh model production, which operates with the principle of raster model production from the position and spectral values of the points with the triangulation logic between the point cloud points, has been started and 3D mesh production has been completed (Fig. 5).

To create models in all detail levels in line with the needs of different LoD levels in the application, drawings were made on the mesh and these drawings were imported to the AutoCAD environment and 3D drawings were provided manually. To create models at different LoD levels in the application, the resulting product of Pix4D was imported to the AutoCAD environment, and drawings were generated. The coordinates of the detail points, which were previously measured with the total station for control measurement, were also measured in the model imported into AutoCAD software. Accuracy checks were made with the RMSE value between the two coordinate differences.

Fig. 5 3D textured mesh model

Results and discussion

3D architectural studies based on the point cloud are characterized by very high accuracy, precision, and detail of information. This process is not dependent on software and modeling techniques [36]. This is particularly evident in modeling cultural heritage cases from geospatial data such as photogrammetric terrestrial studies. The main challenge of current cultural heritage methods is the loss of geometric accuracy during its translation into parametric 3D building information model objects [37]. In contrast to conventional CAD software, which represents data measurements in a collection of 2D drawings and 3D models, cultural heritage building modeling provides sustainable object-level data enrichment ranging from geometry to material and structure [38]. Photogrammetric data obtained from UAV for determining the geometry of cultural heritage details are used for creating the LoD0, LoD1, LoD2, LoD3, and LoD4 models. These different LoD concepts provide a digital representation of the object under investigation. It also acts as a bridge between the virtual environment and the real world. There are steps to be followed in the process of creating a 3D model on different LoDs of the cultural heritage from the photos taken by UAV and digitizing the cultural heritage. The process consists of the following steps: image acquisition with UAV, determination of orientation parameters, initial processing, point cloud classification, model generation, digitization of the facade model in AutoCAD, and 3D modeling of facades. The problems that arise in the processing steps are mainly related to the time required to process a large number of observations stored in the cloud and the hardware capacity used [39]. The solution to these problems is directly related to the complexity of the architectural details. It is important that the hardware to be used has the features to optimize the complexity of the architectural detail. The automation of digitization tools should also be developed by architectural details. The LoD of a cultural heritage model depends on several factors, such as the intended purpose and the need for model complexity, its production data source, the software and information technology tools used, as well as the skills of the person making the model [40]. Each LoD has a different required accuracy, and typically a 3D model is made by integrating multiple spatial data sources.

The facades of the building model at the LoD0 level define only the boundaries and locations of the object. In a model at LoD0, it is not possible to digitize the window and door details on the facades. In the modeling studies carried out using UAV for architectural documentation, each facade of the building should be modeled independently. Therefore, five flights were carried out separately for each facade in this study. Thus, it was possible to produce a building facade model at the LoD3 level. In addition, facade models at the LoD3 level were compared with those at LoD1 before they were produced. The facade details digitized at the LoD3 level were compared with the measurements performed with the total station device. The differences in the digitization of the door and window details calculated as a result of the comparison are shown in Table 1. It should be highlighted that the model accuracy at the LoD3 created in this study is higher compared to the previous studies conducted to produce the cultural heritage model at LoD3 using the UAV photogrammetric method [41]. According to [42], it can be concluded that 3D modeling using point clouds as a result of processing UAV Aerial Photos can be integrated with BIM, where the integration can be observed in the form of color, coordinates, building height, and 3D points.

Basically, it is sufficient to compare the building's actual size and corner points from the building model at the LoD0 level. As it is shown in Fig. 6, the sizes and locations of the building façade, measured with the total station device, were compared with the building facade sizes and locations suggested by photogrammetric studies employing UAV. As a result of the comparisons made at the LoD0 level, it was observed that the results were obtained with high accuracy as a result of the positional and facade dimensions (Fig. 6). For comparisons and analyses performed at the LoD0 detail level, models scaled in the AutoCAD program were taken into consideration.

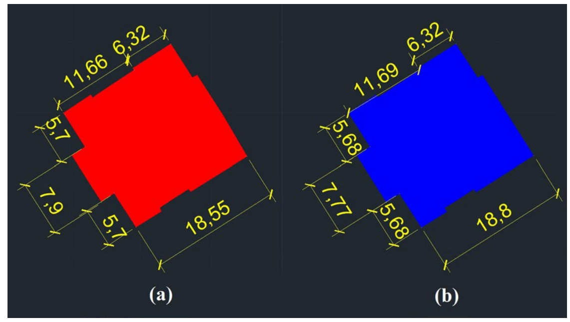

Fig. 6 LoD0 detail level drawings: **a** conservative measure **b** UAV measure

LoD0 and LoD1 were examined and redefined in conjunction because LoD1 was in essence an extrusion of the LoD0 model or its generalized product. Therefore, similar to the comparisons and analyses performed for LoD0, comparative analyses were performed for the LoD1 model. There were still challenges in the reconstruction of 3D models at LoD2, such as the efficient identification of buildings and complete segmentation of building surfaces [43]. Additionally, inaccurate segmentation results, such as over or under-segmentation, could cause unpredictable errors in the subsequent topological reconstruction of the facade. [44] proposed a method for building reconstruction at LoD2 guided by facade structures from a UAV photogrammetric point cloud. The method had the potential to enable a feasible technical solution for large-scale automated production of 3D city models.

In this study, LoD1 and LoD2 were also scaled and the building facade heights were employed as in Fig. 7. Moreover, roof peak points were also used to create the LoD2 model. Since roof details were added to the models at the LoD2 level, they were compared with each other as shown in Table 2. As a result of the comparison, the RMSE was calculated as 0.1153 m. Also, LoD2 Level 3D

Table 1 Positional RMSE of the control points at the LoD3 level

RMSE (m)			
X	**Y**	**Z**	**Distance**
0.019	− 0.019	0.012	0.029
0.010	− 0.010	0.045	0.047
0.000	0.000	0.046	0.046
0.040	0.029	0.020	0.053
− 0.001	− 0.016	0.029	0.033
0.224	0.128	− 0.005	0.258
0.031	− 0.010	0.054	0.063
0.021	0.014	0.064	0.069
0.010	0.014	0.044	0.047
− 0.009	0.038	0.003	0.039
− 0.005	0.019	0.007	0.021
0.004	0.044	− 0.021	0.049
− 0.012	0.020	0.002	0.023
− 0.024	0.004	− 0.020	0.032
− 0.045	0.012	0.000	0.047
− 0.022	0.005	0.013	0.026
0.002	− 0.035	0.002	0.035
0.077	− 0.004	− 0.005	0.077
1.394 cm	0.861 cm	0.694 cm	

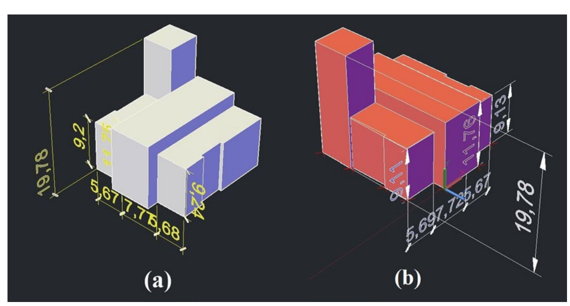

Fig. 7 LoD1 detail level drawing of the building facade and floor height dimensions: **a** conservative measure **b** UAV measure

Table 2 Comparison of rooftop points at LoD2 level

	UAV (m)	Terrestrial measurement of LoD2 level (m)	Difference (m)
Tower rooftop point elevation	176.093	176.190	– 0.097
Mid-rooftop point elevation	168.698	168.639	0.059
Front point upper elevation	165.748	165.561	0.187
Rear rooftop elevation	166.039	165.966	0.073
		RMSE	0.1153

drawings are shown in Fig. 8. Elberink et al. [45] assesses the potential of UAV imagery as an information source for automatic 3D building modeling at LoD2. The evaluation performed according to the ground truth indicates that the building models acquired with UAV photogrammetry have an accuracy of less than 18 cm for the planimetric position and about 15 cm for the height component.

The digitization processes were carried out in AutoCAD software with a 1/1 scale, by taking into account the facade model produced from the building model at the relief LoD3 level. In addition, RMSE values were calculated according to the 1/1 scale. Given the LoD, LoD2 models were remarkable because they were the ones with the high level of detail that has been usually available in practice and they had a very wide range of applications [46]. Also, LoD2 models were not difficult to produce automatically on a large scale. For example, LoD2 models could be automatically produced from airborne LiDAR point cloud data [47]. However, a LoD2 building model was often modeled incorrectly in practice due to mistakes made in data acquisition or modeling processes [48]. Figure 9 shows the positions of the facade details at the LoD3 level in the produced 3D model. In

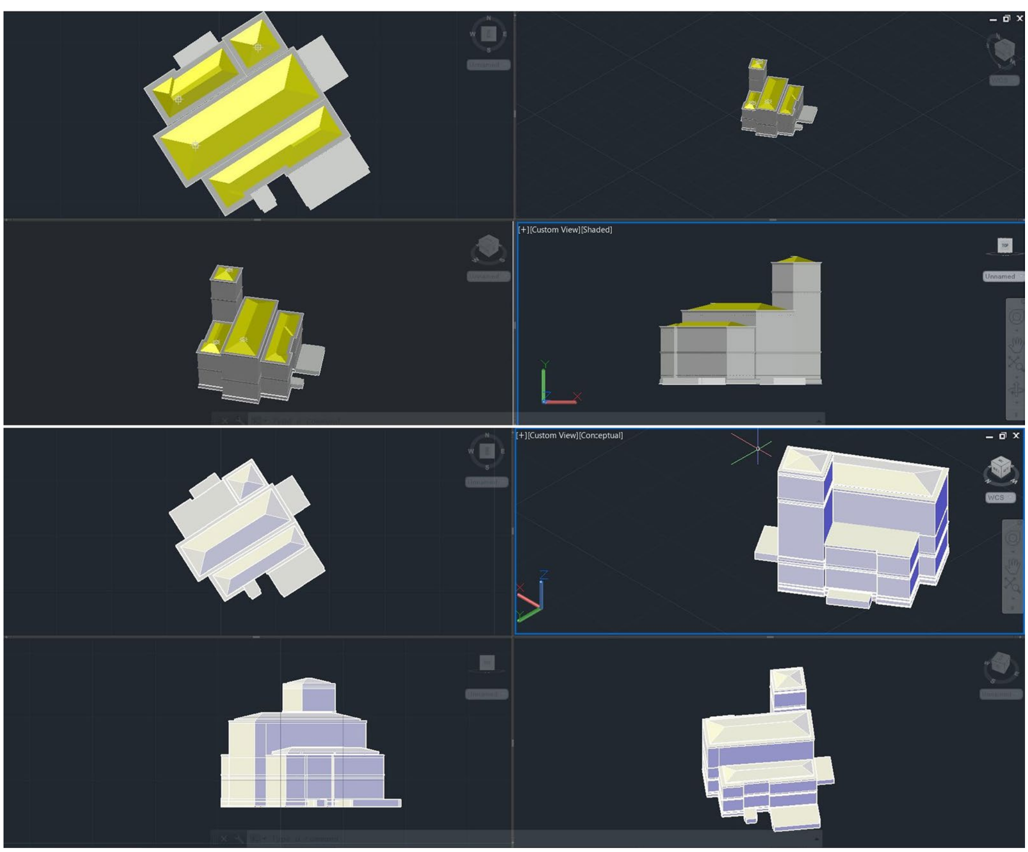

Fig. 8 LoD2 level 3D drawings

Fig. 9 AutoCAD relief digitization for building details on the 3D model

Fig. 11 AutoCAD relief digitization of the western front facade

Fig. 10 AutoCAD relief digitization of the eastern front facade

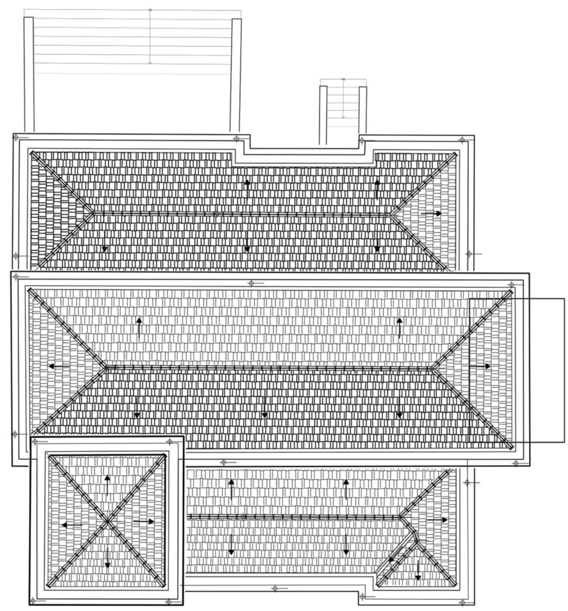

Fig. 12 AutoCAD relief digitization of the roof (→ represents the slope down direction)

the study, it was focused on the door and window details in a 3D model at the LoD3 level (Fig. 9). After the 3D Model was imported into the AutoCAD software, LoD3 level facade drawings of Hekimbaşı Hunting Lodge were prepared (Figs. 10, 11, 12). The survey drawings were made to describe the current situation with scaled drawings for the purposes of closely examining the building, evaluating it in terms of architectural history, and preparing restoration projects. Thus, it has been proven that measurements could be taken from the 3D model of the cultural building produced by the UAV for the preparation of 2D drawings at the LoD3 level.

The facade reliefs produced from the 3D model were produced from an orthophoto image containing the entire point cloud of the surface. The accuracy of the orthophoto to create the 2D relief drawing depended on the accuracy of the 3D point cloud produced photogrammetrically for axes (X, Y, and Z). Therefore, only 2D point accuracy was considered for reliefs created in 2D. In addition, the LoD level obtained from the 3D model was expressed in 2D on the digitization surface [49]. Since the accuracy and coordinates of the 3D point cloud were used in rectification, 2D drawings of the facade surface details were created during the 2D relief digitization processes. The only factor affecting the accuracy in this process was the overall scale accuracy of the 3D model. The overall scale accuracy of the 3D model was the accuracy provided by the software used (Pix4D). In this study, after the completion of all drawings, the measurement values of the door and

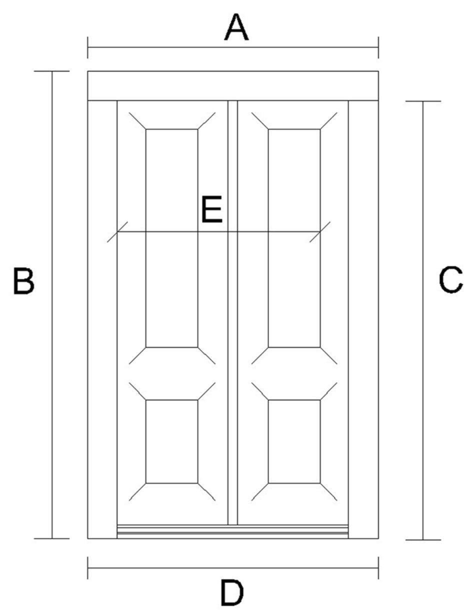

Fig. 13 Details measurement in AutoCAD relief digitization for a door model

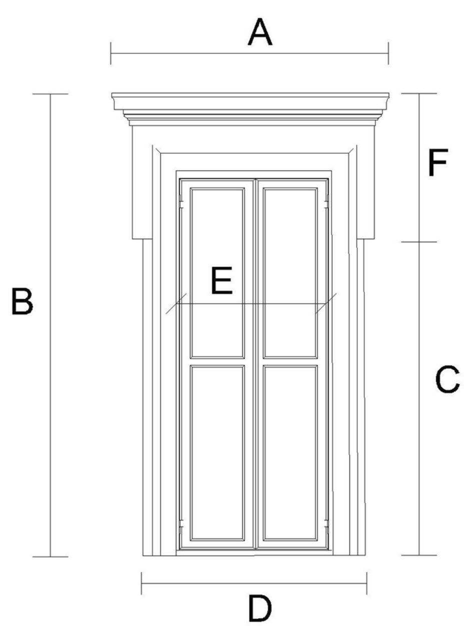

Fig. 14 Details measurement in AutoCAD relief digitization for a window model

window facade details were generalized (Fig. 13 and Fig. 14) and compared positionally; their RMSEs are given in Tables 3 and 4.

Based on the 2D relief drawings, the analysis of the 2D widths and lengths of the details at the LoD3 level determined in 3D relief drawings was conducted. It was

Table 3 RMSE values obtained by comparing positional and facade details for door at the LoD3 level

RMSE at LoD3 level for door details	
Detail	**RMSE (m)**
A	0.0314
B	0.0252
C	0.0399
D	0.0314
E	0.0378

Table 4 RMSE values obtained by comparing positional and facade details for window at the LoD3 level

RMSE at LoD3 level for window details	
Detail	**RMSE (m)**
A	0.0384
B	0.0488
C	0.0398
D	0.0418
E	0.0487
F	0.0209

observed that the digitization accuracy of the lengths and widths on the facade relief could be determined with high precision. In similar studies, it has been stated that the accuracy of 2D relief drawings depended on 3D point accuracy. Since the facade produced from the 3D model could be converted into 1/1 scale (real scale) relief drawings of orthophotos in AutoCAD software, it was digitized with the same accuracy as the 3D model produced by photogrammetric techniques [50–52]. Furthermore, it was observed that the accuracy of the point cloud data on surfaces improved proportionally with the accuracy of the 3D model scale. In line with this information, the 2D digitization of the rectified orthophotos produced for the facades was accurate at the same rate on a 1/1 scale. As the LoD changes, the quantity of detail in the drawings also decreased at the same rate. For architectural studies, the RMSE values given in Table 5 were calculated if the door and window details were printed on a scale of 1/50 scale in the model produced in AutoCAD on a scale of 1/1.

The architectural model of a building is represented by a geometrically exact outer shell in LoD3. Each LoD should enforce a minimum horizontal and vertical accuracy [53], and thus LoD3 should observe a specific accuracy, which is 0.5 m horizontally and vertically [31]. In this study, a 3D model of the Hekimbaşı Hunting Lodge building was produced using UAV and accuracy

Table 5 RMSE values at 1/50 scale obtained by comparing positional and facade details for the window at the LoD3 level

RMSE at LoD3 level for door and window details at 1/50 scale		
Detail	**RMSE (mm)**	
	Door	**Window**
A	0.628	0.768
B	0.504	0.976
C	0.798	0.796
D	0.628	0.836
E	0.756	0.974
F	–	0.418

analysis of different LoD levels was performed. The LoD level can be obtained from facade orthophotos as well as photogrammetric point clouds. In this context, it is recommended drawing from facade orthophotos at LoD3 level in similar studies to increase the accuracy of drawing architectural details and to facilitate the survey drawing of architects.

Conclusion

As a result of the study, it is concluded that a 3D cultural heritage building model obtained with UAVs can be produced with high accuracy. At the LoD3 level, RMSE values for X, Y, and Z axes are calculated as 1.394 cm, 0.861 cm, and 0.694 cm, respectively. It is founded that the use of low-cost UAV should become widespread to visualize and create 3D cultural heritage building models at different LoD levels. As a result of the data obtained from the study, it is thought that the system sensitivity can be increased by establishing more GCP or taking more photographs in comparisons on the height (Z) axis. It is considered that the use of UAV is functional to create different LoD levels and should be included in the literature. In addition, it is suggested that the rapid production of 3D building models at different levels of detail and the ability to transfer and develop the generated data to the users at the desired level will yield professionally beneficial results.

It is extremely important to present realistic geometric 3D cultural buildings model to the users at the desired level. While presenting these data to the user, determining a common standard may be a solution to the problem of obtaining data according to the desired application purpose. Furthermore, it should be provided on the software to create and display their own custom LoD levels, independent of the standard LoD levels, according to the qualifications that users need in their projects or applications. In light of the investigated studies and the results of the current research, the key points are as follows:

- It is necessary to create a common classification concept,
- There is a need for software that can fully use LoD concepts,
- Failure to achieve an exact standard in the creation of geometric reference points causes problems,
- Roof details should be added to the LoD2 level (especially in historical and cultural buildings),
- By adding detailed roof models at the LoD2 level, exterior details should be given at the LoD3 level (landscape areas, trees, etc.),
- In building modeling, it is necessary to determine at which LoD level the exterior details should be visualized or defined as a separate LoD level, to increase LoD classes or to derive new LoD classes for specific situations.

In conclusion, it is expected that the use of UAVs to create desired LoDs for cultural heritage studies will become widespread in the future. The accuracies of details calculated in this study can be reanalyzed by obtaining LiDAR point clouds in future studies. In this context, comparisons of the data obtained by different measurement methods will be performed.

Author contributions

All authors contributed to the conceptualization, methodology, software, validation, investigation, data curation, writing original draft preparation and visualization. All authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 17 April 2023 Accepted: 29 August 2023
Published online: 12 September 2023

References

1. Templin T, Popielarczyk D. The use of low-cost unmanned aerial vehicles in the process of building models for cultural tourism, 3D web and augmented/mixed reality applications. Sensors. 2020;20(19):5457. https://doi.org/10.3390/s20195457.
2. Lezzerini M, Antonelli F, Columbu S, Gadducci R, Marradi A, Miriello D, Lazzeri A. Cultural heritage documentation and conservation:

three-dimensional (3D) laser scanning and geographical information system (GIS) techniques for thematic mapping of facade stonework of St. Nicholas Church (Pisa, Italy). Int J Archit Herit. 2016;10(1):9–19. https://doi.org/10.1080/15583058.2014.924605.

3. Lerones PM, Fernández JL, Gil ÁM, Gómez-García-Bermejo J, Casanova EZ. A practical approach to making accurate 3D layouts of interesting cultural heritage sites through digital models. J Cult Herit. 2010;11(1):1–9. https://doi.org/10.1016/j.culher.2009.02.007.
4. Khoshelham K. Smart heritage: challenges in digitisation and spatial information modelling of historical buildings 2nd Workshop on computing techniques for spatio-temporal data in archaeology and cultural heritage. Melbourne: University of Melbourne; 2018. p. 7–12.
5. Fidosova L, Antova G. Three-Dimensional Modelling of Spatial Data in Urban Territory. In: IOP Conference Series: Earth and Environmental Science, 7th World Multidisciplinary Earth Sciences Symposium (WMESS 2021), 6–10 September 2021, Prague, Czech Republic. https://doi.org/10.1088/1755-1315/906/1/012128
6. Ramos MM, Remondino F. Data fusion in cultural heritage-A review. 2015. In Arch Photogramm Remote Sens Spat Inf Sci. https://doi.org/10.5194/isprsarchives-XL-5-W7-359-2015.
7. Murtiyoso A, Grussenmeyer P, Koehl M, Freville T. Acquisition and processing experiences of close range uav images for the 3D modeling of heritage buildings. In: Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection: 6th International Conference, EuroMed 2016, Nicosia, Cyprus, October 31-November 5 2016. https://doi.org/10.1007/978-3-319-48496-9_34
8. Gallardo-Saavedra S, Hernández-Callejo L, Duque-Perez O. Technological review of the instrumentation used in aerial thermographic inspection of photovoltaic plants. Renew Sustain Energy Rev. 2018;93:566–79. https://doi.org/10.1016/j.rser.2018.05.027.
9. Agüera-Vega F, Carvajal-Ramírez F, Martínez-Carricondo P. Accuracy of digital surface models and orthophotos derived from unmanned aerial vehicle photogrammetry. J Surv Eng. 2017;143(2):1–10. https://doi.org/10.1061/(ASCE)SU.1943-5428.0000206.
10. Sankey JB, Sankey TT, Li J, Ravi S, Wang G, Caster J, Kasprak A. Quantifying plant-soil-nutrient dynamics in rangelands: fusion of uav hyperspectral-lidar, uav multispectral-photogrammetry, and ground-based lidar-digital photography in a shrub-encroached desert grassland. Remote Sens Environ. 2021;253:112223. https://doi.org/10.1016/j.rse.2020.112223.
11. Uysal M, Toprak AS, Polat N. Dem generation with uav photogrammetry and accuracy analysis in Sahitler hill. Measurement. 2015;73:539–43. https://doi.org/10.1016/j.measurement.2015.06.010.
12. Remondino F, Spera MG, Nocerino E, Menna F, Nex F. State of the art in high density image matching. Photogramm Rec. 2014;29(146):144–66. https://doi.org/10.1111/phor.12063.
13. Johansson OE. The hydrodynamic impacts of Estuarine Oyster reefs, and the application of drone technology to this study. Master thesis, Lund University: Sweden. 2021
14. Joyce KE, Duce S, Leahy SM, Leon MJ, Maier SW. Principles and practice of acquiring drone-based image data in marine environments. Mar Freshwat Res. 2018;70(7):952–63.
15. Jeon EI, Yu SJ, Seok HW, Kang SJ, Lee KY, Kwon OS. Comparative evaluation of commercial softwares in UAV imagery for cultural heritage recording: case study for traditional building in South Korea. Spat Inf Res. 2017;25(5):701–12. https://doi.org/10.1007/s41324-017-0137-z.
16. Bakirman T, Bayram B, Akpinar B, Karabulut MF, Bayrak OC, Yigitoglu A, Seker DZ. Implementation of ultra-light uav systems for cultural heritage documentation. J Cult Herit. 2020;44:174–84. https://doi.org/10.1016/j.culher.2020.01.006.
17. Kaamin M, Idris NA, Bukari SM, Ali Z, Samion N, Ahmad MA. Visual inspection of historical buildings using micro UAV. In: International Symposium on Civil and Environmental Engineering, Novotel Melaka, Melaka, Malaysia, 5–6 December 2016, 07003. https://doi.org/10.1051/matecconf/201710307003
18. Sun Z, Zhang Y. Using drones and 3D modeling to survey tibetan architectural heritage: a case study with the multi-door stupa. Sustainability. 2018;10(7):2259. https://doi.org/10.3390/su10072259.
19. Tysiac P, Sieńska A, Tarnowska M, Kedziorski P, Jagoda M. Combination of terrestrial laser scanning and UAV photogrammetry for 3D modelling and degradation assessment of heritage building based on a lighting analysis: case study—St Adalbert Church in Gdansk Poland. Herit Sci. 2023;11:53. https://doi.org/10.1186/s40494-023-00897-5
20. Russo M, Carnevali L, Russo V, Savastano D, Taddia Y. Modeling and deterioration mapping of façades in historical urban context by close-range ultra-lightweight uavs photogrammetry. Int J Archit Herit. 2019;13(4):549–68. https://doi.org/10.1080/15583058.2018.1440030.
21. López FJ, Lerones PM, Llamas J, Gómez-García-Bermejo J, Zalama E. A review of heritage building information modeling (H-BIM). Multimodal Technol Interact. 2018;2(2):21. https://doi.org/10.3390/su10072259.
22. Saccucci M, Pelliccio A. Integrated BIM-GIS System for the enhancement of urban heritage. In 2018 Metrology for Archaeology and Cultural Heritage (MetroArchaeo), Cassino, Italy, 2018. 222-226. https://doi.org/10.1109/MetroArchaeo43810.2018.13625
23. Filip B. The concept of level detail in 3D city models. PhD Thesis, Delft University of Technology: Netherlands. 2013.
24. Löwner M, Benner J, Gröger G, Häfele K. New concepts for structuring 3D city models—an extended level of detail concept for CityGML buildings. In: Murgante B, Misra S, Carlini M, Torre CM, Nguyen H-Q, Taniar D, Apduhan BO, Gervasi O, editors. ICCSA 2013: computational science and Its applications, Ho Chi Minh City, Vietnam. Berlin Heidelberg: Springer, Berlin Heidelberg; 2013. p. 466–80. https://doi.org/10.1007/978-3-642-39646-5_34.
25. Fai S, Rafeiro J. Establishing an appropriate level of detail (LoD) for a building information model (BIM)—west block, parliament hill, Ottawa, Canada. 2014. In ISPRS Ann Photogramm Remote Sens Spat Inf Sci. https://doi.org/10.5194/isprsannals-II-5-123-2014.
26. Biljecki F, Ledoux H, Stoter J. An improved LOD specification for 3D building models. Comput Environ Urban Syst. 2016;59:25–37. https://doi.org/10.1016/j.compenvurbsys.2016.04.005.
27. Jarzabek-Rychard M, Karpina M. Quality analysis on 3D buidling models reconstructed from uav imagery. 2016. In Arch Photogramm Remote Sens Spat Inf Sci. https://doi.org/10.5194/isprsarchives-XLI-B1-1121-2016.
28. Murtiyoso A, Veriandi M, Suwardhi D, Soeksmantono B, Harto AB. Automatic Workflow for roof extraction and generation of 3D citygml models from low-cost uav image-derived point clouds. ISPRS Int J Geo-Inf. 2020;9(12):743. https://doi.org/10.3390/ijgi9120743.
29. Qi H, Cong B, Liu R, Li X, Yan Z, Li Q, Li M. Research on the 3D fine modeling method of In-service road. Adv Civil Eng. 2023. https://doi.org/10.1155/2023/7336379.
30. Pantoja-Rosero BG, Achanta R, Kozinski M, Fua P, Perez-Cruz F, Beyer K. Generating LOD3 building models from structure-from-motion and semantic segmentation. Autom Constr. 2022;141:104430. https://doi.org/10.1016/j.autcon.2022.104430.
31. Malihi S, Zoej MJV, Hahn M. Large-scale accurate reconstruction of buildings employing point clouds generated from UAV imagery. Remote Sens. 2018;10(7):1148. https://doi.org/10.3390/rs10071148.
32. Gruen A, Schubiger S, Qin R, Schrotter G, Xiong B, Li J, Ling X, Xiao C, Yao S, Nuesch F. Semantically enriched high resolution LoD 3 building model generation. 2019. In Arch Photogramm Remote Sens Spat Inf Sci. https://doi.org/10.5194/isprs-archives-XLII-4-W15-11-2019.
33. Sanz-Ablanedo E, Chandler J, Rodríguez-Pérez J, Ordóñez C. Accuracy of unmanned aerial vehicle (uav) and sfm photogrammetry survey as a function of the number and location of ground control points used. Remote Sens. 2018;10:10. https://doi.org/10.3390/rs10101606.
34. Barrile V, Candela G, Fotia A. Point cloud segmentation using image processing techniques for structural analysis. 2019. In Arch Photogramm Remote Sens Spat Inf Sci. https://doi.org/10.5194/isprs-archives-XLII-2-W11-187-2019.
35. Pix4D Documentation, https://support.pix4d.com/hc/en-us/articles/115004864586-How-to-generate-the-point-cloud-classification. Accessed 8 June 2023.
36. Akmaliaa R, Setan H, Majid Z, Suwardhi D. Representing 3D Model of building from TLS data scanning in CityGML. Jurnal Teknologi. 2014;71(4):49–53. https://doi.org/10.11113/jt.v71.3825.
37. Barazzetti L. Parametric as-built model generation of complex shapes from point clouds. Adv Eng Inf. 2016;30(3):298–311. https://doi.org/10.1016/j.aei.2016.03.005.
38. Eastman CM. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. Hoboken: John Wiley & Sons; 2011.

39. Błaszczak-Bąk W, Janowski A, Kamiński W, Rapiński J. Optimization algorithm and filtration using the adaptive TIN model at the stage of initial processing of the ALS point cloud. Can J Remote Sens. 2011;37(6):583–9. https://doi.org/10.5589/m12-001.
40. Klapa P. TLS point cloud as a data surce for multi-lod of 3D models. Geomat Landmanagement Landsc. 2022;2:63–73. https://doi.org/10.15576/GLL/2022.2.63.
41. Cahyono AB, Hidayat H, Dewi AK. 3D Modeling of Bajang Ratu temple using UAV photogrammetry with oblique images. In IOP Conf Ser Earth Environ Sci. 2021;731(1):012022. https://doi.org/10.1088/1755-1315/731/1/012022.
42. Saputra H, Azizan F, Fahmi N. Integrating building information modeling (BIM) and unmanned Aerial vehicle (UAV) for building 3D modeling: a case study of Wisma Sri Mahkota Bengkalis. CSID J Infrastruct Dev. 2022;5(1):122–38. https://doi.org/10.32783/csid-jid.v5i1.283.
43. Verdie Y, Lafarge F, Alliez P. LOD generation for urban scenes. ACM Trans Graph. 2015;34(3):30. https://doi.org/10.1145/2732527.
44. Wang F, Zhou G, Hu H, Wang Y, Fu B, Li S, Xie J. Reconstruction of LoD-2 building models guided by façade structures from oblique photogrammetric point cloud. Remote Sens. 2023;15(2):400. https://doi.org/10.3390/rs15020400.
45. Elberink SO, Vosselman G. Quality analysis on 3D building models reconstructed from airborne laser scanning data. ISPRS J Photogramm Remote Sens. 2011;66(2):157–65. https://doi.org/10.1016/j.isprsjprs.2010.09.009.
46. Boeters R, Arroyo Ohori K, Biljecki F, Zlatanova S. Automatically enhancing CityGML LOD2 models with a corresponding indoor geometry. Int J Geogr Inf Sci. 2015;29(12):2248–68. https://doi.org/10.1080/13658816.2015.1072201.
47. Jayaraj P, Ramiya AM. 3D CityGML building modelling from lidar point cloud data. 2018. In ISPRS Ann Photogramm Remote Sens Spat Inf Sci. https://doi.org/10.5194/isprs-archives-XLII-5-175-2018.
48. Wagner D, Wewetzer M, Bogdahn J, Alam N, Pries M, Coors V. Geometric-semantical consistency validation of CityGML models. In: Pouliot J, Daniel S, Hubert F, Zamyadi A, editors. Progress and new trends in 3D geoinformation sciences lecture notes in geoinformation and cartography. Berlin, Heidelberg: Springer; 2013.
49. De Masi A. Smart cultural heritage and open source as regeneration of historical centers: Fruition, conservation and preservation in current methods of 2D/3D digitization and 3D modelling. In: 2014 IEEE Fourth International Conference on Big Data and Cloud Computing, Sydney, Australia, 3–5 December 2014, 729-736. https://doi.org/10.1109/BDCloud.2014.114.
50. Themistocleous K. Model reconstruction for 3D vizualization of cultural heritage sites using open data from social media: the case study of Soli. Cyprus J Archaeol Sci. 2017;14:774–81. https://doi.org/10.1016/j.jasrep.2016.08.045.
51. Barba S, Barbarella M, Di Benedetto A, Fiani M, Gujski L, Limongiello M. Accuracy assessment of 3D photogrammetric models from an unmanned aerial vehicle. Drones. 2019;3(4):79. https://doi.org/10.3390/drones3040079.
52. Bendea H, Chiabrando F, Tonolo FG, Marenchino D. Mapping of archaeological areas using a low-cost UAV The Augusta Bagiennorum test site. In: XXI International CIPA Symposium, Athens, Greece, 2007.
53. Gröger G, Kolbe TH, Czerwinski A, Nagel C. OGC City geography markup language (CityGML) encoding standard. 2012. https://repository.oceanbestpractices.org/bitstream/handle/11329/1109/08007r1_City_Geography_Markup_Language_CityGML_Encoding_Standard.pdf?sequence=1&isAllowed=y. Accessed 16 Aug 2023.

Publisher's Note